# Analysis on The Influence of Residential Buildings Layout Design on The Heating Energy Consumption in Lhasa

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## Abstract

Along with the living standard enhancement, the residential building's energy consumption of Lhasa had a large-scale expansion. Field surveys showed that the layout design can obviously affect indoor thermal environment. For a deeper understanding of the layout design's effect to heating energy consumption, the basic simulation models were established, analyzing items include south and north balcony space design and unit shape design. Results show that balcony reduces winter heating energy consumption significantly; small sunroom depth design is good for heating energy saving; north sealed balcony depth design has a balance point for the heating energy saving; unit layout's big depth design is better than big width design on heating energy saving. The layout design strategy should be used on local residential building design.

## Introduction

Lhasa is the capital city of the Tibet Autonomous Region. It is located at the north latitude 29 º39’, east longitude 91 º07’ and its average elevation is 3658 m. The yearly average temperature is 7.8℃; the average temperature in its hottest month July is 15.5℃ and the average temperature in its coldest month January is -1.6℃ (Liu Yang, 2010). In general, the Tibetan climate has the typical plateau characters: abundant solar radiation, large diurnal temperature range, low barometric pressure, and low oxygen content.

Lhasa made considerable progress along with Chinese economic development. Its urban construction started to march into the large-scale construction stage at the background of China urbanization (Bureau of Statistics of Lhasa, 2010). No doubt that in the near future, its energy consumption in buildings will largely increase as local people's living standard improves. On one hand, Lhasa has the shortage of fossil energy and fragile natural environment; on the other hand, Lhasa has abundant solar radiation and a long heating demand period, but a not-so-low air temperature. Therefore, the effective passive design methods could be proposed for alleviating the contradictions between better living standard demands and the environmental loads. Residential buildings' layout design is one of the important elements of passive design.

Previous studies about building heating energy saving were mainly done by Chinese researchers. Generally, these studies mainly took envelope's thermal design performance or optimization algorithm of envelope's thermal transfer as the main focus. (Wang Lei, 2008; SANG Guochen, 2009; XIAO Wei, 2010). No doubt that these studies made a great contribution to Lhasa's building energy saving. However, there are few studies focus on architectural design elements, even the field surveys proved the significant roles these elements play on indoor thermal environment. This paper takes residential buildings layout design as a research target to demonstrate the architectural design strategy on heating energy saving.

## Residential building survey in Lhasa

From 2006 to 2015, several field surveys had been carried out. The surveys included measurement and questionnaire, the survey analysis has been published in the other papers ( LI En, 2009; LI En, 2011; LI En, 2012). The details will not be repeated. The survey results are listed as follows. 1. Local residential buildings obviously have the characteristics of solar energy utilizing, such as, big south windows, thick walls and so on. 2. Different layout design can affect the indoor thermal environment, for example, south balcony can obviously increase the adjacent room's temperature. 3. The current winter indoor thermal environment does not satisfy the residents, especially the north rooms are too cold to be used.

## Analysis on layout design factors' influence to the heating energy consumption by simulation

As introduced before, because of the high solar exposure, not only the thermal performance design but also the unit layout design affects indoor thermal environment in Lhasa. This section studies layout design's principles on heating energy saving by simulation.

Three unit types were built for simulation from field surveys. Here the layout design factors include the south and north balcony's space design and the unit layout shape design, in which, the energy saving effect of balcony's space design is compared with south and north wall's insulation. These factors are main design factors on building layout.

It should be pointed out that the purposes of passive design for winter heating energy saving is to get enough solar radiation through envelope. However, if there is no


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shading design, in summer season, it is easy to be overheated. Awning is one facility to keep the extra solar radiation out in summer. On one hand, the outdoor air temperature in the hottest month in Lhasa is only around 16℃, 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 prevent over amount of solar radiation. So, at this stage, winter heating energy saving is the key content of the research in this paper. Shading will be studied in the future.

**Simulation introduction and model setting**

This paper uses THERB as simulation tool. THERB is a simulation program for calculating indoor temperature, thermal loads, etc., which is authorized by the Japanese government as one of the methods for evaluating the thermal quality of houses. (Ozaki A, 2004). It is necessary to make monitoring of the simulation software by field measurement before the study.

The layout shown in Figure 1 is one of the survey targets in 2009. It is a typical apartment in Lhasa. It was finished in 2001. Its walls use 240 mm solid concrete block with cement sand plasters of both in and out sides, its windows use 6 mm single glass, its floor slab is 100 mm cast-in-place reinforced concrete slab. The window-wall ratio of south direction is 0.59, north is 0.18. The size is shown in Figure 1. There is no heating and no internal heating source during the measurement period. THERB is used to build the same model. The time step is one hour. Ventilation of every room is 0.5 times/h. In this simulation, surface heat exchange coefficients are used instead of the sum of convective and irradiative coefficients of the surface of envelope. The Internal and external value are 8.7 $W/m^2K$ and 23 $W/m^2K$. The values are from Design standard for energy efficiency of residential buildings in severe cold and cold zones (China Academy of Building Research, 2010). During the calculation period, outdoor air temperature is from field measurement. Other calculating parameters 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 (Zhang Qingyuan, 2012). This is because there is no such measurement data in the field survey. And same with the survey, there are no internal heat gains in the simulation.

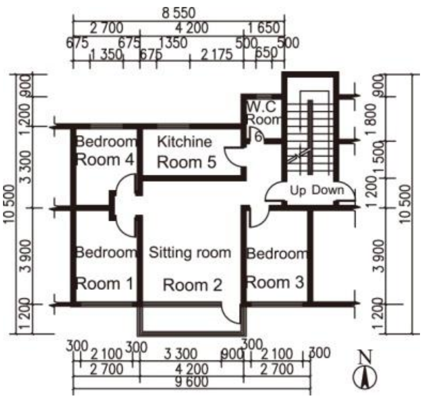



Figure 1: Schematic diagram of the surveyd house

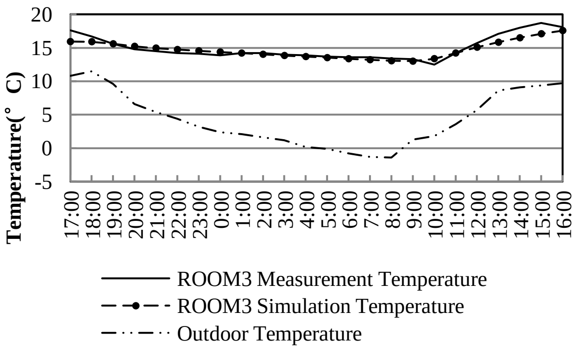



*Figure 2: Comparison of field measurement and simulation*

The comparison period is from 17:00, 26th November, 2009 to 16:00, 26th November, 2009, totally 24 hours.

Figure 2 shows the results of measurement and simulation of ROOM3's indoor air temperature. As the figure shows, the measured value and the simulation value have the same trend. During the comparison period, the average value of measured data is 14.98℃, the average value of simulation data is 14.71℃. The maximum hourly temperature difference of two comparison columns data is 1.67℃ (measurement data bigger). The least hourly temperature difference of two comparison columns data is 0℃. From 19:00 to 11:00, which is the period with less effect of solar radiation, the average hourly temperature difference of two comparison columns data is 0.3℃. In the rest period, this value is beyond 1℃. All the clues illustrate that the difference between two columns data is mainly caused by the calculation parameters of solar radiation. In this verification calculation, the direct normal irradiance from TMY data is smaller than the real value in the measurement. However, as mentioned before, the measured value and the simulation value have the same trend. And, during the period with less solar radiation, the hourly temperature difference of two columns data is very small. All in all, the calculation results of THERB is reliable.

This paper is the stage achievement of passive design study on Tibet. So, some simulation tools setting as calculation parameters and models setting are same as the previous studies (Li En, 2016). Figure 3 is the standard floor of the target building, the research unit is located at the centre. Figure 4 shows the layout drawings of the simulation units which are designed from common local apartments. All the simulation models in this section are heated. The heating rooms include room 1 to 7, balcony is not heated. The indoor temperature is set to 18℃. Same with the survey case, there is no internal heating gains in the simulation. All models have south and north window-wall ratio of 0.58 and 0.23, respectively. All structure's configurations and other calculation parameters are same with the verification case. Moreover, in order to make the calculation not so complicated, assume that there is no heat transfer between the study target and the sounding rooms, and, assuming the air conditioner has COP 3, so that, the

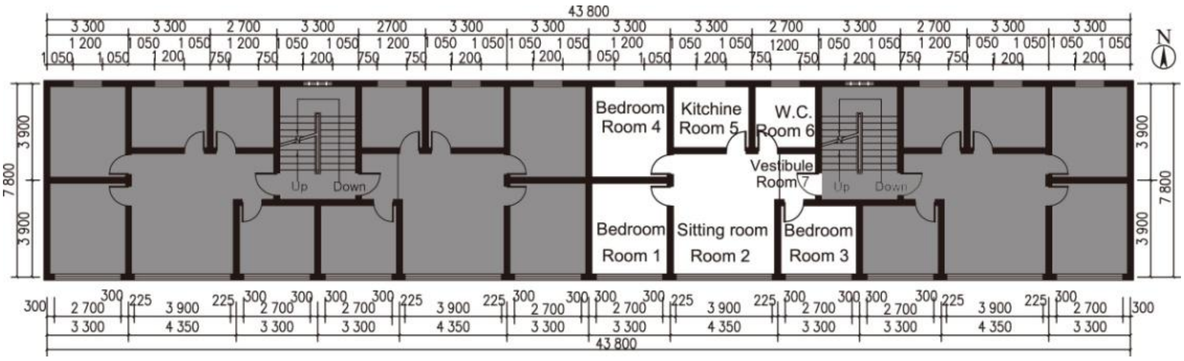
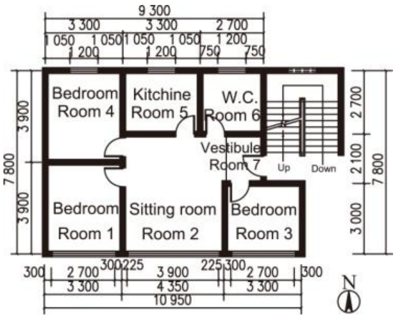


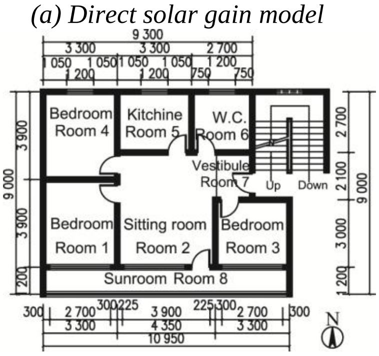

Figure 3: Standard floor plan of the basic model（Unit：mm）

thermal load can be simply expressed as electricity consumption. (Li En, 2016)

The heating period in Lhasa is from October 30th to March 8th, 130 days in total (Construction Bureau of Tibet Auronomous Region, 2007). However, in order not to make the calculation too complicated, this paper uses the integer months of November 1st to February 28th.




(a) Direct solar gain model




(b) Sunroom model

Figure 4: Layout drawings of basic models (Unit：mm)

**Thermal balance of simulation models**

Winter thermal load = Thermal load from envelope + Thermal load from air infiltration - Solar gains from windows - Solar gains from solid envelope - Internal heat gains (1)

Equation (1) is the thermal balance formula of the passive design houses in winter. No doubt that if the simulation models have the same construction of the envelope and the internal heat, the house heating load is mainly affected by the obtained solar gain through the envelope. The two models in Fig.4 use different passive design methods. This will result in different solar gain efficiency and the different thermal load. In addition, the un-heated sunroom of the sunroom model can be considered as an insulation layer for both south walls and windows, which should be good for heating energy saving. For a better understanding of the balcony space design to the heating energy saving, simulations are carried out as following sections.

**Balcony space design and comparison study with insulation layer**

Firstly, energy consumption's difference between two layouts need to be studied. The difference means sunroom's effect to heating energy consumption. Two models have totally same construction setting with the verification case.

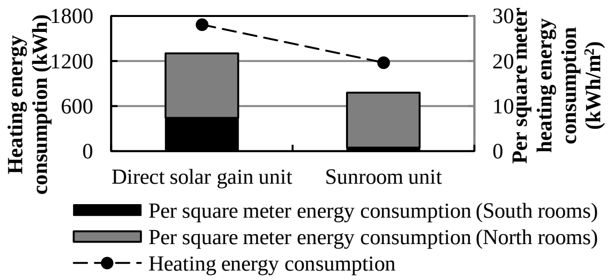



Figure 5: Simulation results of basic models

Figure 5 shows the calculation results. The sunroom models have only 69.9% heating energy consumption of direct solar gain model. And it is clear that the sunroom design mainly reduces the south rooms' heating load. 87.3% heating energy consumption is reduced in the south rooms by sunroom, and 0.6% is reduced in the north rooms. Sunroom design and direct solar gain design are both good methods for utilizing solar energy during the daytime. But at night, the thermal resistant of non-heating sunroom reduces the energy loss from walls and windows. This is the main reason of heating energy difference between two units.

The calculation proves the same results of the field surveys, which means that the north rooms need much more energy to keep suitable thermal environment. To deal with the north rooms thermal load, a no-heating north sealed balcony can be set as one design solution. For a better understanding, the third unit type, double-balcony unit model is set as Figure 6 shows.

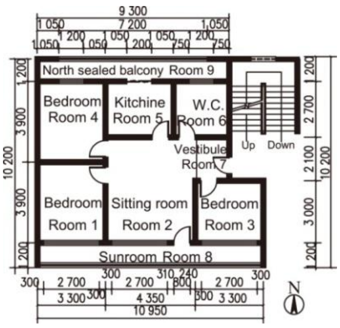



*Figure 6: Layout drawing of double-balcony model (Unit：mm)*

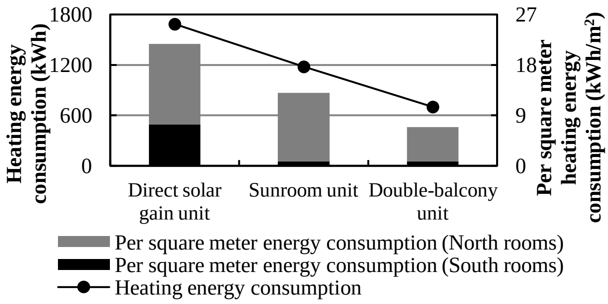
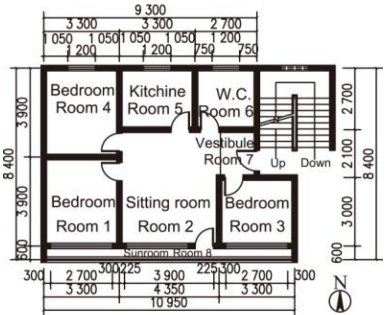


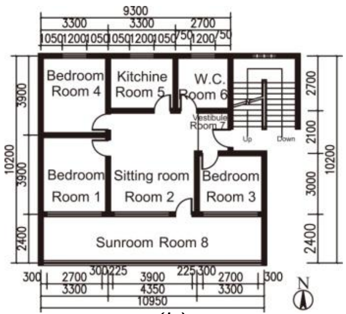

*Figure 7: Simulation results of three unit type models*

Figure 7 shows the calculation results. North balcony design reduces 41.7% of north rooms' heating energy consumption compared with direct solar gain mode. This means the north balcony design is a good way for energy saving. As the figure shows, the double-balcony models have the lowest heating energy consumption among all unit models. Simulation proves that the non-heating cushion spaces contribute greatly to heating energy saving of Lhasa. Balcony design is necessary.

Balcony depth is one of the most important design elements for the balcony space design. From the angle of architecture, sunroom has its space function. From the angle of passive design, sunroom is the most important construction for collecting and storing solar energy. Figure 8 shows two examples of sunroom models with different depth design. There are 6 sunroom depth models in total, 0 m, 0.6 m, 1.2 m, 1.8 m, 2.4 m and 3.0 m. Sunroom depth 0 m here means there is no sunroom, the layout uses the direct solar gain model.




*(a)*




*(b)*

*Figure 8: Schematic diagram of the sunroom depth models：a. depth 0.6 m；b. depth 2.4 m；(Unit: mm)*

As the simulation results shown in Figure 9, with the depth of sunroom increasing, the heating energy consumption gets bigger. As to the per unit area heating energy consumption, with the depth increasing, the north rooms have the heating load decreasing; the south rooms have the heating load increasing. And the total per square meter heating energy consumption for the layout has changed from 13.6 KWh/m$^2$ of depth 0.6 m to 12.6 KWh/m$^2$ of depth 3.0 m, which has a tiny downward trend. Considered the architectural function of the sunroom and the heating energy, small sunroom is recommended.

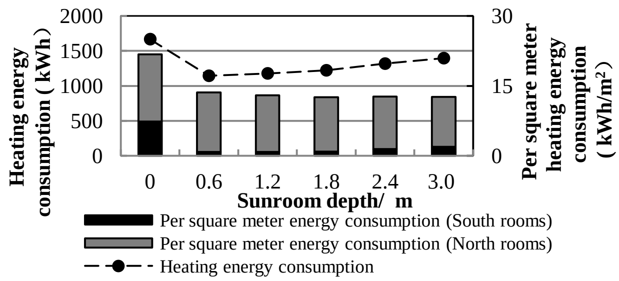



*Figure 9: Simulation results of sunroom depth models*

As mentioned, the sunroom can be considered as an insulation layer. In order to have a better understanding of the energy saving effect of the space design factor and the thermal performance factor, the thermal resistance models are built for comparison study. There are 6 south walls thermal performance models. 5 of them have EPS layers. The thickness of the EPS layer is 2cm, 4cm, 6cm, 8cm and 10cm, respectively. The heat conductivity coefficient of the EPS is 0.042 W/m • K. All the models only have insulation layer on south solid walls. And the layouts use direct solar gain model. The other settings are same with former simulation.

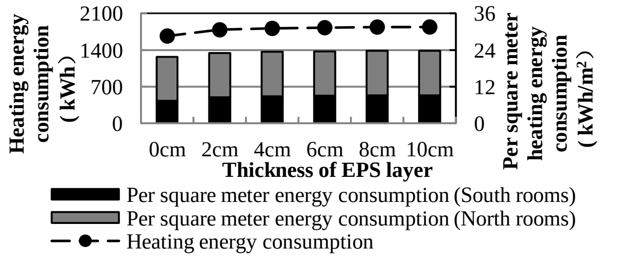



*Figure 10: Simulation results of south walls thermal resistance models*

Fig.10 shows the insulation layer models simulation results. The heating energy of this group keeps increasing along with the south insulation layer became thicker. The result proves that in Lhasa the south walls are important energy collecting construction, and the 6 mm single glass are main heat loss construction. This result proves that the non-balance insulation principle in Lhasa (LI En, 2011), which means, caused by the abundant solar radiation in this area, different direction walls absorb different amount of solar energy, so that the insulation design walls should be different depend on the directions. After all, the conclusion is clear that to design a sunroom is better than to refit the house with insulation layer on south walls.

Same as sunroom design, north balcony has its architectural function. From the angle of heating energy saving, north balcony can be considered as a thick insulation layer. For a better understanding of the north balcony's depth design rule, north balcony depth models ate studied. Figure 11 shows two examples of double-balcony cases. There are 6 models in total, 0 m, 0.6 m, 1.2 m, 1.8 m, 2.4 m and 3.0m, in which, depth 0 m means the layout uses the sunroom model.

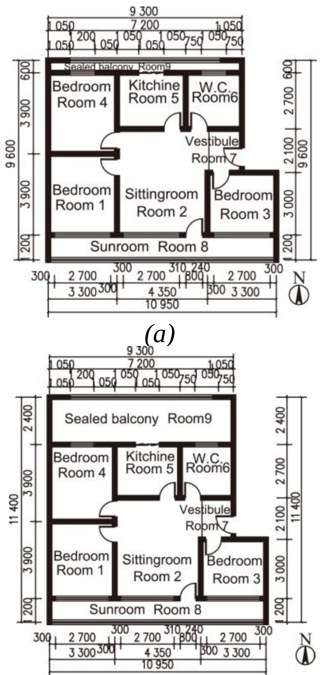



*Figure 11: Schematic diagram of north sealed balcony depth models: a. depth 0.6m; b. depth 2.4m; (Unit: mm)*

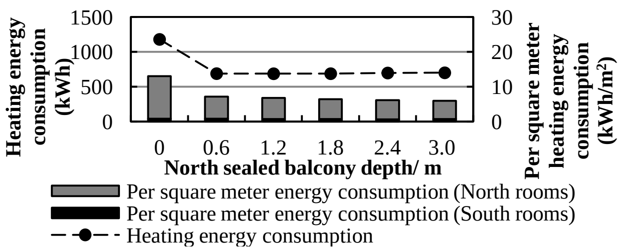



*Figure 12: Simulation results of north balcony models*

As the simulation results in Figure 12 shows, the north balcony depth 1.2m is the balance point. From depth 0.6 m to 1.2 m, the heating energy consumption is getting decreased. But from depth 1.2 m to 3.0 m, the heating energy consumption is getting increased. This is because the heat loss by natural ventilation of north balcony is changed before and after depth 1.2 m. However, the difference between cases is very small, the energy consumption difference between every model to the minimum value is less than 2.0%. So, the first architectural design step about the north balcony is to use it in layout design. Then, the depth should be mainly designed by its architectural function. Among the calculation cases, 1.2 m is the suitable depth.

Same as the sunroom models, the comparison study of thermal resistance models of north walls are built. There are 6 north wall thermal resistance models. The models only have insulation layer on north solid walls. The other settings are same with sunroom depth models.

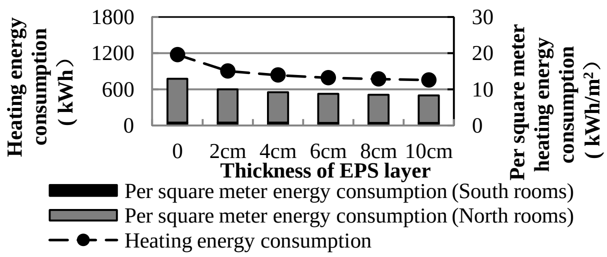
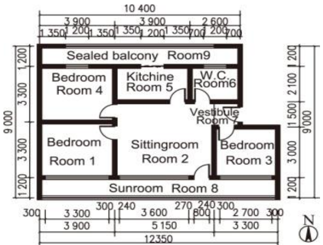



*Figure 13 Simulation results of north walls thermal resistance models*

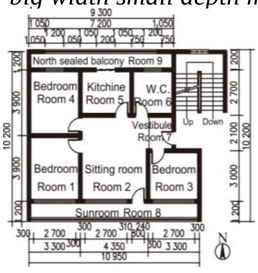
Fig.13 shows the insulation layer models simulation results. 2 cm insulation layer can reduce 23% heating energy compared with the no insulation cases. With the insulation layer getting thicker, the heating energy consumption and the per unit area heating energy consumption both get decreased. But the decreasing rate between models is getting smaller. Comparing the two different energy saving design methods, the heating energy consumption of north balcony depth 1.2m is 5.99KWh/m$^2$; the same value of 10 cm EPS layer model is 7.6KWh/m$^2$, which is the smallest value among the insulation models. The results mean balcony design has the higher weight on heating energy saving than the insulation design. Considering the economic condition of Lhasa, balcony design is good for heating energy saving work at the first stage.

### Unit shape design

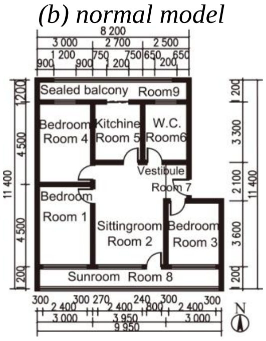
The unit shape means the combination of unit width and depth in the layout design. It is a key element in architectural form design. In fact, there are countless kinds of such combination based on a certain plan area. Usually the function of the room is the first element to be considered in the normal design work. However, as to the passive design, different combination of the width and the depth will result in the different heating energy demand. For a qualitative analysis, on one hand, the unit with large width and small dept can get more solar exposure area (windows and walls ) than the large depth small width unit; on the other hand, the large width small depth unit has more heat loss area from the north/south external walls and windows. It is difficult to judge what kind of combination is better for energy saving by qualitative analysis. So, three different building shape designs for every unit type are studied. They are large width and small depth combination, normal combination, large depth and small width combination. All the unit shape models have the same area in every unit type group, which are 77.5m$^2$, 90.6 m$^2$ and 101.8 m$^2$, respectively. All the models here have the same simulation setting and model setting as the studies before. Figure 14 takes double-balcony unit as an example to show three unit shapes design.




（a）big width small depth model




*(b) normal model*




（c） big depth small width model

*Figure 14: Different unit shape design models for double-balcony unit with same layout area*

The simulation results are shown in Figure 15. It is clear that for all three units, the large depth shape design has the minimum heating energy consumption, the large width shape design has the maximum one. The heating energy difference among models of three unit types are different. The difference of big width model and big depth model in direct solar gain unit is 20.9%, this value of sunroom unit is 11.4%, double-balcony unit is 6.7%. The result shows that the direct solar gain unit is affected by layout shape more than the other two unit types. So direct solar gain unit should use big depth design. The other two unit types, architectural space's function takes the first place, then, big depth design should be used.

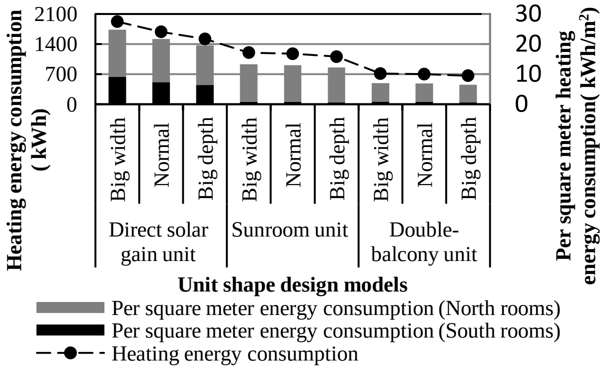



*Figure 15: Heating consumption in different unit shape models for sunroom unit*

## Result

From the former analysis, it is clear that, caused by the strong solar radiation, the residential buildings' layout design in Lhasa should have some specific design rules for local heating energy saving. Results are listed as following: ① Double-balcony unit has only 42% energy consumption of direct solar gain unit. Non-heating balconies are very important heating energy saving design methods in Lhasa. ② South sunroom reduces the heating energy consumption by both solar energy collecting and thermal resistance for south rooms. The heating energy consumption is getting bigger as the depth of sunroom increases. Compared with sunroom design, south solid walls' insulation layer design is not good for energy saving. ③North balcony reduces the heating energy consumption mainly by its thermal resistance effect. And its depth design has a balance point for energy saving, depth 1.2 m is the recommended depth. North solid walls' insulation layer design also contributes to the heating energy saving, however, compared with north balcony design, north solid walls' insulation layer needs to be very thick to get the equal energy saving effect. ④Among the three unit layouts, direct solar gain unit has bigger relevance with the building shape design than the other two units. It should use big depth unit shape. Based on the results, the layout design strategies can be established.

## Conclusion

The field surveys and simulation make it clear that the solar radiation is a very sensitive element for the heating energy saving. Accordingly, strong solar radiation makes a unique design rule for heating energy saving in Lhasa.

To reduce the energy loss caused by the air temperature difference between indoor and outdoor, south and north balcony is a very effective solution. As for the depth of south balcony, a relatively smaller depth is good for energy saving, among the simulation cases in the paper, 1.2 m is a good depth design. As for the depth of north balcony, there is a balance point for energy saving, the depth is 1.2 m, however, the difference between cases is very small. From the simulation results, the insulation layers on south walls will be bad for heating energy saving. The insulation layers on north walls is a good method for heating energy saving. But considered its effect and cost, the north balcony design is a better choice. As for the unit shape, direct solar gain unit is recommended to use big depth design; For the other two unit types, architectural function takes priority, then, big depth design should be used. Based on the simulation results, the layout design's energy saving strategy can be drawn out for the local residential building design.

Because of the topic and paper length limitation, some thermal performance parameters of the building are not studied. In fact, thermal performance like thermal inertia effect and other parameters affect indoor thermal environment in Lhasa effectively. In the next step, more elements of passive design will be analyzed.

## Acknowledgement

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