CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 2

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 2*. Department of Civil Engineering, Aalborg University.

Optimal Design of Passive Solar Buildings for Dormitories in China

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Abstract

Passive solar buildings can adjust the influence of the external environment and create a relatively stable indoor environment. To further improve indoor air temperature and reduce heating energy, the optimized design based on a passive solar dormitory in Tibetan Plateau of China has been conducted by means of building simulations. For a broader assessment, effects of building orientation, location of temperature buffer, window to wall ratio, and heat collecting design were investigated. Results show that the mean indoor air temperature of the building facing the south in winter is 1～3℃ higher than that of the building facing other directions. The embedded temperature buffer on the roof, north wall and west/east wall of the building can obviously improve the indoor temperature, with a maximum increase of 7℃ for the minimum indoor temperature compared with those cases without any temperature buffer. When the window to wall ratio of the south wall reaches 0.7, it is efficient to get more solar energy and increase the indoor temperature at night. In terms of investment and thermal comfort, the direct-gain passive solar house with heat collection window can result in the same indoor temperature as the heat storage wall or floor design does. But the former one is more economical and easier to maintain.

Keywords - Optimal design; Passive solar buildings; Building simulation

1. Introduction

Heating energy use amounts for 40% of the total building energy consumption in China. To save heating energy, the renewable energy source has attracted our attentions. The passive solar building is a type of low-energy buildings exploiting solar energy to create a relatively comfortable environment in buildings [1]. A large number of studies have shown that the greatest opportunities for the passive solar building designs occur at the conceptual design level, by determining the values of parameters that have critical influences on the building performance, such as building orientation, building type and glazing, etc [2-5]. The optimal design of the passive solar building can improve indoor air temperature and reduce the use of fossil energy sources. It was reported by measurements that passive design buildings can save more than 50% of total primary energy consumption [6].

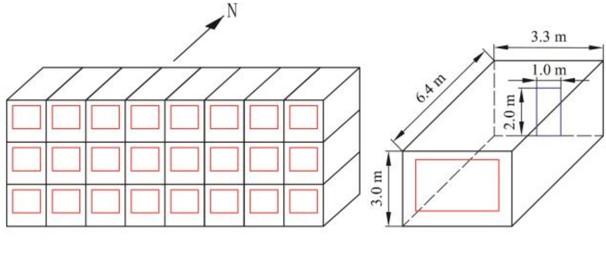
A good passive solar building design for the purpose of minimizing the energy demand involves various aspects of building design, such as the orientation of facades and windows, the wall thickness, the insulation level, the window details, the sunspace for the passive solar heating, etc [7]. For instance, numerical simulations have been carried out by Xinzhi Gong et al [8] and it was found that with the optimization the passive solar building could significantly reduce the annual thermal load of the building. Studies conducted by M.C. Ruiz [9] showed that through optimizing the building direction, the window-wall ratio and the insulation in the facade, the overall thermal consumption was reduced by almost 13%. However, very few studies have focused on building locations with a high altitude and heat collection/storage designs for the passive building.

The objective of this work is to achieve the optimized design for a passive solar dormitory with a high altitude and a strong solar radiation in Ruoergai, Tibetan Plateau of China. Based on this optimized design, the basic heating requirements without the use of electrical or mechanical equipment can be met.

2. Descriptions of building simulations

2.1. Building model

Fig. 1(a) shows a dormitory building with three stories, and Fig. 1(b) presents a single room in this building with the dimension of 3.3 m×6.4 m×3.0 m. Each room has one window facing south and one door with the size of 2.0 m×1.0 m. The detailed constructions of the building are listed in Table. 1, and the thermal properties of various materials are given in Table. 2.



(a) Skeleton view of the dormitory building (b) A single room

Fig. 1 Dormitory building model

Table. 1 Constructions of the building

Construction	Material
External wall	80 mm polyurethane + 240 mm brick wall
Internal wall	240 mm brick wall
Roof	80 mm polyurethane + 120 mm concrete
Ceiling	180 mm concrete
Floor	60 mm concrete + 80 mm polyurethane + 120 mm concrete
Window	3 mm double glass
Door	60 mm wood

Table. 2 Thermal properties of materials

Material	Thermal conductivity (W/m·K)	Heat capacity (J/kg·K)	Density (kg/m^3)
Brick wall	0.89	1000	1800
Polyurethane	0.033	1380	40
Concrete	0.93	1050	2300
Wood	0.15	1630	608
Window	U-value: 1.4W/m^2·K		

2.2. Assumptions

Building simulations for the dormitory were carried out using EnergyPlus software. It is based on the method of air heat balance and can obtain relatively accurate results [10]. In this study, the time step for the calculation was 10 minutes. The main assumptions considered for the simulation process are as follows:

(a) All thermal properties were kept constant.
(b) The air change rate was 1.0 h^{-1} for every single room.
(c) There was no heating equipment in the room.
(d) The heat releases from light and people were not considered.

2.3. Climatic conditions

The dormitory was built in Ruoergai, a county in the northeast of Tibetan Plateau of China. The local average altitude is 3500 m. Heating season in each year is from November 1st to April 1st of the next year. During the heating season, the outdoor mean air temperature is -4.8 ℃, and the corresponding maximum and minimum temperatures are 15.1 ℃ and -21 ℃, respectively. The mean intensity of solar radiation during the daytime is 387.4W/m^2 and the corresponding peak intensity can reach up to 1064 W/m^2 at noon. The variations of these weather conditions are presented in Fig. 2.

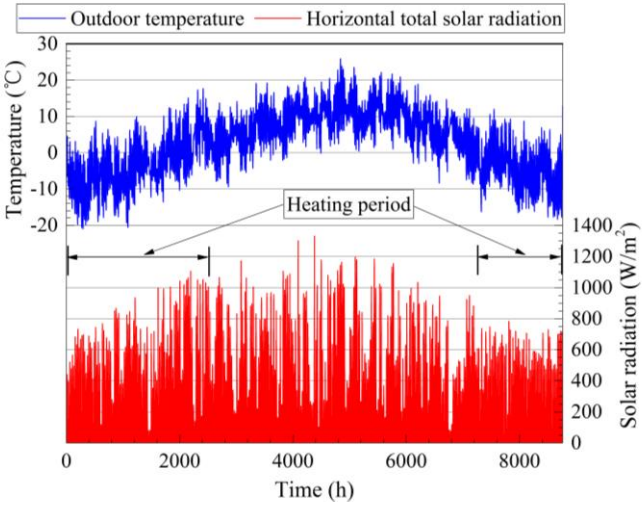


Fig. 2 Variations of weather conditions

2.4. Optimization parameters

Considering the architectural features of the dormitory, four critical parameters could have significant influences on the indoor thermal environment: building orientation, location of temperature buffer, window to wall ratio, and heat collecting design. In this paper, all these four critical parameters were optimized. Each time one parameter was changed while the others were kept constant. These parameters were analyzed in an order mentioned above, and the optimization of each parameter was based on the results of the last parameter optimization.

3. Results and Discussions

3.1. Effect of building orientation

Building orientation of the dormitory affects its indoor thermal environment, especially for the passive solar house. Fig. 3 presents the range of the mean indoor air temperature in the dormitory with the building orientation. In Fig. 3, the value on x-axis represents the angle from the south to the east. Changing the building orientation from 0 to 30 degree results in a drop of 2.1 ℃ for the mean indoor air temperature during the heating period. Thus, the building facing the south obtains the maximum mean indoor air temperature. In the dormitory design process, it is necessary to decrease the angle of the southeast or southwest in order to acquire a higher indoor air temperature. Due to the limitation of the practical construction site, the minimum angle from the south to the east is 15 degrees shown in Fig. 3. Therefore, southeast 15 degrees is selected as the final building orientation.

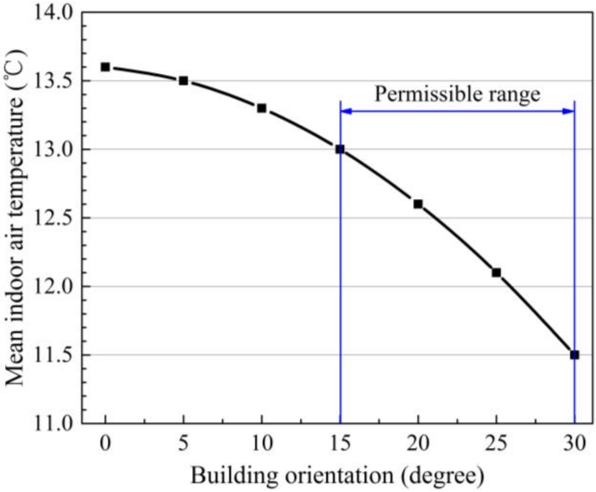


Fig. 3 Mean indoor air temperature for various building orientations

3.2. Effect of location of temperature buffer

The temperature buffer behaves as a “coat” wrapped around the building that can reduce the impact of the outdoor environment on the indoor air temperature. The diverse locations of the temperature buffer in the room change the indoor temperature at different levels. To investigate the effect of the temperature buffer location, we chose five common locations of the temperature buffer, which are presented in Fig. 4.

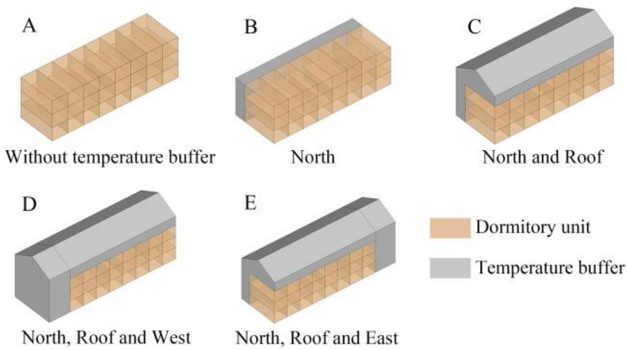


Fig. 4 Locations of temperature buffer for the dormitory

Fig. 5 presents the mean and extreme minimum values of indoor air temperature for the dormitory during the heating period under five different designs of the temperature buffer. The embedded temperature buffers on the roof, north wall and west (or east) wall of the dormitory obviously improve the indoor temperature and the extreme minimum indoor air temperature obtains a maximum increase of 6.6℃ than those without temperature buffer. Hence, from the perspective of improving the indoor air temperature, the best solution is to integrate temperature buffers on the roof, north wall and east wall.

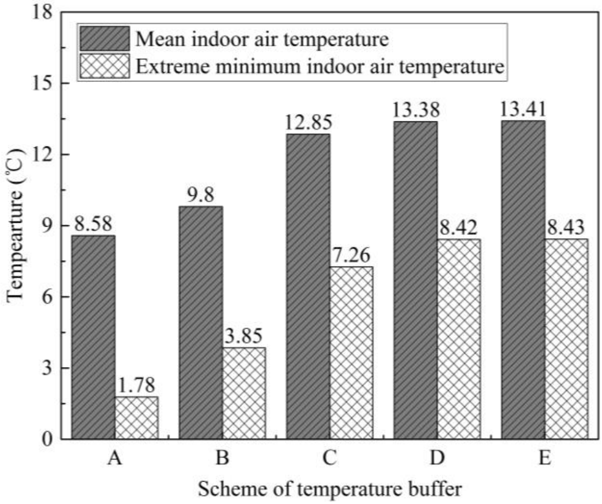


Fig. 5 Indoor air temperature for diverse schemes of temperature buffer

3.3. Effect of window to wall ratio

For the passive solar house, increasing the window to wall ratio of the south facade improves the indoor air temperature significantly. During the heating period, increasing the window to wall ratio from 0.3 to 0.9 results in a rise of 9.2 ℃ for the mean indoor air temperature and an increase of 7.6 ℃ for the extreme minimum indoor air temperature (Fig. 6). Based on the existing conditions and the limitation of the building structure, the maximum value of window to wall ratio can only reach 0.7. As a result, the optimized design for the window to wall ratio of the south facade is 0.7.

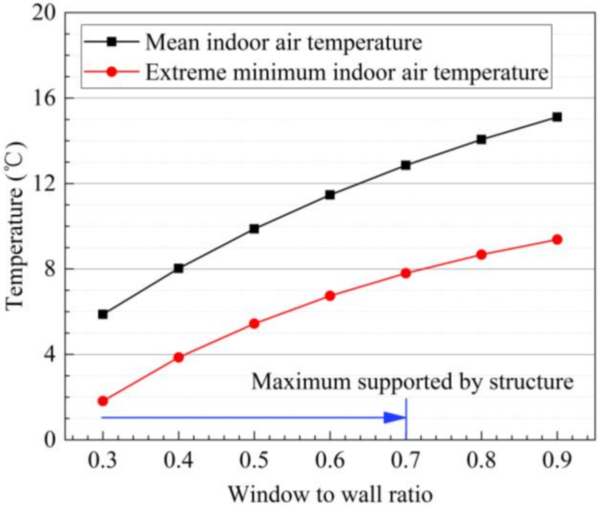


Fig. 6 Mean and extreme minimum indoor air temperatures for various window to wall ratios

Fig. 7 provides the variations of indoor air temperature from January 1st to January 5th under five different window to wall ratios. It can be seen that when the window to wall ratio increases to 0.7, the indoor air temperature has a rise of 6 ℃ compared with the case of the window to ratio 0.3.

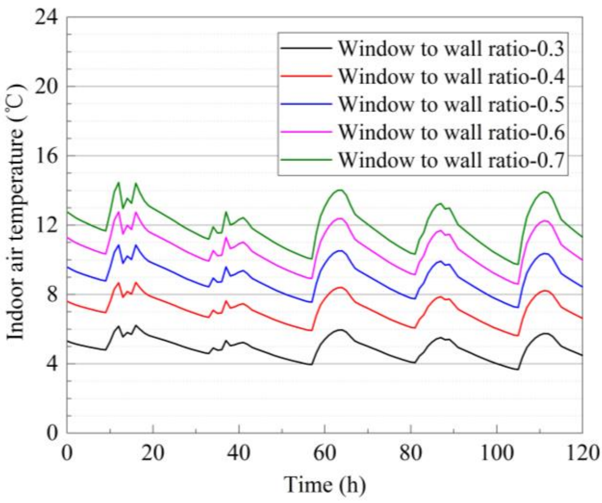


Fig. 7 Effect of window to wall ratio on indoor air temperature

3.4. Effect of designs for heat collection and storage

Based on the practical projects, three designs for solar collection and storage are proposed in Fig. 8. Fig. 8(a) shows a heat storage wall which collects solar energy by the Trombe wall and delivers the hot air to the cavity in the middle of the partition wall between two rooms. The partition wall is used for thermal storage in the daytime and for heat release at night. Fig. 8(b) shows a heat storage floor which collects solar energy also by the Trombe wall and delivers the hot air to the cavity in the middle of the floor slab between two rooms. The floor slab is used for thermal storage in the daytime and for heat release at night. Fig. 8(c) shows a direct-gain passive solar house with a heat collection unit made of the outer single-glazed window and the inner double-glazed window. The cavity between these two windows is applied to collect the solar energy and provide the hot air for the indoor space together with the opened double-glazed window in the daytime. At night it reduces the heat loss to the outside with the double-glazed window closed.

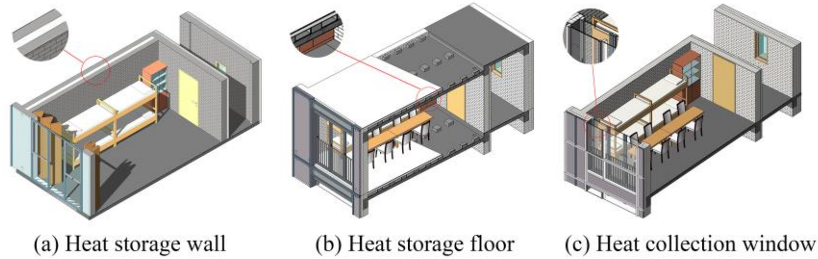


Fig. 8 Designs for heat collection and storage

Fig. 9 displays the variations of indoor air temperature throughout the year under three different designs of heat collection and storage. During the heating period, the mean indoor air temperatures for the heat storage wall, the heat storage floor and the heat collection window are 12.8 ℃, 13.2 ℃ and 12.4 ℃, respectively. In terms of thermal comfort, the direct-gain passive solar house with heat collection can result in the similar indoor temperature as the heat storage wall or floor design does. Since the former one is more economical and easier to maintain, it is selected as the final design.

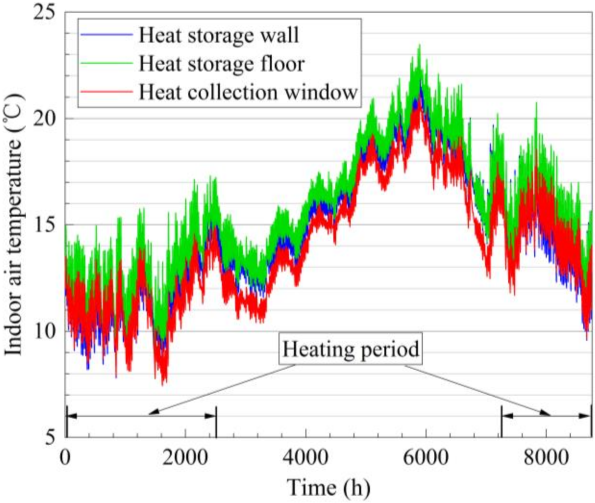


Fig. 9 Indoor air temperature for diverse designs of heat collection and storage

4. Conclusions

To improve the indoor thermal comfort of a passive solar dormitory in Ruoergai, building simulations were carried out to optimize the building design. Results show that the reasonable building orientation can improve the indoor temperature and constructing temperature buffers significantly increases the mean indoor air temperature. It also can be concluded that increasing the window to wall ratio of the south wall would improve the indoor temperature in the daytime and at night. Moreover, the direct-gain passive solar house with heat collection window is an effective way to use solar energy and achieve higher energy saving.

Acknowledgments

This work was supported by the National Science & Technology Pillar Program during the twelfth Five-year Plan Period of China, Project No. 2013BAJ03B04, China Southwest Architectural Design & Research Institute Ltd. We gratefully thank Gang Hong and his wife for the financial support in the process of project construction.

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