Analysis on the influence of occupant behavior patterns to building envelope's performance on space heating in residential buildings in Shanghai

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Abstract:

Shanghai is situated within the Hot Summer and Cold Winter zone, where the requirement of improving the indoor thermal environment in winter grows rapidly. However, meanwhile we put effort in improving the indoor comfort, energy conservation should be considered for the constraints of total energy consumption. The building envelope plays important roles in heating energy use. In this paper, using building energy consumption simulation software DeST, different occupant behavior patterns and the life cycle energy consumption of external wall insulation were taken into account to help setting an appropriate standard of the heat transfer coefficient of building envelope in residential buildings. It was found that the energy saving potential of building envelope improvements could be significantly reduced under the “part-time, part-space” heating modes than “full-time, full-space” heating modes. Considering the life cycle energy consumption, it’s necessary to increase external insulation to a suitable thickness rather than blind increasing insulation since energy consumption of insulation materials manufacturing could not be ignored.

Keywords: occupant behavior, building envelope, DeST-h

1. Introduction

Shanghai, located in Hot Summer and Cold Winter zone in China, is not equipped with district heating system. With the economic development and scientific advance, people’s living standard improves significantly, thus residents’ demand for better indoor thermal environment in winter are increasing rapidly in Shanghai. Many studies have shown that winter indoor temperature is relatively low, only about 12-15℃[1-4], prove that the indoor thermal environment needs much improvement. But at the same time, considering energy pressure in China and the constraints of total energy consumption, energy saving measures should be taken like reducing building heat consumption, improving the system efficiency of heating equipment, advocating green life style and so on. For reducing building heat consumption, the role of building envelope's performance cannot be ignored.

A number of studies have analyzed the building envelope's performance in residential buildings in Shanghai. Dezhi Li[5] reported that strengthening the building envelope and improving equipment efficiency is the most important measures of building energy saving. Zheng Shao[6], using DeST-h energy consumption calculation analysis software, made the conclusion that external wall heat transfer coefficient should be lower than 0.6 W/(m^2・K) while external wall heat transfer coefficient should be lower than 2.0 W/(m^2・K) to meet design of 65% energy saving design. Yu Jinhua[7] performed a study on the determination of optimum insulation thickness for residential roof. Optimum insulation thickness of a typical roof in Shanghai are between 0.061 and 0.235m and the payback period are between 1.9 and 4.2 years. Qian Liu[8] compared the effect of various envelop insulation measures on energy saving rate for annual total energy consumption and found that it’s not appropriate to enhance the wall performance simply without taking account of window insulation and sunshade measures.

Most of these studies given hardly any focus on the effect of occupant behavior to the determination of proper building envelope. Nevertheless, occupant behavior play a vital role on the heating energy use. Figure 1 shows a significant difference, up to 10 times more heating energy use, between those household in the same housing estate in spite of their similar building envelope performance and room orientation. Using the software of DeST-h to simulate the heating energy consumption, the effect of occupant behavior to the determination of proper building envelope is analyzed in this paper.

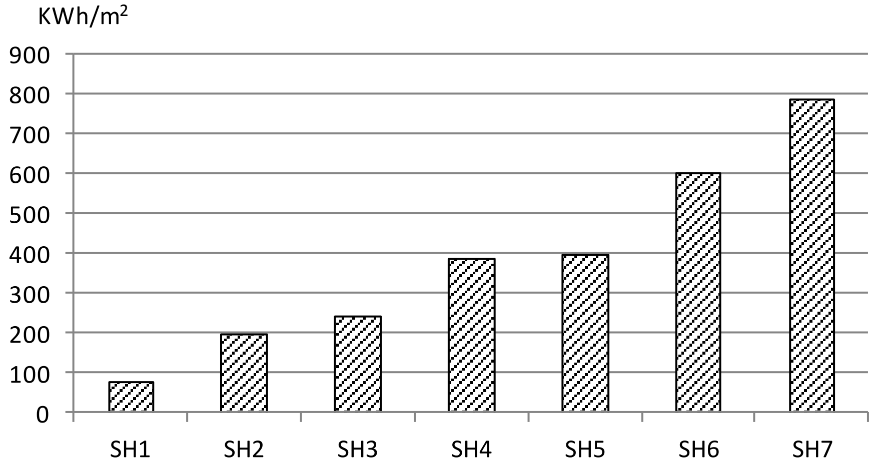

Figure 1. Heating energy use of different household in Shanghai

2. Method

The sample model is a real residential building in Shanghai, shown in Figure 2. The software of DeST-h is chosen to simulate the heating energy consumption, based on the hourly outdoor temperature and humidity of the typical meteorological year of Shanghai.

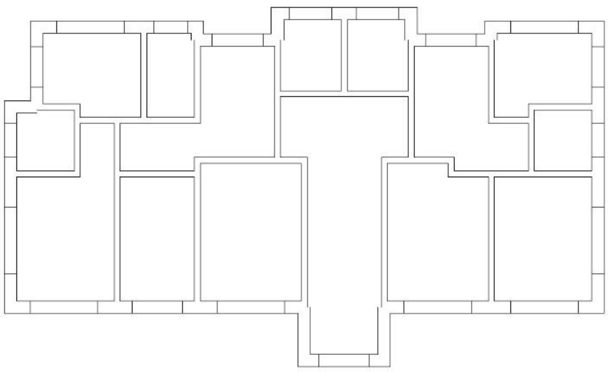

Figure 2. Typical building model

The building has 12 floors and there are two households in each floor. The split-type heat pump air conditioner is used in the living room, two bedrooms and the study in each household while the kitchen and the storage room not.

The shape coefficient of this building is 0.24, and the window-wall ratio is shown in Table 1:

Table 1. Window-wall ratio

orientation	east	south	west	north
WWR	0.35	0.4	0.35	0.4

Recording to national code "Design Standard for Energy Efficiency of Residential Building in Hot Summer and Cold Winter Zone", the indoor heat gain is set to 4.3W/m^2 and the heating season is December 1st to following February 28th.

Every household is a family of three people, two adults and one child. Daily routine of weekdays and weekends is shown in Figure 3 and Figure 4. Take weekdays for example, three people wake up at 6 am, eat breakfast in living room at 7 am, then leave home, and go back home and eat dinner in living room at 5 pm, the child write homework in his bedroom, while two adults rest in living room, then one adult go to study to read book, then the child sleep at 9 pm and two adults go sleep at 10 pm.

The number represents indoor residents number at that time:

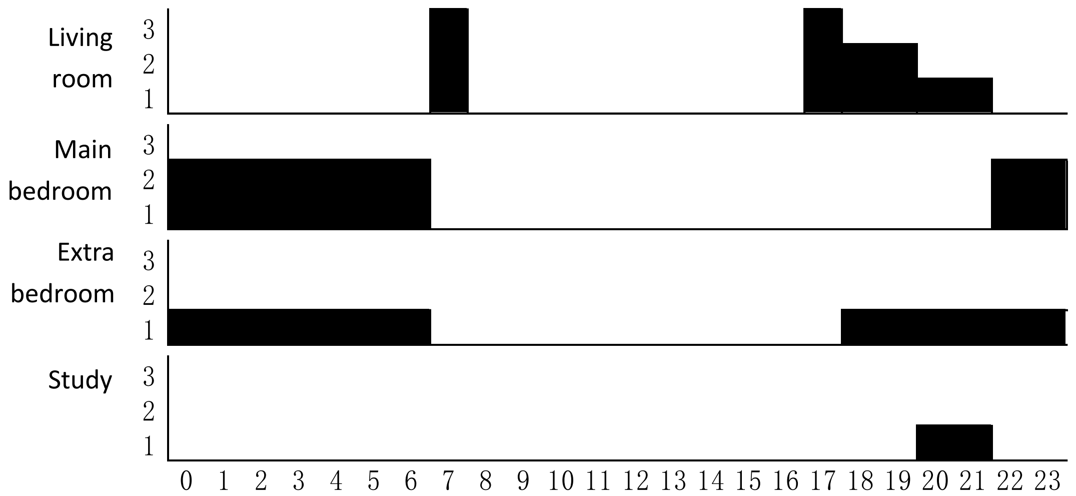

Figure 3. Daily routine in weekdays

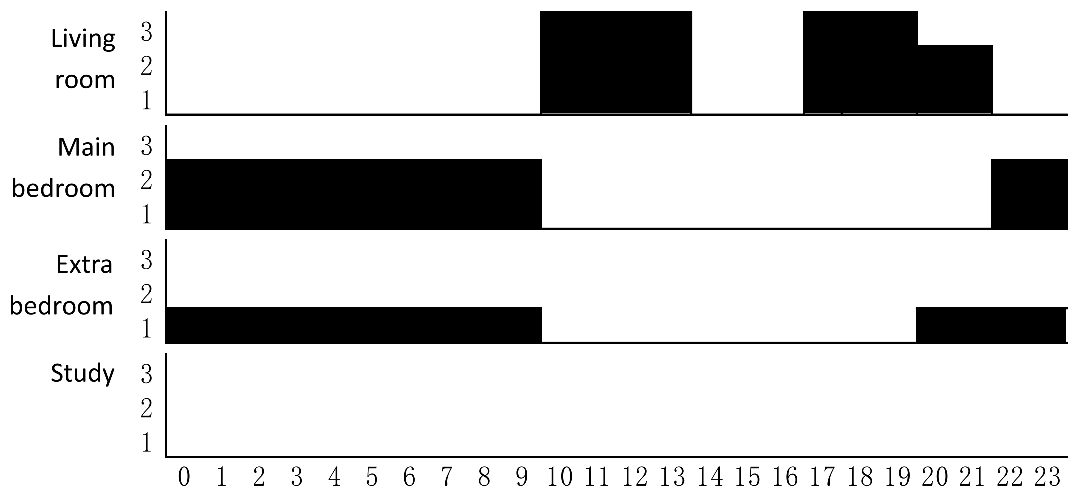

Figure 4. Daily routine in weekends

To analyze the relationship of occupant behavior patterns and the appropriate building envelope performance, fifteen cases differing in the building envelope performance and occupant behavior patterns were simulated. To prevent any confusion of these simulation results, any other settings not mentioned, like illumination intensity and ventilation settings, are the same with each other. There are three building envelope insulation measures and five occupant behavior patterns. One of the insulation lever is set according to the national codes in Hot Summer and Cold Winter zone, while the other two measures are respectively above and below the national codes, as shown in Table 2. Five occupant behavior patterns are chosen on the basis of practical survey and measurement data, as shown in Table 3.

Table 2. Occupant behavior patterns

Pattern 1	Heating for 24h, all the room maintain 18℃ above
Pattern 2	Heating as long as anyone come back home, maintain 18℃ above
Pattern 3	Heating only when residents feel cold, maintain 15℃ above
Pattern 4	Heating only when residents feel cold and stop heating when sleep, maintain 15℃
Pattern 5	Heating only when residents feel cold and stop heating when sleep, maintain 12℃

Table 3. Heat transfer coefficient of building envelope (W/(m^2・K))

	Wall	Roof	Window
Below national codes	2	1.7	4.7
Current national codes	1.5	1	3.2
Above national codes	1	0.6	2.7

3. Results

The heating energy use of the residential buildings in each building envelope insulation level with different occupant behavior patterns are shown in Figure 5. It is revealed that the energy saving potential of building envelope improvements differ a lot because of the various living patterns. In pattern 1, which might be called “full time, full space” heating patterns, strengthening the building envelope could lead a large amount of energy saving, however, the heating energy use varies slightly between the below national codes case and the above national codes case in pattern 5 which might be call “part time, part space” heating patterns. Patterns 3 to pattern 5 are known as the general heating patterns in this area through lots of investigation around Hot Summer and Cold Winter zone. If all residents turn to pattern 1, the heating energy consumption in this area will be 6~8 times than present and cannot match the ceiling of energy consumption in China. Thus the influence of occupant behavior patterns should be taken a full consideration in the design of the building envelope performance and determine the optimum insulation level based on actual living patterns.

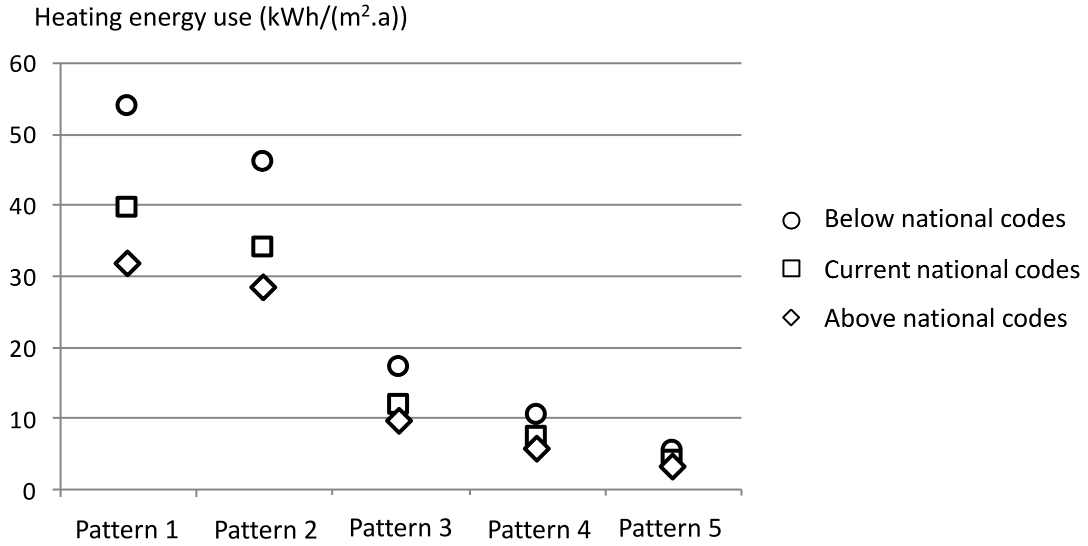

Figure 5. Heating energy use of different cases

Because the envelope must consume energy in manufacture process, the energy cost may outweigh the energy saving if blind increasing insulation. So it is necessary to consider full life cycle costs and life cycle savings to evaluate whether the building envelope design is energy saving.

Take the expanded polystyrene insulation material, a common used material, as a sample. The production energy consumption of this material is 90 MJ/kg, and its density is 22kg/m^3[10]. The heating energy use of residential buildings differing in insulation thickness are simulated using DeST software and three typical living patterns are considered. Based on the no envelope insulation case, the energy savings could be calculated. Suppose that the insulation materials can be used for 20 years, the total practical energy saving=annual energy saving- production energy consumption/20, shown as Figure 6. The patterns are the same as these mentioned before.

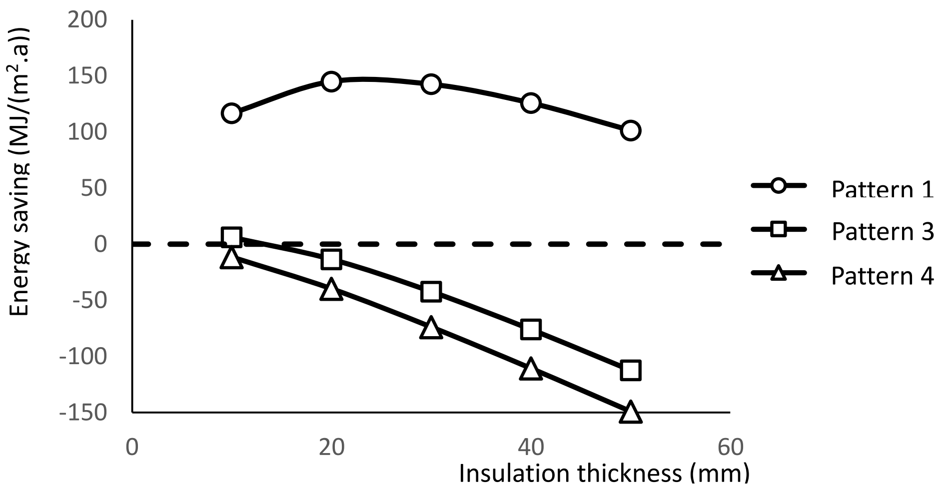

Figure 6. Total practical energy saving

It is found that 20mm is the optimum insulation thickness when occupants hold a "full time, full space" heating patterns. If "part time, part space" heating patterns are kept, a few energy is saved when the insulation thickness is 10mm, yet it's not energy saving considering life cycle cost when further strengthen the insulation level. So a designer cannot blind increase insulation thickness to design the building envelope. Meanwhile it's essential to reduce insulation materials' energy consumption in production period.

4. Conclusion

This paper, through establishing a sample residential building in DeST-h, presents a comparison of the influence of the change of occupant behavior patterns and the improvement of building envelope performance to heating energy use in Shanghai. Furthermore, the life cycle assessment of insulation material is also be conducted to judge practical energy saving of different insulation thickness. The major findings and conclusions of this study are summarized as follow:

(1) Occupant behavior significantly influences the heating energy consumption. Even in the same housing estate with similar building envelope performance and room orientation, the households might have 10 times difference in heating energy use.

(2) The energy saving amount of different building envelope insulation level varies from different occupant behavior patterns. In "full time, full space" heating patterns, strengthening the building envelope could lead a large amount of energy saving, meanwhile, the heating energy use varies slightly with the change of building envelope in "part time, part space" heating patterns.

(3) Considering the life cycle energy consumption, it's necessary to increase external insulation to a suitable thickness rather than blind increasing insulation and seldom think about living patterns since energy consumption of insulation materials manufacturing could not be ignored.

Reference:

[1] Hiroshi Yoshino, Yasuko Yoshino, Qingyuan Zhang, etc. Indoor thermal environment and energy saving for urban residential buildings in China[J]. Energy and Buildings, 2006,38:1308-1319.

[2] Huibo Zhang, Hiroshi Yoshino. Analysis of indoor humidity environment in Chinese residential buildings[J]. Building and Environment, 2010,45:2132-2140.

[3] Xudong Wan, Jingchao Xie, Yaohua Zhao, etc. Survey and measurement result analysis on the thermal environment and energy consumption of urban residential buildings[J]. Energy Conservation Technology, 2008, 1(26):68-74.

[4] Jei Shi, Wei Su, Jing Lv, etc. Thermal comfort analysis of Shanghai High-rising Dwellings[J]. Building Energy & Environment, 2008,27(1):75-80.

[5] Dezhi Li, Jin Zhu, Eddie C.M.Hui, etc. An energy analysis-based methodology for eco-efficiency evaluation of building manufacturing[J]. Ecological Indicators, 2011,11:1419-1425.

[6] Zheng Shao. Feasibility analysis on 65% energy saving of Shanghai residential building[J]. Housing Science, 2007,12:34-37.

[7] Jinhua Yu, Changzhi Yang, Liwei Tian, etc. A study on optimum insulation thickness of external walls in hot summer and cold winter zone of China[J]. Applied energy, 2009,86:2520-2529.

[8] Qian Liu, Xu Zhang. Energy consumption simulation and energy-saving analysis on residential building envelope in Shanghai[J]. Building Science, 2007,23(12):24-38.

[9] Tsinghua University Building Energy Research Center, 2009 Annual Report on China Building Energy Efficiency[M]. Beijing: China Construction Industry Publish House, 2009:5.

[10] Lijing Gu. Study on the environment impact of the building industry in China based on the life cycle Assessment[D], Beijing: Tsinghua University, 2009.