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Procedia Engineering 205 (2017) 730–737

Procedia Engineering

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10th International Symposium on Heating, Ventilation and Air Conditioning, ISHVAC2017, 19-22 October 2017, Jinan, China

Study on the Influence of Window-wall Ratio on the Energy Consumption of Nearly Zero Energy Buildings

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Abstract

Window-wall ratio (WWR) is one of the key energy-saving design parameters affecting the energy consumption of nearly zero energy building (NZEB) in severe cold regions. The analysis and optimization of WWR is an important way to achieve nearly zero energy consumption. This paper takes one typical NZEB in severe cold area of Shenyang city as model. The influence of different orientations' WWR on energy consumption of NZEB was studied finally through the simulation method of dual energy consumption influence factors with a single variable, and the simulation software of EnergyPlus. The results showed that: the greater impact of different orientations' WWR on energy consumption order is east (west) > south > north; the most energy-efficient east (west) WWR for NZEB in severe cold area is between 10%-15%, south WWR is between 10%-22.5%, north WWR should be appropriately reduced when the lighting and ventilation conditions allowed it.

Keywords: Nearly zero energy building; Window-wall ratio; Energy consumption simulation

1. Introduction

Actively respond to global warming, reducing carbon emissions and slowing down the burning of fossil fuels has become a global strategic choice. As the medium and long term development goal of Chinese architecture, nearly zero energy building (NZEB) has become a new international trend, and it is the fundamental way to achieve energy-saving and emission-reduction. Passive house, mini energy consumption house, climate house, ultra-low energy

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1877-7058
10.1016/j.proeng.2017.10.003

consumption building are different forms of NZEB. As shown in Figure 1, by the end of February 2016, China has one hundred nearly zero energy projects, but only 13% is located in the severe cold area, and there is no study on the energy-saving design parameters of window-wall ratio (WWR).

Based on the climatic characteristics of cold regions, there are many studies on the WWR. Martin Thalfeldt et al. studied the surface structure of NZEB in cold area Estonia, it was concluded that highly transparent triple low emissivity glazing with WWR is about 25% and external wall insulation thickness is 200mm(U = 0.16) , which could meet the demand of ultra-low energy consumption in Estonian. This is one of the few studies on the WWR of NZEB. Several other studies on the conventional buildings have been made. Susorova has simulated the office buildings in 6 different climate zones. The results showed that the optimal north WWR is between 20-30%, south WWR is between 50-80%. And the total energy consumption will increase with bigger WWR. Similarly, Motuziene studied one air conditioning office building in cold region Lithuania, and concluded that the most energy-saving south WWR is 20%, while the north is between 20-40%. Hu Songtao took one typical office building Qingdao as a model, and studied the impact of different orientations and the WWR on building load. The results showed that the greater impact of different orientations' WWR on load order is east (west) > south > north. The most energy-efficient east (west) WWR for NZEB in severe cold area is 36%, south is 38%, north is 23%. Poirazis made some office building energy consumption simulations in cold area Goteborg, studied WWR of 30% to 100%, different glasses, shading and orientations. The results showed that the office building with smaller WWR will be more energy-saving. Fang Tao analyzed the impact of key envelope energy-saving design parameters on passive residence energy consumption in cold area. And concluded that the energy-efficient transparent envelope heat transfer coefficient of south and north is 0.78W/(m^2•K), east and west 1.0W/(m^2•K). Solar heat gain coefficient SHGC values are not less than 0.474, south WWR is between 70%-80%, but this study didn't do enough study on the different orientations.

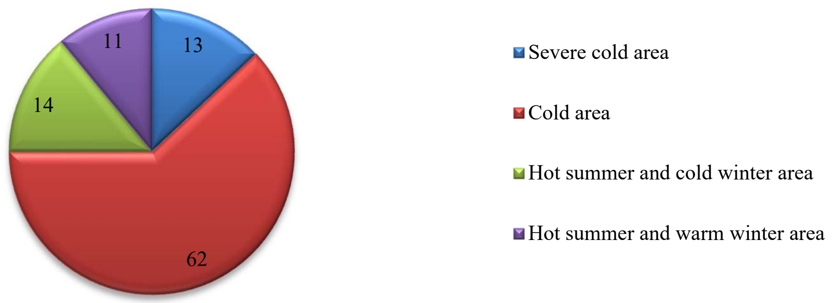


Figure. 1. Nearly zero energy demonstration buildings distributed in different climate areas

All in all, the above studies fully reflect that no matter which kind of buildings, determine the WWR reasonably is an important way for building energy-saving design. Today, although the NZEB has become a new international trend, most of the studies are not involved in WWR. And most studies of WWR were not based on severe cold area. Besides the NZEB is based on Climatic characteristics for guidance, energy consumption goal for performance design principle. So research the impact of different orientations' WWR in severe cold area on NZEB energy consumption is imperative.

2. Methods

In this paper, SketchUp is used to establish a model of typical demonstration NZEB in severe cold area. This NZEB is a rectangular building, whose shape coefficient is 0.54. The building size of length*width*height is 18m*8.4m*6.9m, the total area is 302.4m^2 with two floors. The first floor height is 3.3m, which is used as a residential demonstration. The second floor height is 3.6m with open and closed office, which is used to do scientific research. Thermal performance of envelope is shown in Table 1.

Table 1. Thermal performance of envelope

	External wall	Roof	Ground	External window
K (W/(m^2·K))	0.099	0.090	0.113	1.000

EnergyPlus simulation is based on Thermal Zone. Thermal Zone means the same or similar thermal condition rooms in the building divided into the same thermal zone. The room in the Thermal Zone may be unconnected. As the research goal is energy consumption of NZEB without studying specific individual rooms, the rooms with the same function (bedroom, bathroom and staircase) will be divided for one Thermal Zone. Other function rooms are respectively divided into different Thermal Zone during the procedure of modelling. As shown in Figure 2, there are nine thermal zones in the model, which are shown in different colors. The staircase and equipment room are unified no heating or cooling, so it was set as a no air conditioning area, residual thermal zones are air conditioning areas.

The NZEB energy sources are heat pump and solar system with long-term storage device, whose end are fan coil unit plus fresh air heat recovery system and radiant floor system. Besides the fan coil is only used for cooling, the fresh air does not bear the heat and humidity load, and the low temperature floor radiation heating system is only used for heating.

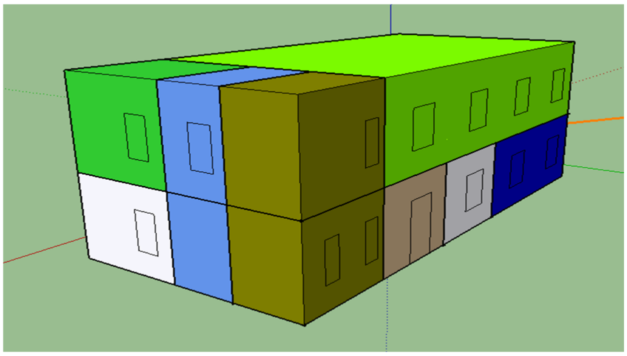


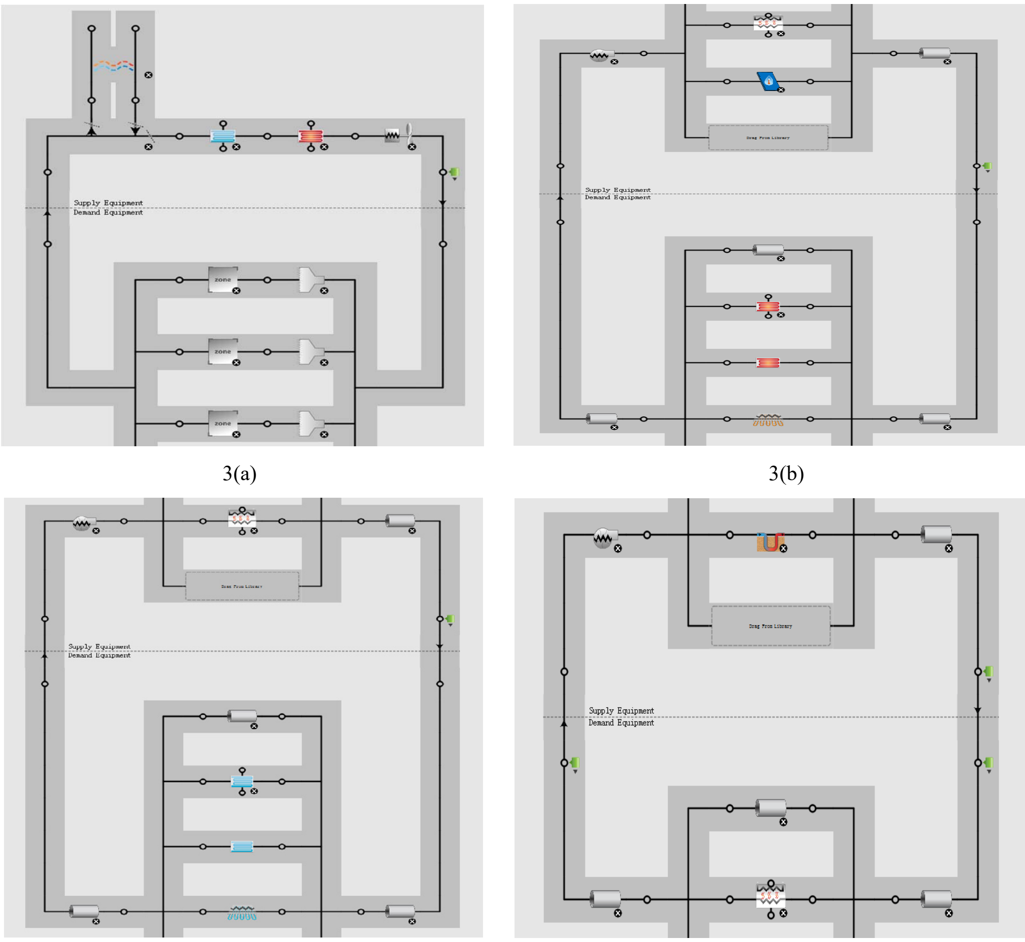
Figure. 2. Thermal Zone distribute picture

In this building each floor set one fresh air system, each Air Loop have four parts of heat exchanger, heating coil, cooling coil and fan as shown in Figure 3(a). Because the fresh air system does not bear the heat or humidity load, the supply air temperature set for the winter indoor setting temperature and kept constant. Under the rated condition of 75%, the heat recovery efficiency of sensible heat and latent heat is respectively 81% and 73%. The efficiency of the fan is about 80%, and the pressure is 500Pa. Fan was set to run daily at 8:00~21:00. When the building has no heating or cooling requirements, the night ventilation mode will open.

The Plant Loop includes a hot water loop, a cold water loop, and a water source side loop(including two loops for heating and cooling).The hot water loop provides hot water for the end of heating coil, low temperature hot water radiant heating system and the air system in the HVAC system, as shown in Figure 3(b). The outlet temperature of the hot water loop is 40℃, and the temperature difference between the water supply and return water is 8℃. The cold water loop provides cooling water for the end of cooling coil and the air system of HVAC system, as shown in Figure 3(c). The outlet water temperature of the cold water loop is 7℃, and the water supply temperature difference is 5℃. The water source side loop exchange heat with underground through vertical buried pipe as shown in Figure 3(d). In summer condition, underground pipe outlet temperature is 16℃, in winter condition, underground pipe outlet temperature is 12℃, the temperature difference between supply and return is 5℃.

The weather parameters of ASHRAE Shenyang area are selected for the simulation. According to the "Technology Guidelines for Passive Green Ultra Low Energy Building(Trial) (Residential Buildings)", lighting power density value is 3W/m^2, the building internal heat gain except for the light is 2W/m^2, the ventilation rate is 0.4 times/h. Set Venetian blinds in the east, south, and west.

In setting up each WWR of the model, the simulation should give full consideration to the impact of WWR on the heating and cooling energy consumption. If WWR increases, the solar radiation heat gain through the window will increase. However, at the same time as the window heat transfer coefficient is 3.5 times more than the external wall, the heat loss through window will increase, too. So in the NZEB design stage, optimization design for performance parameter of each orientation's WWR is conducive to energy-saving design of buildings. According to the "Civil Construction Energy Conservation Design Standards" JGJ26-2010, north WWR of residential building in severe cold area is no more than 25%, east (west) is no more than 30%, south is no more than 45%. In the simulation, each set of WWR values is shown in Table 2.



3(a) 3(b)

3(c) 3(d)

Figure.3. HVAC system setting picture

Table 2. Set the WWR values

East WWR (%)		South WWR (%)			West WWR (%)		North WWR (%)	
5.0	20.0	5.0	20.0	35.0	5.0	20.0	5.0	20.0
7.5	22.5	7.5	22.5	37.5	7.5	22.5	7.5	22.5
10.0	25.0	10.0	25.0	40.0	10.0	25.0	10.0	25.0
12.5	27.5	12.5	27.5	42.5	12.5	27.5	12.5	
15.0	30.0	15.0	30.0	45.0	15.0	30.0	15.0	
17.5		17.5	32.5		17.5		17.5	

3. Results

Change the orientations of the model, make the total energy distribute figure with different WWR. East (west) as shown in Figure 4(East WWR), north in Figure 4(North WWR), south in Figure 4(North WWR). To compare the impact of different orientations on total energy consumption, the total energy consumption is summarized, which is shown in Figure 5. The average heat gain and loss rate with different WWR of different orientations is shown in Table 3. In order to optimize the demonstration building model's WWR, the study needs to consider the heating, cooling, and the total energy consumption with the change of WWR, as shown in Figure 6 for east (west), Figure 7 for south, Figure 8 for north.

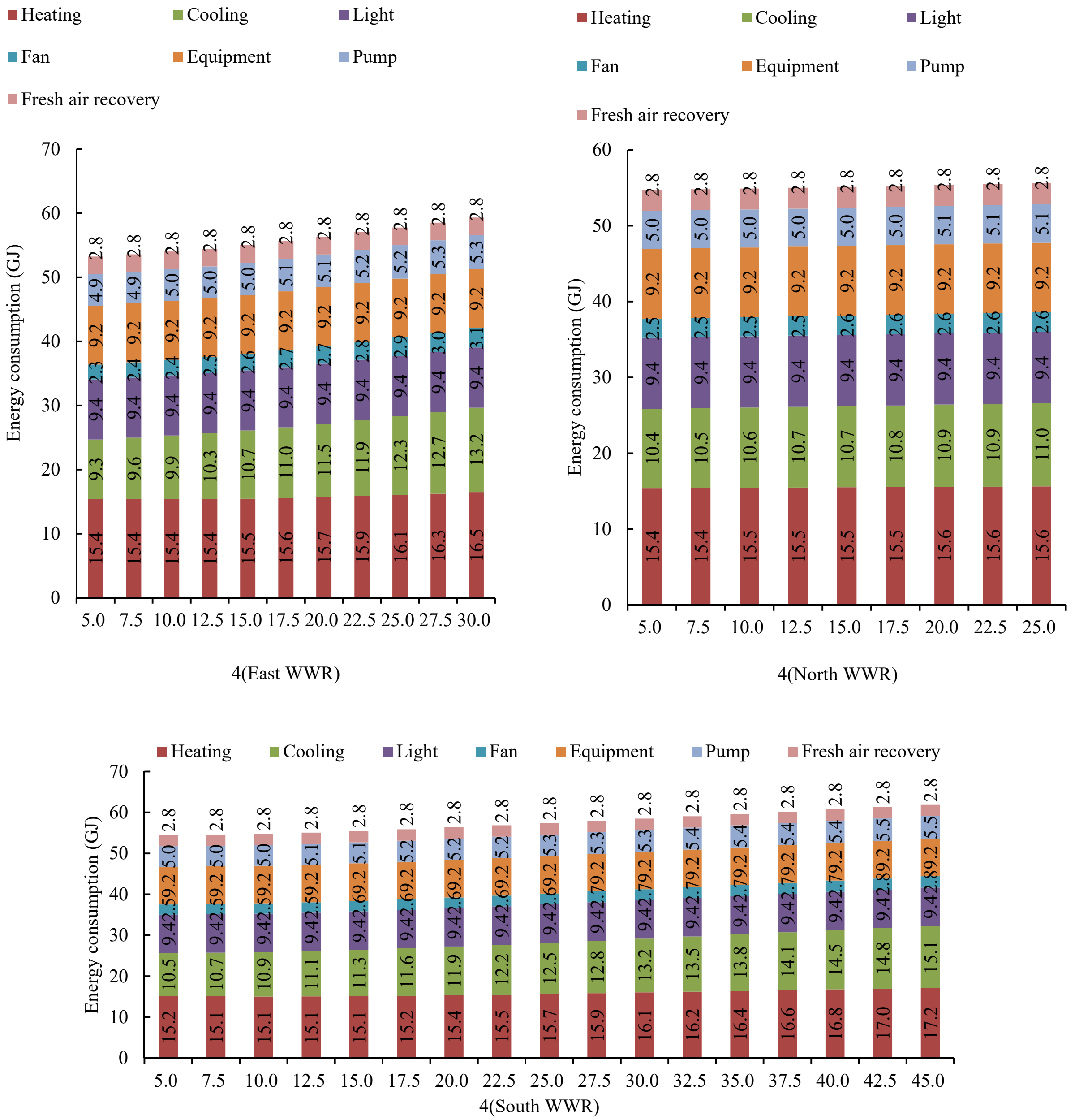


Figure.4. Energy consumption distribute picture

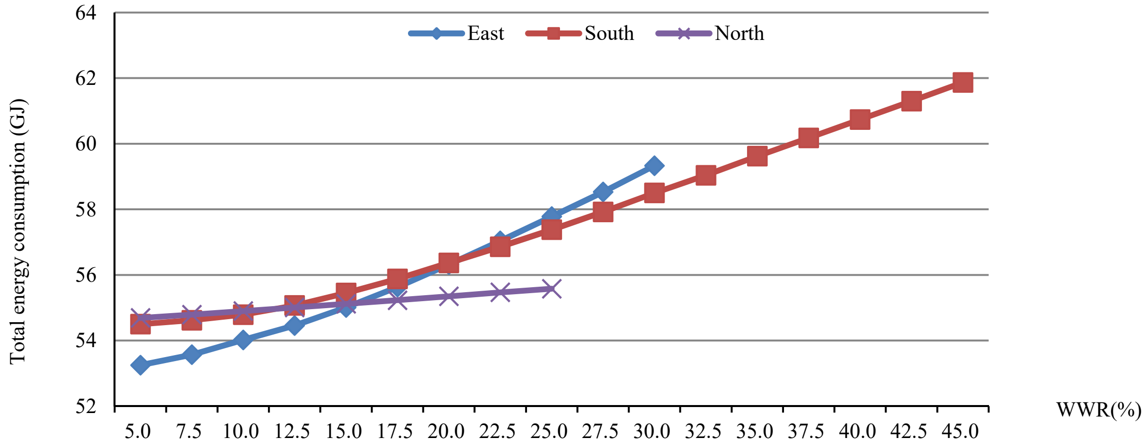


Figure.5. Total Energy consumption of different orientations

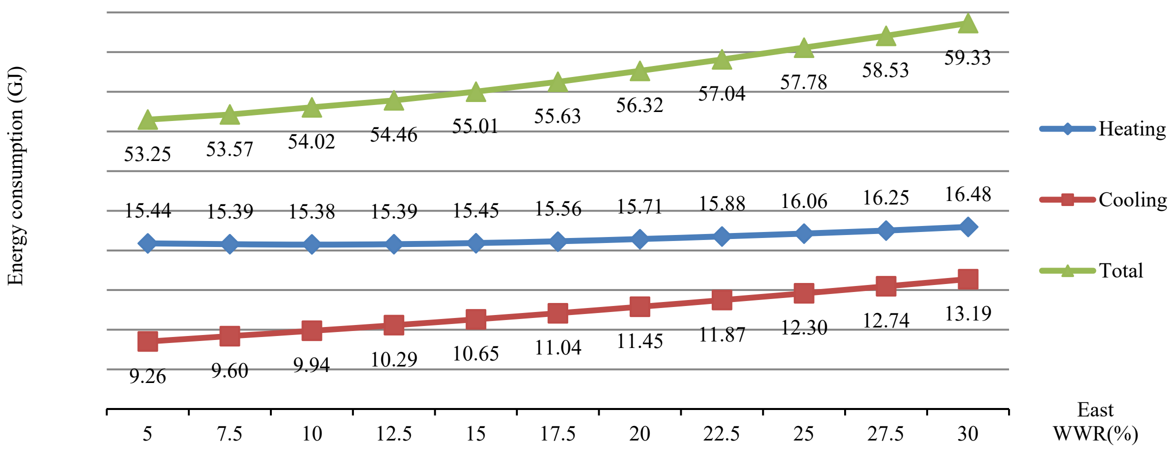


Figure.6. Energy consumption changes with different east WWR

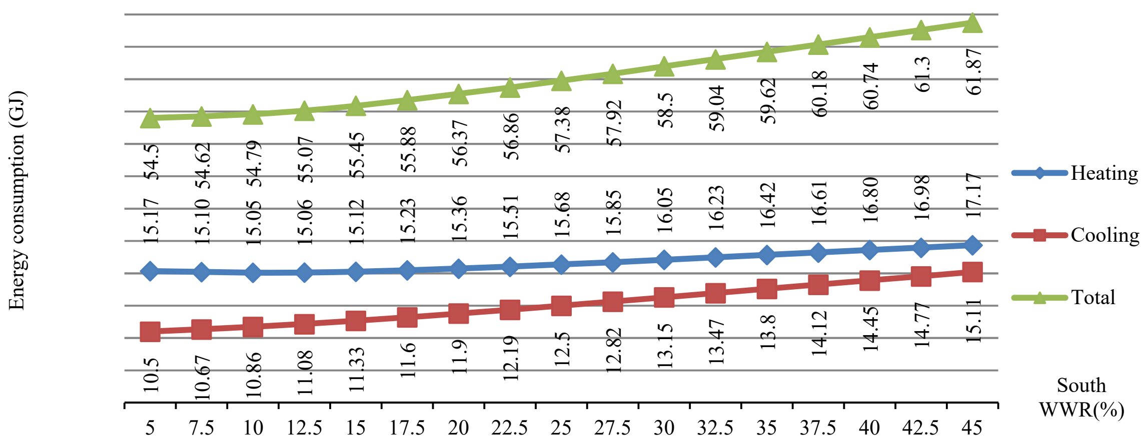


Figure.7. Energy consumption changes with different east WWR

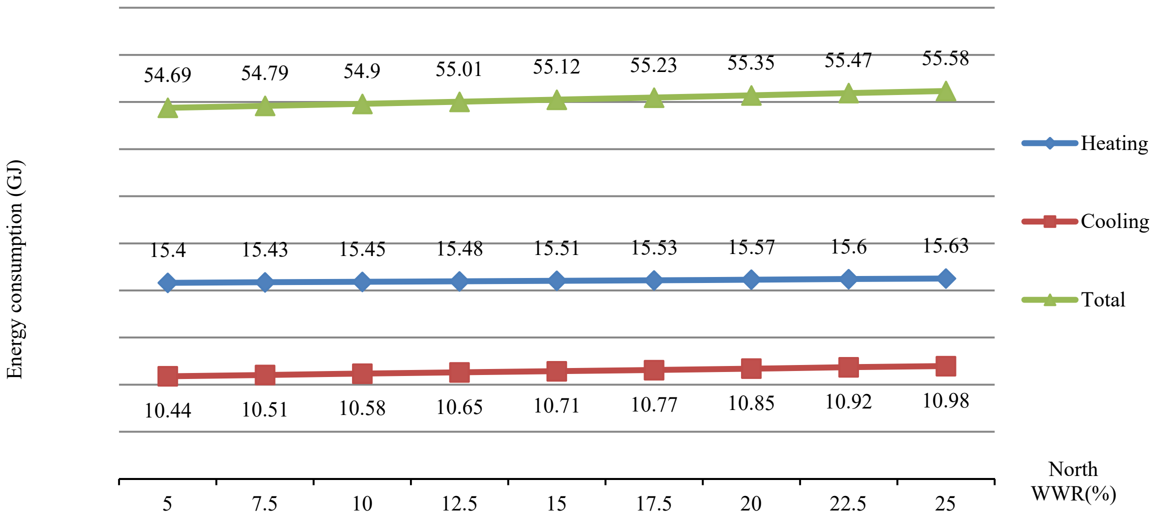


Figure.8. Energy consumption changes with different east WWR

Table 3. Heat gain and loss rate table

	East WWR		South WWR		North WWR	
	10%	30%	10%	30%	5%	25%
Average heat gain rate (W/h)	408.35	672.94	141.26	213.86	62.36	117.01
Average heat loss rate (W/h)	13	29.21	5.86	8.91	2.79	5.96

4. Discussion

Figure 4 shows that cooling and heating energy consumption dominate the total energy consumption. The heating energy consumption's proportion is large, however, the change is not obvious. The total energy consumption increases with the increase of WWR. Figure 5 shows the greater impact order of WWR on energy consumption of NZEB in severe cold area is east (west) > south > north.

In Table 2, when the east WWR increased from 10% to 30%, the average heat gain rate increased obviously by 264.59W/h, the average heat loss rate increased by 16.21W/h. Heat rate increase is 16 times of loss increase, so increase the east WWR result in summer cooling energy consumption increased significantly. When the south WWR increased from 10% to 30%, while the average heat gain rate radix is large, but only increased by 72.64W/h and the heat loss rate increased by 3.05W/h. The same WWR increased from 10% to 30%, the heat gain rate increment of south is reduced by 191.95W/h than east, the heat loss rate increment is only reduced by 13.16W/h, so the impact of east WWR on energy consumption is larger than south. When the north WWR increased from a minimum of 5% to a maximum of 25%, the average heat rate only increased by 54.65W/h, the average heat loss rate increased by 3.17W/h, obviously increase north WWR will lead to the increase of cooling energy consumption, and it is under the condition of maximum range WWR values, so compared with east and south when increase WWR the change is smaller obviously.

In Figure 5, when the east WWR is between 10%-15%, the heating energy consumption will increase. However, it offset the energy consumption between 5%-10% reduced. And the cooling energy consumption will increase, too. However, the per unit cooling energy consumption increment relative to the whole is the smallest, and the change of total energy consumption is minimum. In Figure 6, when the south WWR is between 10%-22.5%, similarly the heating energy consumption increased offset between 5%-10% reduced. And per unit cooling energy consumption increment relative to the whole is the smallest, the change of total energy consumption is minimum. In Figure 7, the heating, cooling and total energy consumption change little when increase the north WWR. This is because 50% of the north rooms are bathrooms without windows facing the north. But all the heating, cooling and total energy consumption increased when increasing the north WWR. Therefore, it is necessary to appropriately reduce the north WWR when the lighting, ventilation and other conditions allow it.

5. Conclusions

1. The greater impact order of different orientations' WWR in severe cold area on NZEB energy consumption is east (west) > south > north.
2. Increase the east (west), south WWR will increase cooling energy consumption more significantly than the heating energy consumption.
3. The change of average heat gain and loss rate with the increasing of WWR in summer verify conclusion 1. And it further explain conclusion 2 that cooling energy consumption increased significantly because average heat gain rate is 16-20 times of loss rate.
4. Most energy-saving WWR design scheme of NZEB in severe cold area is that the east WWR is between 10%-15%, the south WWR is between 10%-22.5%. And decrease the north WWR appropriately when the light and ventilation conditions allow it.

Acknowledgements

This paper is supported by "12th Five Year" national science and technology support program (2014BAJ01B04-2).

References

[1] IDA Users Online http://www.equaonline.com/ice4user/.
[2] V.Motuziene, E.S.Juodis, Simulation based complex energy assessment of office building fenestration, Journal of civil Engineering and management, 16(3) (2010) 345-351.
[3] H.Poirazis, Å.Blomsterberg, M.Wall, Energy simulations for glazed office buildings in Sweden, Energy and Buildings, 40(7) (2008) 1161-1170.
[4] S.T.Hu, L.J.Li, G.D.Liu, L.Zhang, Exploration on an optimal Wall-window ratio in public buildings based on building energy consumption in Qingdao area, Building Science, 32(06) (2016) 85-89.
[5] I.Susorova, M.Tabibzadeh, A.Rahman, L.Herek, C.M.Elnimeiri, The effect of geometry factors on fenestration energy performance and energy savings in office buildings, Energy and Buildings, 57 (2013) 6-13.
[6] T.Fang, Z.Z.Guan, W.J.He, Research on energy efficiency design key parameters of envelope for residential passive house building: a case study of cold zone in Tianjin, Journal of Shandong Jianzhu University, 30(06) (2015) 558-563.
[7] M.Thalfeldt, E.Pikas, J.Kurnitski, H.Vollb, Facade design principles for nearly zero energy buildings in a cold climate, Energy and Buildings, 67 (2013) 309-321.
[8] W.Xu, Z.J.Liu, X.Chen, S.C.Zhang, Thoughts of development of Chinese nearly zero energy buildings, Building Science, 04 (2016) 1-5.