CHEMICAL ENGINEERING TRANSACTIONS

VOL. 71, 2018

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216

DOI: 10.3303/CET1871004

Energy Saving and Emission Reduction Evaluation Method of Assembled Housing Considering Effective Utilization of Solar Energy

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In view of the characteristics of the prefabricated residential buildings that are different from those of traditional ones, the prefabricated housing modes are generally sorted out in present study based on the principle of efficient solar energy utilization. This paper selects the green residential buildings with evaluation mark in Jiangsu coastal areas as the research object to carry out an in-depth analysis on the main influencing factors of energy saving and emission reduction effects of prefabricated residential buildings, on the energy-saving effects of the three most commonly used residential green technologies, including natural ventilation, natural lighting, as well as solar hot water system, and on the economic efficiency of these three technologies through numerical simulation method. In addition, the results of simulation are also comprehensively evaluated in the paper. The results show that green residential buildings that adopt passive technologies and solar hot water system have greater energy saving potential, and thus can achieve a significant economic return. Prefabricated green buildings can be a building mode with high cost and high returns.

1. Introduction

In recent years, the rapid development of fabricated residential buildings in China has drawn more and more attention. The advantages of prefabricated residential buildings mainly lie in high construction efficiency, good housing quality and energy saving and emission reduction (Yu and Zhang, 2018). Their advantages also include the improvement of construction efficiency, the shortening of construction period, the improvement of housing quality and efficiency, the great potential of energy saving and emission reduction, and other aspects (Chen et al., 2013). Therefore, it can be said that prefabricated residential buildings will be a reliable way to effectively popularize green buildings (Dan et al., 2013; Zhou, 2018; Balocco and Petrone, 2018).

The urbanization in China continues to accelerate. As of the end of 2016, the proportion of urban population in China had reached 53.75%. Reliable statistics show that by 2020, China's urbanization rate will reach 60%. At present, the proportion of building energy consumption to the total energy consumption has increased to 31.2%. The proportion of energy consumption for heating and air conditioning in residential buildings accounts for 20~30% (Peyrac et al., 2016; Yin et al., 2013). As an important means of saving resources and realizing sustainable development, green prefabricated buildings have made a great leap forward both at home and abroad in recent years (Šešlija et al., 2011). However, due to the late start of green building practice in China and many problems still existing in the application of green technologies in different regions, there is a misunderstanding about the green buildings among the public and developers, which has affected the healthy development of green buildings in China.

In view of the characteristics of the prefabricated residential buildings in Jiangsu coastal areas that are different from those of traditional ones, the prefabricated green residential buildings with evaluation mark are collected and summarized in present study based on the principle of efficient solar energy utilization. Through numerical simulation and quantitative calculation method, the energy saving potential and economical efficiency of the three kinds of green technologies, including natural ventilation, natural lighting and solar hot water system, are analyzed and further studied to promote the development of prefabricated green buildings.

Please cite this article as: Wang J., He F., 2018, Energy saving and emission reduction evaluation method of assembled housing considering effective utilization of solar energy, Chemical Engineering Transactions, 71, 19-24 DOI:10.3303/CET1871004

2. Climatic characteristics of Jiangsu coastal areas and selection of prefabricated building forms

2.1 Climatic characteristics of Jiangsu coastal areas

Most areas of Jiangsu boast sufficient rainfall, rich light energy, abundant heat and clear seasons, with typical characteristics of hot summer and warm winter (Sandifer, 2015). With the annual average of 1100~2000 sunshine hours, the total solar radiation a year in Jiangsu is 3450~4800MJ/m^2 (Shen et al., 2014). The seasonal distribution in Jiangsu is characterized by longest summer, especially in July and August, shortest winter, and the spring and autumn season varying from place to place. In the summer daytime in Jiangsu, the temperature is high, the radiation strong, the wind speed fast, and the hot wind rampant (Sherif et al., 2014). It has become an important way to reduce building energy consumption by designing the buildings based on regional climatic characteristics (Tiruvenkadam et al., 2015).

2.2 Prefabricated building forms in Jiangsu coastal areas

In the design of public buildings, the form of architectural plane is diversified (Liu et al 2016). But in the design of residential building, square architectural plane is commonly used in order to improve the utilization efficiency of the plane (Sa'Atlu, 2014). In designing low rise residential buildings, the plane is mainly rectangular, but there are units which are dislocated to shape a "Z" or an "L". As the length and width of the plane of the high-rise tower buildings are nearly equal, the plane is mainly laid out around the core tube.

3. Simulation analysis on energy saving and emission reduction of prefabricated buildings

3.1 Simulated scheme design

In this paper, the natural ventilation of the typical buildings A, B, C and D in the summer and the transitional period is studied based on the principle of efficient solar energy utilization by numerical simulation with air age used as the main index of ventilation evaluation (Li et al 2014). In this paper, the CAD model is used to build the simplified model of the research object, then the model information is introduced into the Pointwise V17.2R1, afterwards the grid data is imported into the simulation software Star-CD for indoor ventilation simulation (Crec'Hriou et al 2008).

A total of 8 cases are simulated, of which A is a 12-floor building with one staircase for two households, B is a 33-floor building with one staircase for three households a staircase, both C and D are 33-floor buildings with one staircase for four households. The height of all the buildings is 2.8m. In order to simplify the calculation, this paper only simulates the houses on the middle floors.

In order to visually present the setting of each case, the cases are illustrated in the form of diagrams in this paper. Assuming that the wind is blown from bottom to top at the time of simulation, specific parameters are as shown in Table 1.

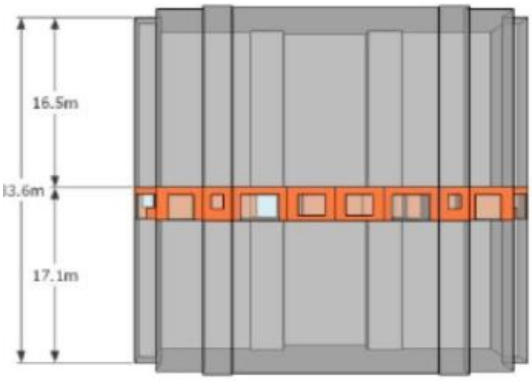

Figure 1: Schematic diagram of building A

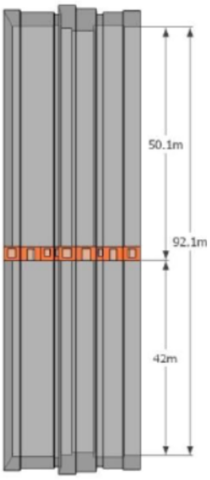

Figure 2: Schematic diagram of building B

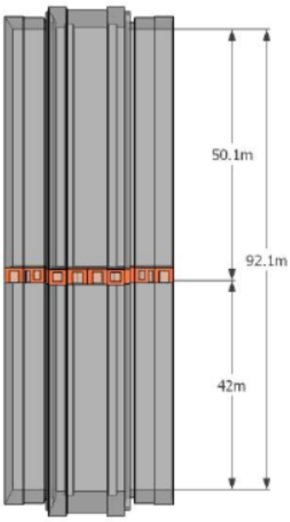

Figure 3: Schematic diagram of building C

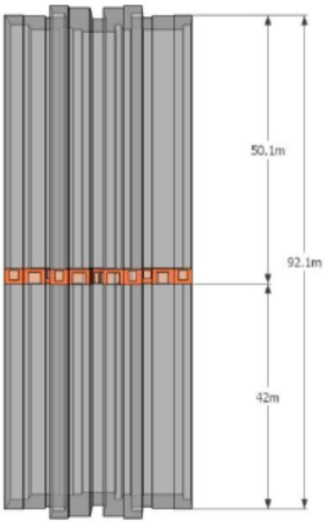

Figure 4: Schematic diagram of building D

Table 1: Basic case setting

Case name	Angle between building and inflow direction	Building orientation	Direction of flow
Casea-7F-45°	45°	S	SE
Caseb-17F-45°	45°	S	SE
Casec-17F-45°	45°	S	SE
Cased-17F-45°	45°	S	SE
Casea-7F-157.5°	157.5°	S	NNE
Caseb-17F-157.5°	157.5°	S	NNE
Casec-17F-157.5°	157.5°	S	NNE
Cased-17F-157.5°	157.5°	S	NNE

3.2 Numerical simulation of natural ventilation

There is a probability distribution function $f_p(t)$ for the air age of all the air micelles at a particular location in the selected typical case room. τ (p) is the average age of all air micelles, and its expression is as shown in formula (1).

$$\tau(p)=\frac{\int_0^\infty t f_p(t)dt}{\int_0^\infty f_p(t)dt} \tag{1}$$

The indoor air age distribution is calculated through the ventilation efficiency index SVE3, and the expression of SVE3 is as follows.

$$\int_0^t f_p(t)dt = 1-\frac{C_P(t)}{C_P(0)} \tag{2}$$

where, $C_p(t)$—tracer gas concentration of the testing location at the testing time t, mg/kg; $C_p(0)$—tracer gas concentration of the testing location at the initial time, kg/mg.
The mass diffusion equation for tracer gas is as follows.

$$\frac{\partial \rho C_P(t)}{\partial t}+\frac{\partial}{\partial x}(\rho u_i C_P(t))=\frac{\partial}{\partial x_i}(\Gamma\frac{\partial C_P(t)}{\partial x_j})+S_c \tag{3}$$

In the above equation, ρ—tracer gas density, mg/kg; u_j—velocity component in j direction, m/s; Γ—diffusion coefficient; Sc—source term.

3.3 Numerical simulation analysis of energy saving effect

The room temperature and air conditioning cooling capacity of the four buildings A, B, C and D are simulated by De ST-h, and the results are as shown in Tables 2 and 3.

Table 2: Natural ventilation energy saving in typical buildings

	Calculation mode 1	Calculation mode 2	Natural ventilation energy saving	Percentage of energy saving
Building A	63911	5210.99	1180.3	18.44
Building B	153314.2	123573.8	29634.4	19.52
Building C	177127.4	140503.5	37532.3	20.73
Building D	198274.5	163164.8	34905.78	17.78

Table 3: Natural ventilation energy per unit area of typical building

	Calculation mode 1	Calculation mode 2	Natural ventilation energy saving
Building A	17.68	14.41	3.25
Building B	19.43	15.62	3.77
Building C	18.55	14.68	3.82
Building D	17.64	14.55	3.12

Through the comparative analysis of the data in Tables 2 and 3, it can be found that the annual natural cooling capacity can be saved about 18 to 20 percentage points after natural ventilation. The energy consumption of building C has dropped by about 20.62%, and that of building D has decreased by 17.76%. Through comparisons, it is found that the energy saving potential of building C is about 2.86% higher than that of building D.

3.4 Analysis of energy saving effect of solar hot water system

The calculation formula of useful heat provided by solar energy system is,

$$\Delta Q_{\mathrm{save}} = A_{in} J_T (1-\eta_L)\eta_{cd} \tag{4}$$

Formula (4) is used to calculate the energy saving of solar hot water system in four typical buildings. The results are as shown in Table 4.

The sunlight situation of building D in actual case is analyzed. There are 13 residential buildings within the building red line, all of which are 34-floors with one staircase for 4 households, and a volume rate of 3.77. Sunshine time shall be calculated for the time period of 8:00-16:00 on Great Cold day. In order to find out whether the residential area meets the sunlight standard for residential buildings, the Ecotect light simulation software is used to simulate and analyze the total sunshine duration of the residential area, and the results are as shown in Figure 4.

Table 4: New energy solar water heater

	Building A	Building B	Building C	Building D
New energy solar water heater	152962.04	188761.58	250697.3	250597.3

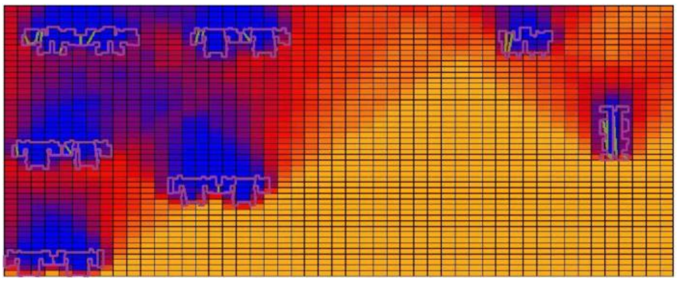

Figure 4: Total plane sunshine time analysis

Analysis of the simulation results in Figure 4 shows that the sunshine time of the main rooms on the lower floors in the residential area has reached more than 2h, which can meet the basic requirements. But for the building D, its roof area cannot meet the hot water demand of the whole building. Through the numerical simulation and analysis of the sunshine hours of the south facade, the balcony fence and the roof of the building D, the layout and locations of the collector can roughly be determined if the building uses the solar hot water system.

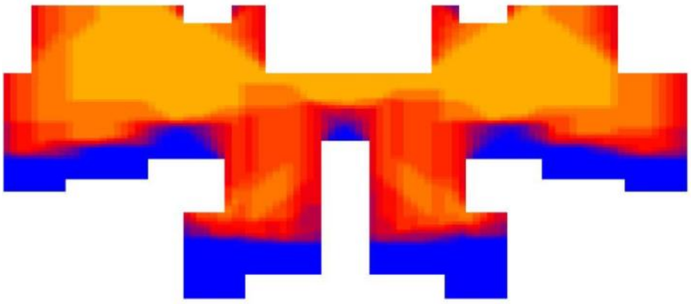

Figure 5: Sunshine time distribution of roof

The simulation results of Figure 5 show that the sunshine hours on the south facade of building D increase with the increase of the number of residential floors, thus it is suitable to install solar collectors there. On the whole, the south facade of 16 floors and above can meet the requirement of 4 sunshine hours for installing solar collector.

3.5 Economic analysis of green energy saving technologies for residential buildings in Jiangsu province

Based on the principle of efficient solar energy utilization, the calculation of the energy saving of green residential buildings takes the saved energy per unit area as the evaluation basis. Incremental benefits include two types, incremental economic benefits and incremental environmental benefits.
(1) Incremental economic benefits

$$\Delta B_{\mathrm{E}} = \Delta Q_{\mathrm{E}} \times P_{\mathrm{E}} \tag{5}$$

Where, ΔQ_E—energy saving per unit area, kwh; P_E—price per kilowatt, kwh/yuan.
The calculation results of energy saving per unit area of natural ventilation, natural lighting and solar hot water are as shown in Table 5.

Table 5: unit area energy statistics (unit: kwh/ (m.A))

	Building A	Building B	Building C	Building D
Natural ventilation energy saving	3.26	3.77	3.82	3.13
Natural lighting energy saving	7.55	7.33	5.24	8.92
Solar water heating energy saving	7.57	4.98	5.32	5.43
Total node energy	18.38	16.12	14.34	17.48

According to Table 8, the annual incremental economic benefit per unit area of A building can reach 10.49 Yuan, that of B building 9.19 Yuan per year, that of C building 8.19 Yuan per year, and that of D building 9.98 Yuan per year. Residential buildings adopt passive technologies and solar hot water system, which have greater potential for energy saving and better economic effect, since the economic returns generated by energy saving is also very generous.

4. Conclusions

Combined with the new energy saving technologies of prefabricated buildings and based on the principle of efficient solar energy utilization, their energy saving potential and the resulting economic benefits brought are calculated and simulated, with the specific conclusions as follows.
(1) Overall, the wind speed in the transition season has changed greatly compared to that in the summer, and the adopted natural ventilation can save 18 to 20 percentage points of the annual cooling capacity. The

smaller the average air age is, the better the indoor ventilation effect is maintained, thus the greater the potential of natural ventilation is and the more obvious the effect of energy saving is.
(2) According to the simulation results of plane A, B, C and D, the four typical planes save the total energy consumption of the building across the year about 3% to 7%, the natural lighting saving electricity per unit area increases as the ratio of window to ground increases.
(3) Prefabricated residential buildings in the region adopt passive technologies and solar hot water system, which have greater potential for energy saving and better economic effect, since the economic returns generated by energy saving is also very generous.

Acknowledgement

1). Jiangsu Province Industry, Universities, Research Institutions Forward-Looking Joint Research Projects. Research on Passive Energy Saving Technology for the Enclosure Products of Assembled Residential Buildings in Jiangsu Coastal Area (No.BY2016065-50).
2). Ministry of Housing and Urban Rural Development of Science and Technology of Projects in People's Republic of China. Research on Integration Technology of Energy Saving Renovation of Existing Residential Buildings in Jiangsu Coastal Area. (No.2014-K1-050)
3). Top-notch Academic Programs Project of Jiangsu Higher Education Institutions

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