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Impact of Window-Wall Ratio and Thermal Comfort 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. Also Chartered Institution of Building Services Engineers Technical Memoranda 52 (CIBSE TM52) is used to evaluate the thermal comfort conditions, and the state of overheating within the case study dwelling. The results indicate that increasing the thermal mass of the external walls significantly reduces the risk of overheating within the case study dwelling.
Keywords: Nearly zero energy building; Window-wall ratio; Energy consumption simulation

1. INTRODUCTION

Sustainability has progressively become a pressing issue throughout the world, with many countries supporting policies to reduce carbon emissions. A large portion of domestic buildings are still dependant on fossil fuels as a source of energy, contributing to more than 30% of carbon emissions in the United Kingdom, 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 once criteria one and two have been met, the remaining carbon emissions must be reduced to zero. The Zero Carbon Hub states that the zero carbon policy comprises of fabric energy efficiency, on site low or zero carbon heat and power, as well as allowable solutions.

2. METHOD

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

	xternal 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.

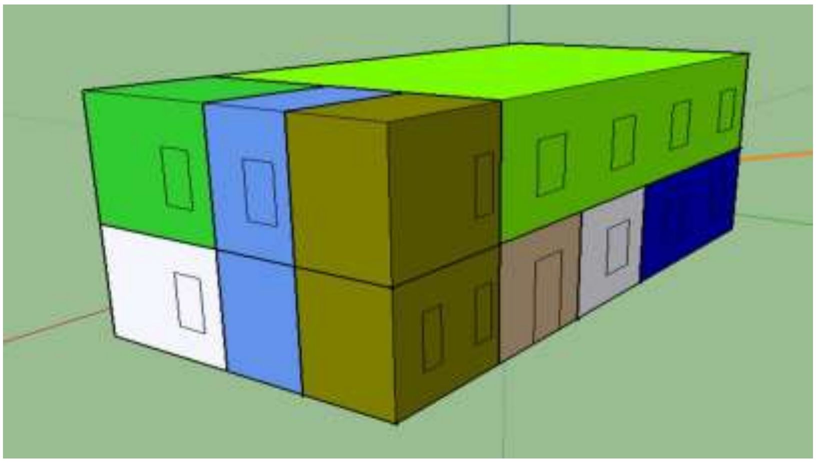

Fig 1. Thermal Zone distribute picture

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.

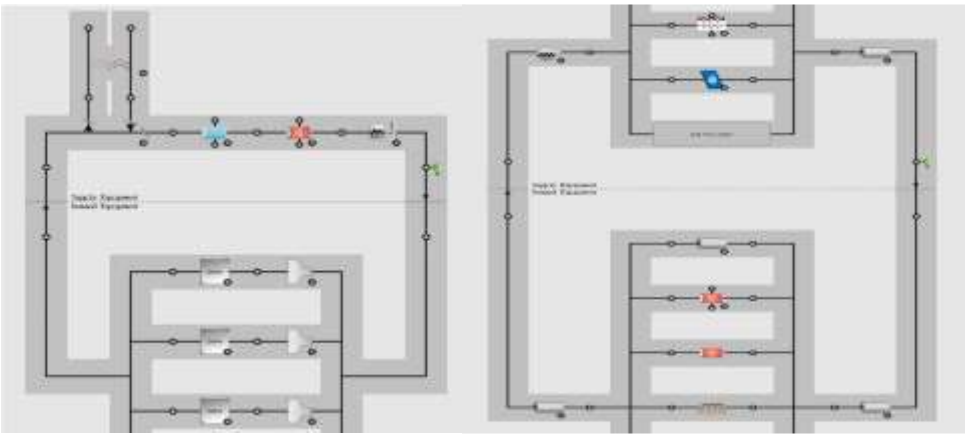

Fig 2. HVAC system setting picture (a)

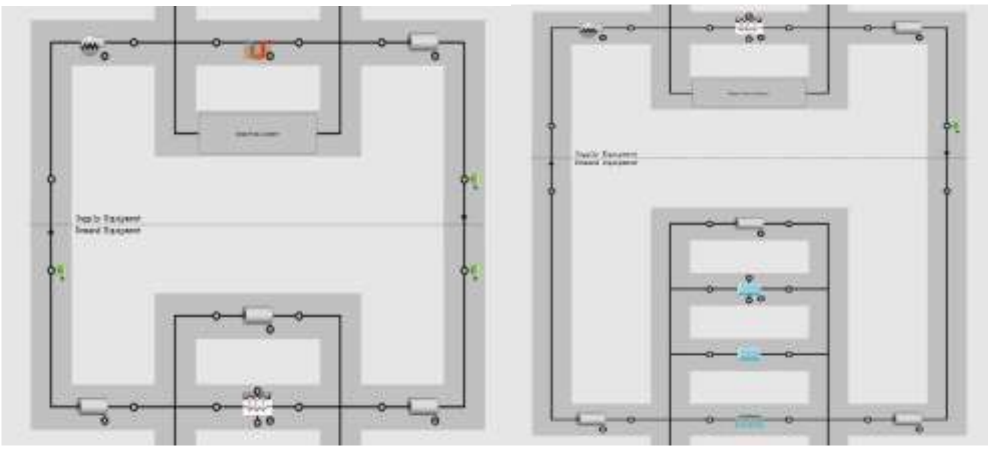

Fig 3. HVAC system setting picture (b)

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	

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.

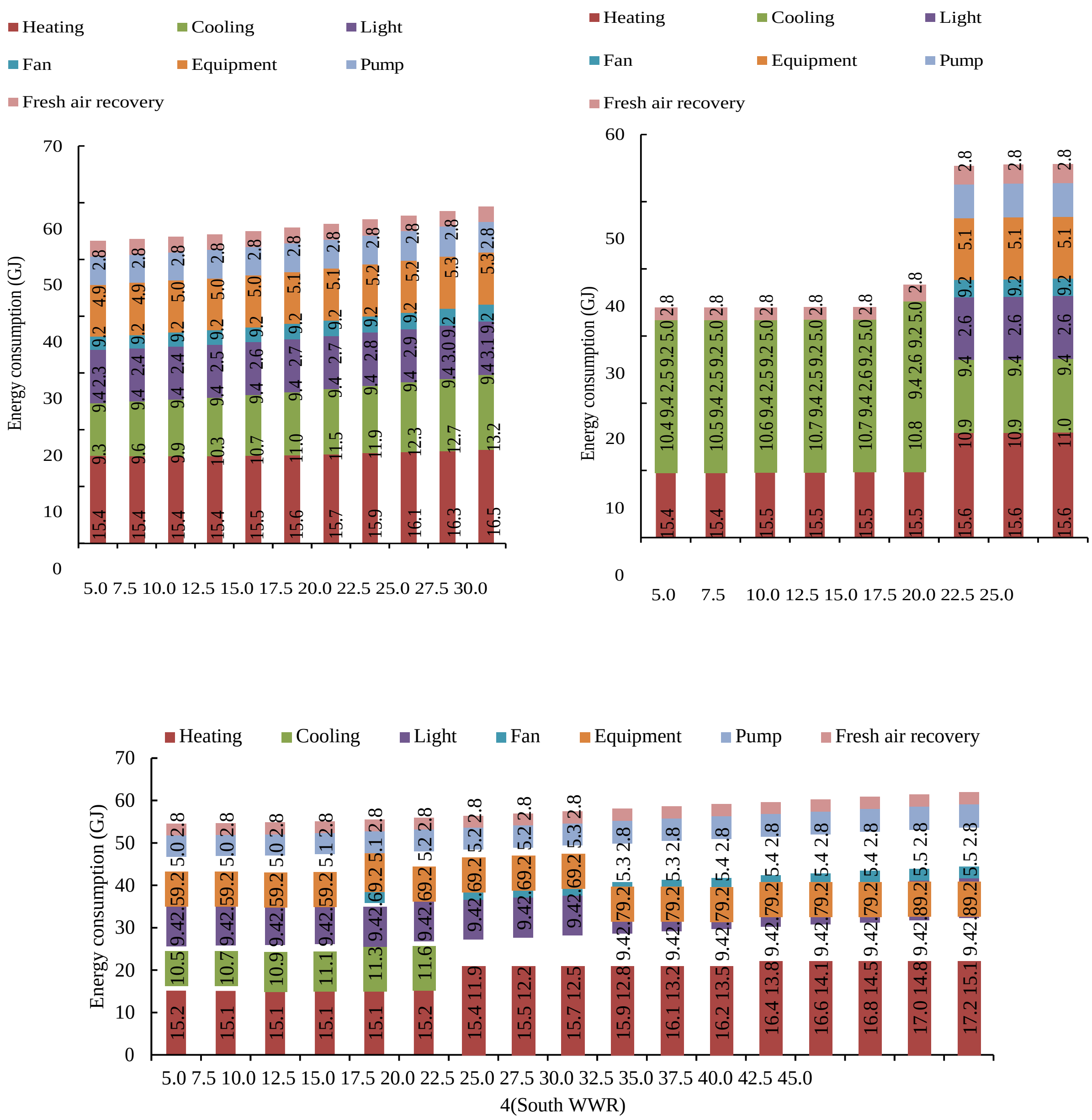

Fig.4. Energy consumption distribute picture

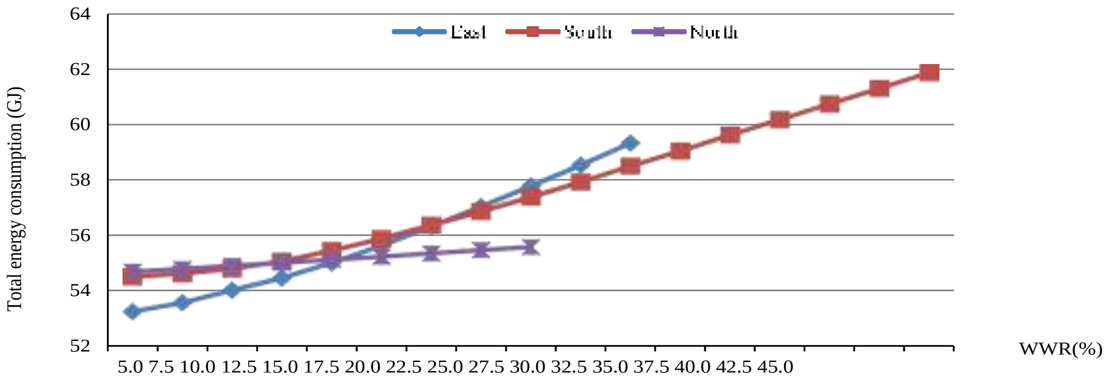

Fig.5. Total Energy consumption of different orientations

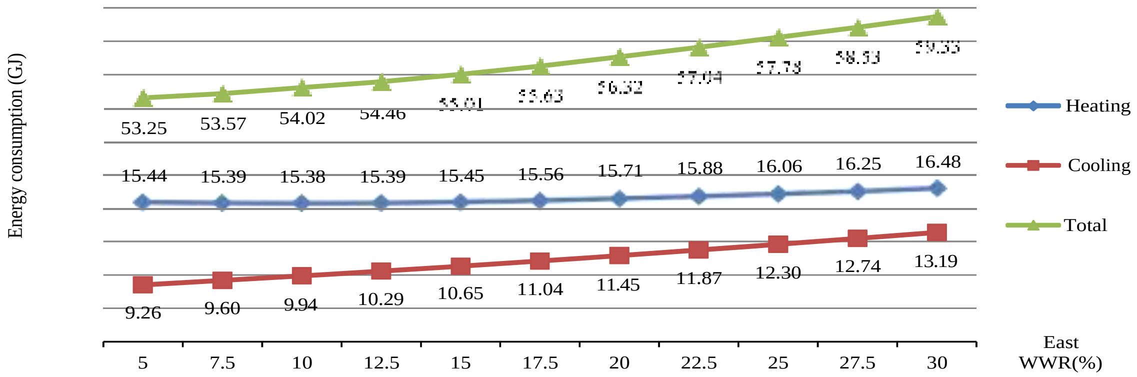

Fig.6. Energy consumption changes with different east WWR

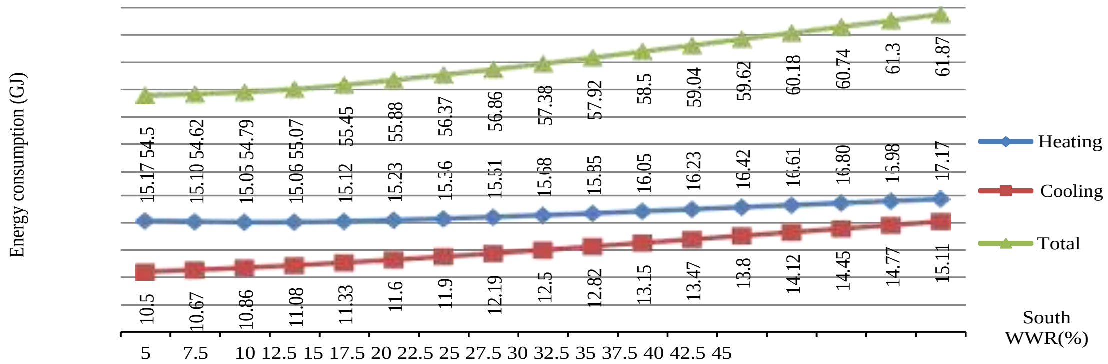

Fig.7. Energy consumption

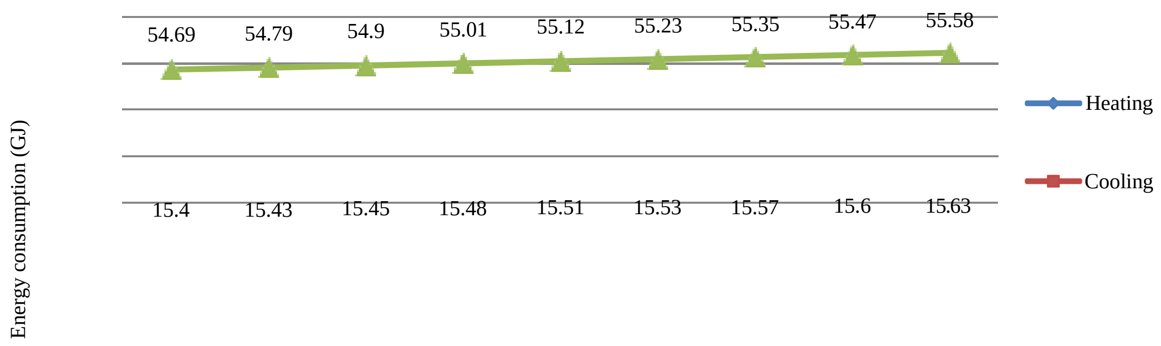

Fig.8. Energy consumption changes with different east WWR

Table 3. Heat gain and loss rate table

	East WWR		South WWR		North WWR	
	10%	30%	10%	30%	5%	25%
Average heat gain r	408.35	672.94	141.26	213.86	62.36	117.01
Average heat loss	13	29.21	5.86	8.91	2.79	5.96

3. CASE STUDY BUILDING

The Sigma Home (Fig. 1) forms the initial prototype within the United Kingdom designed to achieve Code 5 (zero CO2 for regulated energy) of the Code for Sustainable Homes [21]. The building consists of a semi-detached dwelling, with the adjacent dwelling forming a mirrored construction and design. The semi-detached construction consists of a four storey dwelling, to reduce the required footprint of the structure [22]. The home was constructed in 2007 by The Stewart Milne Group and is located within the BRE Innovation Park, Watford. The dwelling portrays a usable floor area of approximately 122m^2 with total of five occupied thermal zones corresponding to five simulated thermal zones. The thermal zones incorporating the following uses: ground floor open plan kitchen, dining, family area, first floor living room, first floor bedroom, second floor bedroom, third floor master bedroom. Table 2 portrays the as built constructions of the case study, as well as the associated U-values.

Table 4. The Sigma Home Construction Breakdown

Case Study Component	Construction build up	U-Value
Foundations	Pre-case concrete pile and beam	-
External Walls	5mm External Render, 12mm Recycled Backing Board, 30mm Cavity and Battens, 75mm	0.15W/m^2

	Celotex Insulation, 9mm OSB/3 Boards, 140mm Solid Timber Studwork and Glasswool Insulation, 9mm OSB/3 Boards, 25mm Battens, 12.5mm Plain Plasterboard, 12.5mm Internal Plain Plasterboard, 5mm Emulsion Paint.	
Internal Floors	10mm Faenza Clip Tiles, 18mm Chipboard, 15 OSB Decking, 300mm Deep Solid Timber Joists, 15mm Plain Plasterboard	0.18W/m^2
Ground Floor	10mm Faenza Clip Tiles, 18mm Chipboard, 15 OSB Decking, 300mm Deep Solid Timber Joists and Glasswool Insulation, 9mm OSB Boarding	0.18W/m^2
Roof	External Zinc Sheet System, Pre-fitted Weather-Proof Membrane, 15mm OSB Decking, 300mm Deep Solid Timber Joists and Glasswool Insulation, 9mm OSB Boarding, 25 x 38mm Service Zone Battens, 15mm Internal Plain Plasterboard	0.15W/m^2
Glazing	High Performance Triple Glazing: 14.52m^2 on the West elevation, 5.76m^2 shown on the South Elevation, 18.16m^2 incorporated on the East elevation, and 1m^2 on the North Elevation	0.68W/m^2

Fig. 9. The Sigma Home Case Study

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

This paper provides advances in the field regarding the issues related with low energy buildings. Previous research has incorporated methods to achieve zero carbon in existing buildings through retrofitting, the potential of incorporating renewable sources in existing buildings, system boundaries surrounding zero carbon buildings, and assessments of carbon emission generation related to buildings. This paper progresses from previous literature due to the focus on the effects of zero carbon dwellings on the occupied indoor environment, rather than concentrating on strategies to incorporate low carbon in existing buildings.

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.

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