Journal of Southeast University (English Edition) Vol. 33, No. 4, pp. 457 – 465 Dec. 2017 ISSN 1003—7985

Analyses of influence of residential buildings' space organization on heating energy consumption in Lhasa

Li En

(School of Architecture, Xi'an University of Architecture and Technology, Xi'an 710055, China)

Abstract: The heating load simulation models of the residential buildings in Lhasa are established for enhancing the space organization's adaptability to climate and radiation and improving its energy saving performance. The space organization items are analyzed for both the existing buildings without insulation and new buildings with good insulation. The items include orientation design, south and north balcony design, the north and south partition wall's position design, storey height design and window-wall ratio design. Simulation results show that orientation is the key design element for energy saving design, and adverse orientation can obviously increase heating energy consumption; south and north balconies can reduce winter heating energy consumption; partition walls move to the north, which means that the south room's big depth design leads to less heating energy consumption, but the effect is not inconspicuous; smaller storey height results in less heating load. For the existing buildings, the window-wall ratio of south side has a balance point for energy saving design in the calculation condition. For the new buildings with good insulation, enlarging the south window-wall ratio can continuously reduce heating energy consumption, but the energy saving rate between models gets smaller. The heating energy consumption comparison study between the common model and optimal space design model demonstrates that the energy saving design can significantly reduce heating energy consumption.

Key words: residential building; space organization; heating energy consumption; energy saving design

DOI: 10.3969/j.issn.1003 –7985.2017.04.011

Lhasa has the typical climate characteristics of the plateau area: low oxygen levels, low barometric pressure, abundant solar radiation, and a large diurnal temperature range. The average temperature in its hottest month July is 15.5 ℃ and the average temperature in its coldest month January is −1.6 ℃. In general, it has a very cool summer and a relatively long but not-so-cold winter[1-2]. Documents show that along with its population, society development and residents' living level enhancement, the urban construction of Lhasa is marching towards the large-scale construction stage[3-5]. No doubt that in the near future, its energy consumption in buildings will largely increase. Therefore, with the constraints of both the local natural environment and social development, the effective passive design methods should be proposed for avoiding heating energy disorderly growth.

There is no doubt that the envelope's thermal performance design is very important to the indoor thermal environment in passive design. In previous studies, the importance of the envelope to heating energy consumption has been proved[6-7]. At the same time, field surveys and previous studies showed that, due to strong solar radiation, some architectural space design methods also contributed to the indoor thermal environment in Lhasa. For example, given similar thermal performance in two different rooms, the room with a solar space design had higher temperature at night than the one without solar space. Hence, this paper explores the influence of a residential building's space design elements on heating load using simulation and field surveys.

Regarding the heating energy saving research of Lhasa, previous studies were mainly completed by Chinese researchers. The feasibility analysis of indoor heating by only passive design was studied by dynamic calculation in southwest Tibet with its abundant solar energy[8]. The corresponding problems between the envelope thermal performance and active heating system were solved by analyzing the design elements of the active system and building thermal performance[9]. The thermal effect of the equivalent temperature of solar radiation on the solid wall in Lhasa was studied[10].

Generally, previous studies mainly focused on the envelope's thermal design performance or the optimization algorithm of the envelope's thermal transfer, which made contributions to controlling the heating energy load of Lhasa. However, few studies focused on the energy saving design rules for the residential buildings architectural space design, even though the field surveys had already proved its effect. The basic models are built from the most common residential buildings in Lhasa to study the impact of space design elements on heating energy con-

Received 2017-05-03, **Revised** 2017-08-29.

Biography: Li En(1982—), male, doctor, associate professor, lien801@163.com.

Foundation items: The National Natural Science Foundation of China (No. 51608426, 51590913), the Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry (No. (2014)1685).

Citation: Li En. Analyses of influence of residential buildings' space organization on heating energy consumption in Lhasa[J]. Journal of Southeast University (English Edition), 2017, 33(4): 457 – 465. DOI: 10.3969/j.issn.1003 –7985.2017.04.011.

sumption. Research subjects include orientation design, the south and north sealed balconies design, north and south partition walls' position design, story height design and south window-wall ratio design.

1 Field Survey and Measurement

Most of the residential buildings in Lhasa are multi-storeyed unit-divided apartments and townhouses. The research group made a continuous study on residential buildings in Lhasa. From 2006 to 2016, several field surveys had been carried out. The survey items included measurement and a questionnaire. The survey analysis has been published in other papers[3, 11]. The results are listed as follows: 1) Local residential buildings clearly have the characteristics of solar energy utilization, such as south orientation, low storey height, compact space, and some townhouses are refitted to create sunrooms; 2) Given similar thermal performance of the envelope, different space design can affect the indoor thermal environment, for example, the south balcony can obviously increase the adjacent room's temperature, especially at night; 3) The current winter indoor thermal environment does not satisfy the residents, particularly, the north rooms are too cold to be used.

2 Simulation and Analysis

This study takes unit-divided apartment as an example and analyzes how space organization influences heating energy saving in winter by simulation. In actual residential building design work, architects usually start with the function when doing space design. Common design items that affect function include orientation, balcony, north and south partition walls' position, storey height and building skin portal design. In fact, the design logic of former items, which related to dimension design, is human engineering. However, as previously mentioned, in the high solar exposure area, those space design elements also affect heating load. This paper studies their effects on heating energy consumption by quantitative analysis.

According to field surveys, almost all the apartment buildings face south. Three unit types are built for simulation study. They are direct solar gain unit, attached sunroom unit, and a double-balcony unit. Among them, the direct solar gain unit and the attached sunroom unit are the most common unit types in Lhasa.

It should be pointed out that the purpose of passive design for winter heating energy saving is to obtain enough solar radiation through the transparent envelope in the south. However, if there is no shading design, the building can become easily overheated during summer periods. Awning is one facility to keep the extra solar radiation out in summer. On the one hand, the outdoor air temperature in the hottest month in Lhasa is only around 15.5 ℃, and with shading and natural ventilation, the cooling load can be controlled. On the other hand, shading design is a flexible design process, even the mobile awning can be installed to block the extra amount of solar radiation. Hence, at the first stage, winter heating energy saving is the key content of the research in this paper. Shading will be studied in the future.

2.1 Introduction of simulation models and software

As introduced before, basic models are built from most common unit types in Lhasa. The building has four floors, and the target unit is located on the 3rd floor. Floor height is 3 m. The window-wall ratio in the south direction is 0.58, and that of the north is 0.23. Fig. 1 shows the basic unit types, which include a direct solar gain unit, an attached sunroom unit and a double-balcony unit. Fig. 2 shows the standard floor plan. The simulated unit is located at the central area. As shown in the figure,

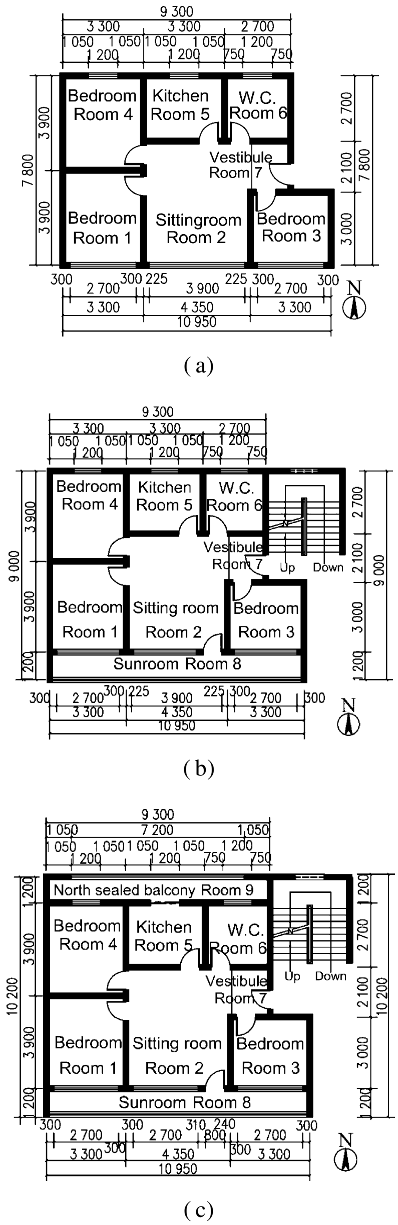


Fig. 1 Layout design of basic simulation model (unit: mm). (a) Direct solar gain unit; (b) Sunroom unit; (c) Double-balcony unit

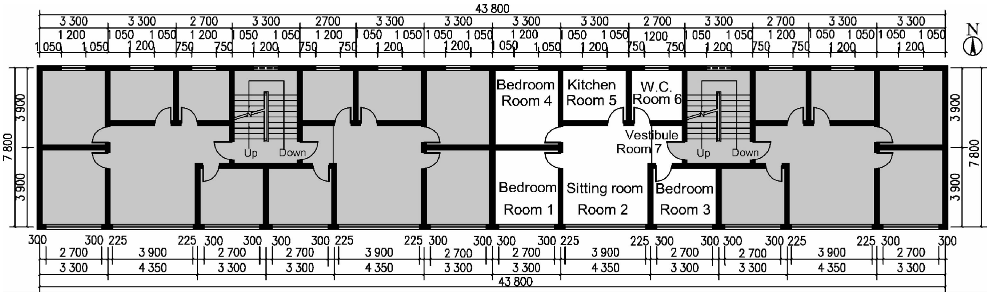


Fig. 2 Schematic diagram of standard floor plan (unit: mm)

the target unit is surrounded by the other rooms which are neighbouring and upstairs/downstairs rooms. The building shape coefficients of three unit types are 0. 30, 0. 27 and 0. 24, respectively. The heating rooms include Rooms 1 to 7, and the balcony is not heated.

Considering the rapid speed of the urbanization process of Lhasa, more and more unsupervised self-built houses located in rural areas are classified as urban buildings, and the heating system will be installed. Hence, not only the new design urban buildings are studied, but the existing buildings are also examined. Two kinds of the construction of the models for these two scenarios are set in the simulation. Tab. 1 shows the first kind of configuration. There is no insulation design for this scenario, which is the same thermal design as the building in the field survey. For the second scenario, the construction design follows the energy efficiency design standard[12], which means that the insulation design follows the design rules of the cold zone area (A) in the standard. To meet the design rules, the construction in Tab. 1 is improved. First, there is 5 cm EPS external insulation layer in the external wall. Secondly, double glass windows (6 mm glass + 12 mm air layer + 6 mm glass) for the north windows and low-e double windows (6 mm glass + low-e layer + 12 mm air layer + 6 mm glass) for the south windows are used. Thirdly, the window-wall ratio in the south direction is changed to 0. 50.

Tab. 1 Configuration of basic model

Unit envelope	Configuration	Thickness/m	Thermal conductivity/ (W · (m · K)$^{-1}$)	Specific heat capacity/ (J · (kg · K)$^{-1}$)
Wall (in to out)	Cement plaster	0. 150	0. 810	1 050
	Sand-lime brick	0. 370	1. 100	1 050
	Cement plaster	0. 150	0. 810	1 050
Window	Single glass	0. 006	0. 760	840
Floor	Cast-in-place reinforced concrete slab	0. 100	1. 740	920

This paper uses THERB as a simulation tool. THERB is a simulation program for calculating indoor temperature and humidity, thermal loads, etc., which is authorized by the Japanese government as one of the methods for evaluating the thermal quality of houses[13]. Before simulation, it is necessary to monitor the software by field measurement.

The layout shown in Fig. 3 is one of the survey targets in 2009. It is a typical apartment in Lhasa. Its walls are 240 mm solid concrete blocks with cement sand plasters of both in- and outside. The other configuration is the same as Tab. 1. The window-wall ratio of south direction is 0. 59, and that of the north is 0. 18. The size is shown in Fig. 3. There is no heating during the measurement period.

THERB is used to build the same model. The time step is 3 600 s. Ventilation of every room is 0. 5 times/h. Internal and external surface heat exchange coefficients are 8. 7 and 23 W/(m^2 · K), respectively. There is no heating in the model. During the calculation period, the outdoor air temperature is from the field measurement. Other calculating parameters such as direct normal irradiance, total horizontal irradiance, wind direction, wind speed and so on, are from the same day's TMY data in the document[1]. This is because there is no such measurement data in the field survey.

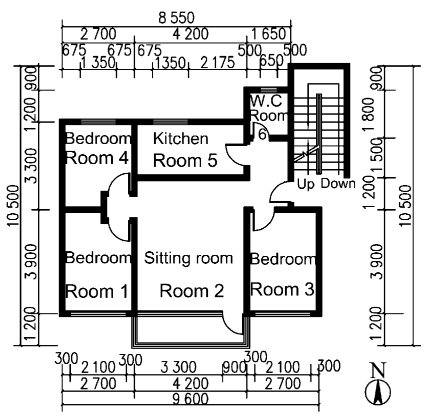


Fig. 3 Schematic diagram of field measurement layout

The comparison analyzing period is from 0:00, 27th November, 2009 to 23:00, 27th November, 2009, totally 24 h.

Fig. 4 shows the results of measurement and simulation of the indoor air temperature of Room 3. As shown in the figure, the measured value and the simulation value have the same trend. During the comparison period, the average value of the measured data is 14. 85 ℃, and the average value of simulation data is 14.12 ℃. It is clear in the figure that the peak hourly temperature difference period is between 12:00 and 18:00 o'clock, which is also the period with strong solar radiation. The average hourly temperature difference of this period is 1.95 ℃. In the rest period, which is the period with less solar radiation, the average value (absolute value of the hourly temperature difference) is 0.43 ℃. All the clues illustrate that the difference between the two columns of data is mainly caused by the calculation parameters of the solar radiation. In this verification calculation, the direct normal irradiance from the TMY data is smaller than the real value in the measurement.

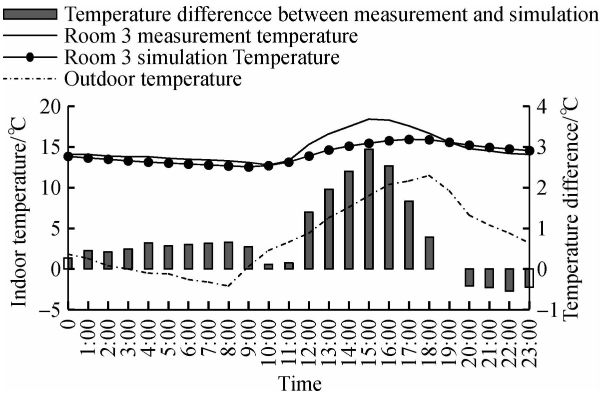


Fig. 4 Comparison of field measurement and simulation

However, as mentioned before, the measured value and the simulation value have the same trend. And, during the period with little solar radiation, the hourly temperature difference of the two columns of data is very small. All in all, the calculation result of THERB is reliable. In the simulation study, all the settings of THERB is the same as the verification case, except for one condition where the models are heated.

Lhasa's heating period in winter is 126 d[12]. However, in order to make the calculation less complicated, the integer number of months from November 1st to February 28th is used in the calculation, 120 d in total. Moreover, assume that there is no heat transfer between the study target and the surrounding rooms, and the air conditioner has COP 3 for a simple calculation. In this way, the thermal load can be expressed as electricity consumption. The indoor temperature is set to be 18 ℃, and the climate data is from document[1].

2.2 Orientation design

In the passive design, orientation is very important for solar energy collection. According to the basic design logic, there is no doubt that south is a good orientation. However, orientation can become a problem in the future as society develops. For a better understanding of the orientation's effect on heating energy, simulation models are built. The south direction is set to be 0°, and models are set every 15° clockwise. So, there are 24 models for one unit type. Three units have 72 models. There are a total of 144 models for both scenarios.

Fig. 5 shows the calculation results. As the figure shows, the results of three units for both scenarios have the same trend. From south to the other direction clockwise, there are two times fluctuations, the first increasing, and the second decreasing the energy load. The energy consumption valley between two peaks is around north direction. This is because in the north model, the original north direction turned south, which means that the models have a new direct solar gain system or sunroom system. Although the new system has a small window-wall ratio, which affects the passive design efficiency, the heating loads are still smaller than the models without such passive systems.

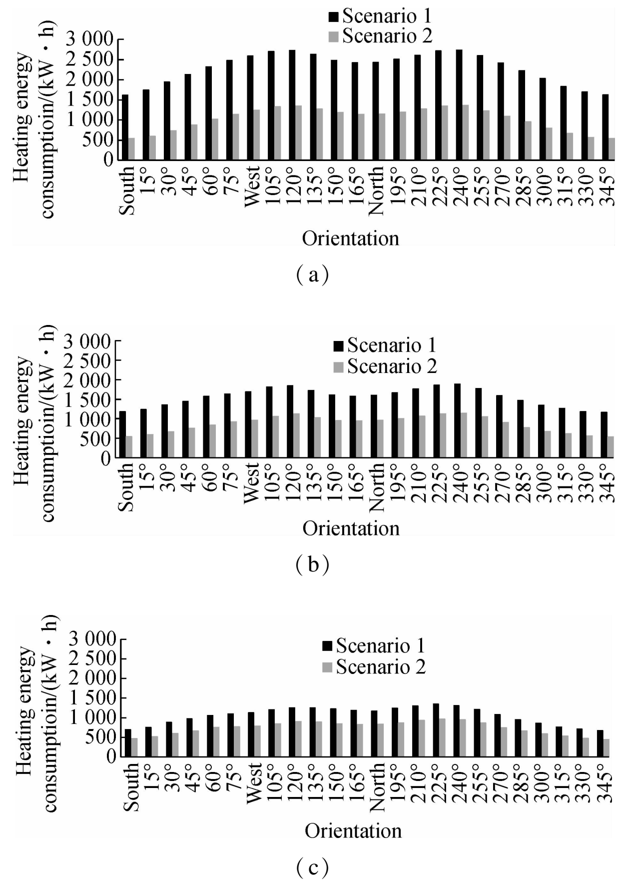


Fig. 5 Simulation results of orientation models. (a) Direct solar gain unit; (b) Sunroom unit; (c) Double-balcony unit

In Scenario 1, as the figure shows, for all three units, the most adverse orientation models have an over 60% energy consumption increase compared with the minimum model. The orientation is a very important design element in energy saving designs. Regarding the direct solar gain unit, from south by west 15° to south by east 30°, the models have less than a 10% heating energy consumption increase. As for the sunroom unit and double-balcony unit, the orientation range is from south by west 15° to south by east 45°. In the actual design work, the orientation range mentioned previously is acceptable for heating energy saving. As for the other orientations, the extra energy saving strategy, like the improvement of the envelope's thermal performance, should be used to reduce the negative influence caused by the orientation. In Scenario 2, for all three units, the most adverse orientation models have over 100% energy consumption increase compared with the minimum model. Moreover, for all three units, the orientation range from south by west 15° to south by east 30° is recommended for heating energy saving.

At the same time, in Scenario 1, the balcony design was found to have a very good heating energy saving performance. Fig. 6(a) takes four main orientations as targets to show the heating energy consumption changing trend from the direct solar gain unit to the double-balcony unit. Using south orientation as an example, the sunroom design reduces 30% of heating energy consumption from the direct solar gain model; the double-balcony design reduces nearly 60% heating energy consumption from it. The results show that the non-heating balconies make great contribution to heating energy saving. However, in Scenario 2, as for the south direction, due to the great thermal performance of the envelope, the difference between the sunroom unit and direct solar gain unit is only 0.24%. However, the double-balcony design reduces 13.5% of the heating energy consumption. This means that the north envelope is the weak insulation part. As for the other directions, the results show the same trend in the south direction. There is no doubt that sealed balconies are the effective space design method for energy saving design in the existing buildings. However, with the thermal performance of the envelope improving, the effects of sealed balconies are becoming weaker.

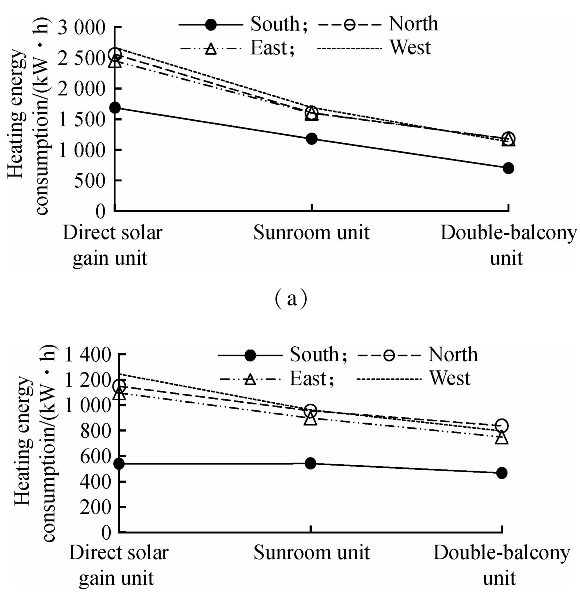


Fig. 6 Simulation results of three unit type models. (a) Scenario 1; (b) Scenario 2

2.3 North and south partition walls' position design

In the field survey, some traditional residential buildings were found to have only south rooms and no north rooms. This is one of the coping strategies for traditional buildings to deal with the local climate. However, there are no such examples in the unit-divided apartments in the urban area; the urban apartments have both south and north rooms, which is similar to other inland city examples. Using qualitative analysis, under the condition of the same layout area and layout shape, if the partition walls between the south and north rooms are moved towards the north direction, which also can be described as enlarging the area of the south rooms and reducing the area of the north rooms; the floor area for absorbing and storing solar energy will be larger. This is good for heating energy saving. For a better understanding of the effect of the partition walls' position on heating energy consumption, simulation models are built for all three unit types.

Fig. 7 takes the direct solar gain model as an example to show the position of partition walls. In the figure, H stands for the distance of partition walls moving from south side towards the north side. When H equals 0 m, the model has the layout plan of Fig. 7(a), which can also be described as Room 1 with the depth of 3.3 m, Room 4 of 4.5 m, Room 2 of 4.5 m, Room 5 of 3.3 m. When H equals 1.2 m, the model has the layout plan of Fig. 7(b), which can also be described as Room 1 with the depth of 4.5 m, Room 4 of 3.3 m, Room 2 of 5.7 m, Room 5 of 3.1 m.

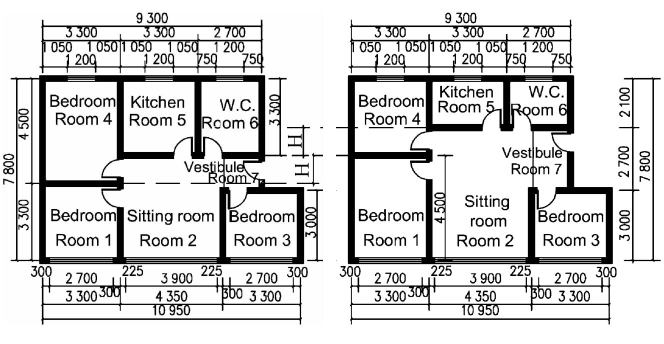
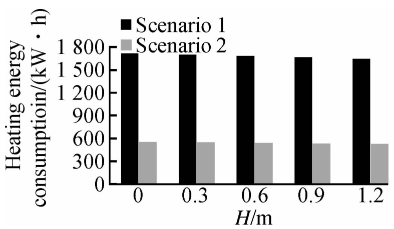


Fig. 7 Schematic diagram of north and south partition walls' position models (unit: mm). (a) Direct solar gain model with small depth of south rooms; (b) Direct solar gain model with big depth of south rooms

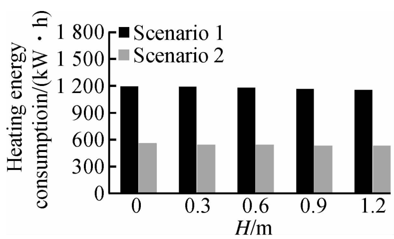
In this section, every unit type has five partition-wall-location models. The H values of five models are 0, 0.3, 0.6, 0.9 and 1.2 m, respectively. As for Room 1, the depths of five models are 3.3, 3.6, 3.9, 4.2, 4.5 m, respectively. Other rooms' depths respond with H. For all three unit types, there are 15 models. For two scenarios, there are 30 models in total. The sunroom unit and double-balcony unit have the same model setting as Fig. 7

shows, and their figures are not given. The other simulation setting is the same as the former calculation.

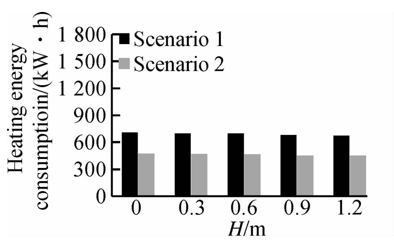
Fig. 8 shows the simulation results. As shown in the figure, for all three unit types in two scenarios, along with the partition walls moving toward north side, which means that the area of south rooms increases and the area of north rooms decreases, the heating energy consumption has a sustained downward trend. The simulation proves the qualitative analysis. However, the energy difference among models is small. For both two scenarios, the energy saving rate from the minimum model to the maximum one is less than 5.5% for all three unit types. Therefore, in the actual design work, the function of rooms takes priority. With the conditions allowing, the big south depth small north depth design style needs to be used.



(a)



(b)



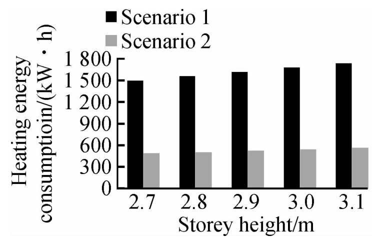
(c)

Fig. 8 Simulation results of south and north partition walls' position models. (a) Direct solar gain unit; (b) Sunroom unit; (c) Double-balcony unit

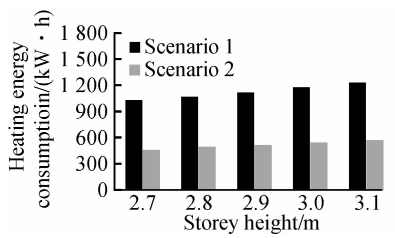
2.4 Storey height design

By qualitative analysis, higher story height results in more heating energy consumption. For a better understanding of the storey height's effect on heating load, five models are built. The storey heights are 2.7, 2.8, 2.9, 3.0 and 3.1 m, respectively. There are 15 models for three unit types. For two scenarios, there are 30 models in total. The other simulation setting is the same as in the former analysis.

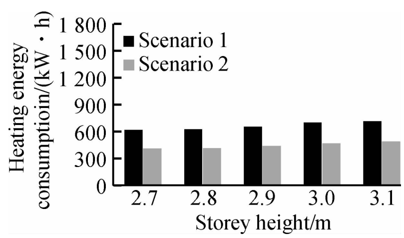
Results are shown in Fig. 9. The three unit types have the same trend in both two scenarios. As shown in the figure, for all three unit types, along with the storey height increasing, the heating energy consumption rises. For both two scenarios, every 0.1 m storey height increase results in an average 4.3% heating energy consumption rise. Therefore, the storey height should be low for a lower heating energy consumption. However, on the one hand, there are other elements that affect storey height, such as the psychological and physiological health of the occupants; on the other hand, the energy consumption difference among models is small. Therefore, avoiding huge space in the storey design is the design rule in the actual design work.



(a)



(b)



(c)

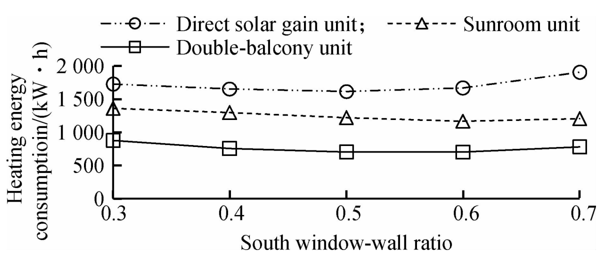
Fig. 9 Simulation results of story height models. (a) Direct solar gain unit; (b) Sunroom unit; (c) Double-balcony unit

2.5 South window-wall ratio design

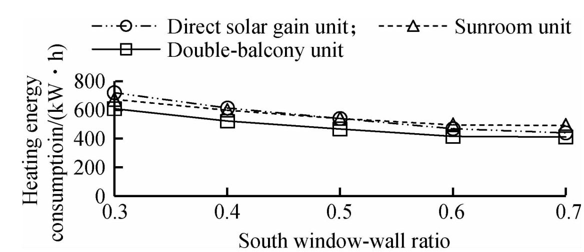
From the angle of building physics, the building skin portal design represents the window-wall ratio design. It is the key design element that affects lighting and ventilation. By the concept of passive design, the window-wall ratio of the south side is very important for solar energy collection. As for Lhasa, an area with extremely abundant solar energy, qualitative analysis demonstrates that greater south window-wall ratio is good for collecting solar energy in the daytime; however, the windows are also the main cause of heat loss, and a large window-wall ratio design easily loses heat at night. To understand the design rule of the south window-wall ratio for heating energy saving, five models are built. They are models with a south window-wall ratio of 0. 3, 0. 4, 0. 5, 0. 6 and 0. 7, in which, the window-wall ratio from 0. 4 to 0. 6 is the actual south window-wall ratio range in the local residential buildings. The ratios 0. 3 and 0. 7 are set for analyzing the south window-wall ratio design rule. The rest of the ratios such as those smaller than 0. 3 or greater than 0. 7 are obviously not good for solar energy utilizing or insulation. Therefore, the models with the south window-wall ratio from 0. 3 to 0. 7 are built for every unit type. Three unit types have 15 models for each scenario.

The south windows' location and size in the layout plan are shown in Fig. 1. The window-wall ratio models are adjusted by changing the windows' vertical size. The other simulation setting is the same as in the former analysis.

As shown in Fig. 10(a), in Scenario 1, for all three unit types, the energy consumption changing trend is first decreasing and then increasing. The window-wall ratio with the minimum energy consumption of the direct solar gain unit and double-balcony unit is 0. 5; and the one of the sunroom unit is 0. 6. All the unit types have the balance point for energy saving since south windows are not only a heat gain part but also a heat loss part. From ratio 0. 3 to the balance point, the increased solar gain is larger than the increased heat loss. This is why the heating energy consumption decreases from ratio 0. 3 to the balance point. However, single-glass windows have a poor thermal resistance performance. When the south window-wall ratio exceeds the balance point, even if the solar gain increases, heat loss plays the main role. This is why the heating energy consumption starts to increase from the balance point to the larger window-wall ratio. Therefore, the transparent part is one of the most important controlling elements for energy saving design in Lhasa. At the same time, the



(a)



(b)

Fig. 10 Simulation results of south window-wall ratio models. (a) Scenario 1: Existing buildings; (b) Scenario 2: New buildings

maximum energy consumption difference among the models for all three units is beyond 16% of the corresponding balance point value. Therefore, the balance point of the south window-wall ratio is necessary. It should be pointed out that the results are based on one certain calculation condition that the windows are single glass, which have bad thermal performance and are commonly used.

As shown in Fig. 10(b), in Scenario 2, for all three unit types, the energy consumption changing trend decreases when the ratio changes from 0. 3 to 0. 7. This is because the south windows in this scenario are low-e double windows and their heat insulation performance is very good. Therefore, a larger window-wall ratio in the south facade is better for heating energy saving. However, the energy saving rates for three units get smaller along with the increase in the ratio. Comparing the heating energy saving rates of two ranges, ratio 0. 3 to 0. 4 and ratio 0. 6 to 0. 7, the direct solar gain unit has changed from 14. 9% to 6. 3%, the sunroom unit from 11% to 0. 9% and double-balcony unit from 14. 1% to 1. 2%. All in all, in this scenario, the ratio 0. 7 has the best heating energy saving effect. If considering the effect and the cost of low-e double windows, ratio 0. 6 is recommended in the actual design work.

3 Results and Verification

It is clear in the former analysis that the architectural space design elements, such as orientation design, balcony design, south and north partition walls' position design, storey height design and south window-wall ratio design, all affect the building's heating energy consumption. Among them, the orientation design and south window-wall ratio design have great impact on the heating energy consumption in both scenarios. Moreover, the balcony design also affects heating energy significantly in Scenario 1. In the actual design work, the building orientation that ranges from 15° to −30° or −45° (south is 0°, clockwise positive) should be used in both scenarios; the double-balcony design is recommended; the balance point of the south window-wall ratio in Scenario 1 and ratio 0. 6 or 0. 7 in Scenario 2 are suggested. The influence of elements like the south and north partition walls' position design and storey height design is not as much as that of the former three design elements. The energy saving design methods as the big south room depth design and small storey height design are recommended when the conditions allow. To verify the effectiveness of the energy saving space design rules, the new model is built. In Scenario 1, the model uses south orientation, double-balcony, big south rooms depth, a storey height of 2. 8 m and south window-wall ratio 0. 58. In Scenario 2, the model has the south window-wall ratio 0. 7 and the insulation design and other settings are the same as Scenario 1. Fig. 11 shows the schematic diagram of the energy saving design model. The basic comparison models use the direct solar gain model in Fig. 1 and the simulation settings are the same as in the former calculation cases.

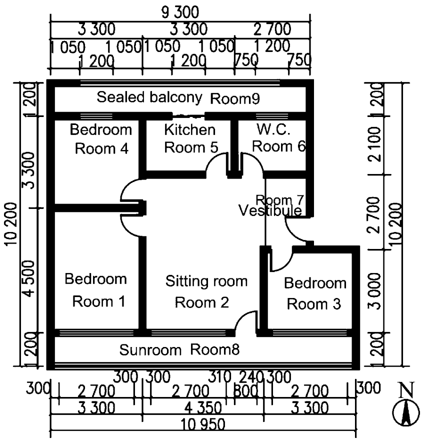


Fig. 11 Schematic diagram of energy saving design model (unit: mm)

Fig. 12 shows the comparison of calculation results. As shown in the figure, in Scenario 1, the energy consumption of the energy saving design unit decreases by 64% compared with the basic model. In Scenario 2, this value is 34.1%. The result proves the effect of energy saving space design rules. One more point needs to be noted. For the original direct solar gain unit, two scenarios have the heating energy difference of 1 128.4 kW · h, which means that the insulation design is very effective. As to the energy saving unit, the difference is 244.5 kW · h. The two values indicate that after energy saving space design, the insulation's effect becomes weaker.

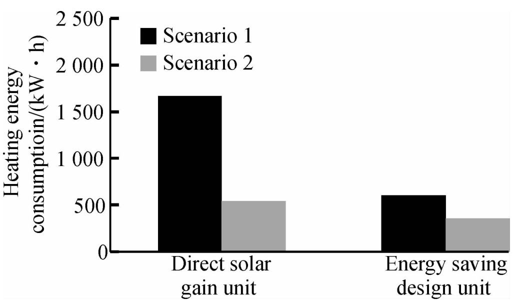


Fig. 12 Simulation results of direct solar gain model and energy saving design model

4 Conclusions

1) Orientation affects the heating energy consumption greatly. No matter in Scenario 1 or in Scenario 2, the adverse orientation significantly increases heating energy consumption. For scenario 1, the most adverse orientation increases heating energy consumption by over 60%; for Scenario 2, the value is 100%. In Scenario 1, for the direct solar gain unit, building orientation that ranges from 15° to −30° (south is 0°, clockwise positive) is good for energy saving; for the sunroom unit and double-balcony unit, an orientation range from 15° to −45° is good for energy saving. In Scenario 2, for all three unit types, building orientation that ranges from 15° to −30° is good for energy saving.

2) For existing buildings, the south and north sealed balconies' design is the space design rule with great heating energy saving effect. The sunroom design reduces 30% of heating energy consumption from the direct solar gain model, and the double-balcony design reduces near 60% heating energy consumption from it. With the thermal performance of the envelope improving, the effects of the sealed balconies are getting weaker.

3) Moving the south and north rooms' partition walls towards the north, which means the south room's big depth and north rooms' small depth design, leads to less heating energy consumption, but the energy saving effect is small. The energy saving rate from the best case to the worst case scenario is smaller than 5.5% for all three units in the two scenarios. When the condition allows, the design principle should be used.

4) Smaller storey height results in less heating load. For both scenarios, every 0.1 m storey height's increasing results in about average 4.3% heating energy consumption increase. In the storey height design, huge spaces should be avoided.

5) For the existing buildings, the relationship between south window-wall ratio and heating energy consumption is a nonlinear function. For single-glass windows, with the south window-wall ratio increasing, all three unit types have the changing trend of firstly increasing and then decreasing. As for the calculation cases in this paper, the south window-wall ratio from 0.5 to 0.6 is recommended for energy saving. For the new building with good insulation, the energy consumption changing trend is decreasing from ratio 0.3 to ratio 0.7, but the energy saving rate becomes smaller. In this scenario, the south window-wall ratio 0.6 or 0.7 is recommended.

Due to the length limitation, this paper focuses on the space design parameters only in Lhasa city. As for other cities with abundant solar energy, the space design rules will be different according to the differences in climate conditions. In the next step, more cities will be analyzed.

Acknowledgement

We express our thanks to Associate Professor Suolang Baimu and other teachers and students from the Architectural School of Tibetan University for their support in field surveys.

References

[1] Zhang Qingyuan, Yang Hongxing. *Typical meteorological database handbook for buildings* [M]. Beijing: China Architecture Industry Press, 2012: 55 − 56. (in Chinese)

[2] Li En, Akashi Y, Liu J P. Design methodology of ener-

gy saving building in developing cities—The geography, climate, society and indoor environment of Tibet [J]. *Journal of Habitat Engineering*, 2009,**1**(1): 125134.

[3] Li En, Akashi Y, Sumiyoshi D, et al. Energy consumption analysis of house in Lhasa based on survey and simulation [C]//*12th Conference of International Building Performance Simulation Association.* Sydney, Australia, 2011: 1535 - 1542.

[4] Zhang J K. Evaluating regional low-carbon tourism strategies using the fuzzy Delphi-analytic network process approach [J]. *Journal of Cleaner Production*, 2017, **141** (1): 409 - 419.

[5] Huang L J, Huang Z D, Hamza N, et al. Energy-efficient retrofitting and energy consumption in a historic city centre—An example from Lhasa [J]. *disP—The Planning Review*, 2014, **50**(3): 55 - 65.

[6] Li En, Liu J P, Yang L. Research on the passive design optimization of direct solar gain house for residential buildings in Lhasa[J]. *Industrial Construction*, 2012, **42** (2): 27 - 32. (in Chinese)

[7] Li En, Liu J P, Yang L. Analysis on the passive design optimization for residential buildings in Lhasa based on the case study of attached sunroom system for apartment buildings[J]. *Journal of Xi'an University of Architecture and Technology* (*Natural Science Edition*), 2016, **48** (2): 258 - 264. (in Chinese)

[8] Xiao Wei. Study of the direct-gain solar heating in remote southwest Tibet[D]. Beijing: School of Architecture, Tsinghua University, 2010. (in Chinese)

[9] Wang L, Feng Y, Cao Y C. Thermal performance optimization of solar heating building envelope in Tibet of China[J]. *Journal of Civil, Architectural & Environmental Engineering*, 2013, **35**(2): 86 - 91. (in Chinese)

[10] Li En. Study on unbalanced insulation of residential building in solar energy abundant area—Solar radiation analysis and indoor thermal environment test in Lhasa during heating period[J]. *Building Science*, 2011, **27**(8): 56 - 60. (in Chinese)

[11] Li En, Akashi Y, Sumiyoshi D. Passive design strategy on residential buildings for sustainable development of Lhasa [J]. *Journal of Environmental Engineering*, 2013, **78**(688): 471 - 480.

[12] Ministry of Housing and Urban-Rural Development of the People's Republic of China. JGJ 26—2010 Design standard for energy efficiency of residential buildings in severe cold and cold zones[S]. Beijing: China Architecture Industry Press, 2010. (in Chinese)

[13] Ozaki A, Watanabe T, Takase S. Simulation software of the hydrothermal environment of buildings based on detailed thermodynamic models [C]//*eSim* 2004 *of the Canadian Conference on Building Energy Simulation*. Vancouver, Canada, 2004: 45 - 54.

拉萨居住建筑空间组织对采暖能耗的影响分析

李　恩

(西安建筑科技大学建筑学院, 西安 710055)

摘要:为了提高拉萨居住建筑空间组织对气候与辐射的适应性,改善建筑空间组织的节能效果,以拉萨市居住建筑为基础建立了热工计算模型. 针对无保温的既有建筑与良好保温的新建建筑 2 种情况,分别模拟分析了建筑朝向、封闭阳台、进深方向上隔墙位置、层高、南向窗墙比对采暖能耗的影响规律. 模拟结果显示:朝向是建筑节能设计的重要影响要素,不利朝向会引起能耗大幅增加;南北向封闭阳台能减小采暖能耗;南北向隔墙位置北移能够降低采暖能耗,但节能效果有限;较小层高对节能有利;对于既有建筑,在一定工况下,南向窗墙面积设计存在平衡点,过大或者过小都不利于节能;对于良好保温的新建筑,扩大南向窗墙比能够降低能耗,但模型间的节能率会逐渐减小. 节能设计模型与基础模型的能耗对比显示,空间组织优化设计方法能有效降低采暖能耗.

关键词:居住建筑;空间组织; 采暖能耗; 节能设计

中图分类号:TU118