PASSIVE SOLAR ENERGY BUILDING IN MOUNTAIN RESIDENCE
Strategies and Design

by

Jing MA[a*] and Yin LIU[b]

[a] Henan University of Technology, Zhengzhou, Henan, China
[b] Zhongyuan University of Technology, Zhengzhou, Henan, China

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Mountain dwellings rely strongly on topographical conditions and are sometimes limited by terrain. A stratega is proposed for a passive solar building design in a Taihang mountainous area to utilize flexibly good sunshine and natural ventilation for the building and to organize a shady courtyard next to the mountain to form a cold source of the outdoor environment. This design has made a positive attempt for the application of passive solar building strategies to mountain dwellings.

Key words: *passive, solar building, mountain-dwelling*

Introduction

As the energy crisis and environmental problems continue to be serious, green buildings have been catched much attention, and passive solar building strategies have become hotspots in the field of construction [1-5]. The architectural design and structural design should use the natural conditions to meet the comfort of the building and reduce the dependence on air conditioning. In May 2018, a passive solar house designed by the authors was completed in Taihang Mountain. Through architectural design, structural design, plant configuration, and other measures, solar energy, wind and courtyards were carefully organized to heat and cool the building to improve indoor microclimate and greatly reduce the use of mechanical air conditioning. A valuable attempt has been made for the application of passive solar building strategies in mountain dwellings.

The residence is located in a village in the Taihang Mountains in Henan Province. The owner's homestead is located on a hillside halfway up a hillside beside the village mouth road. It is 29 m long from North to South and 27 m wide from East to West. The village path is under the cliff on the East side and the fields and villages in the valley can be overlooked. The base area is 810 m^2, the building area is 518 m^2, and there are 2 floors in part. The concepts of the passive solar design of the building will be introduced in the forthcoming sections.

Passive solar building strategies

As shown in figs. 1 and 2, under unfavorable layout conditions, the courtyards are organized flexibly so that the main rooms face South to get more solar energy. A cliff is on the East side of the base. The village path is under the cliff on the East side and the fields and

* Corresponding author, e-mail: mjja@163.com

villages in the valley can be overlooked. The backs of local traditional houses are mostly close to the courtyard walls, but a wide courtyard is attached to the front of the hall. In addition, vehicles and other person things require the base to leave some open space on the East side. The owner adheres to tradition and considers *front yard style*, insisting on building concession to the East base boundary of 13 m. After the retreat, the building land is narrow in the North and the South, and it is only 13 m wide from East to West. As a last resort, the building has to adopt an East-West layout. Under such unfavorable layout conditions, the designer flexibly organizes the architectural layout, designing courtyards and roof gardens, so that important spaces such as the parlor, living room, and master bedroom enjoy a South-facing layout, obtaining good lighting conditions and more solar energy.

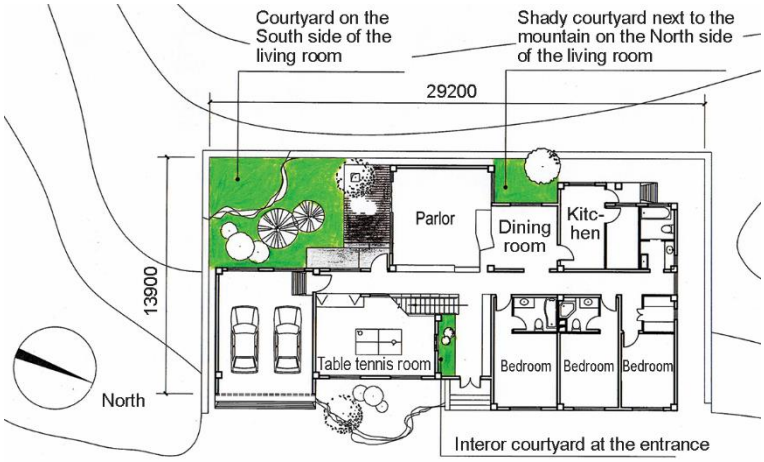

Figure 1. Ground floor plan

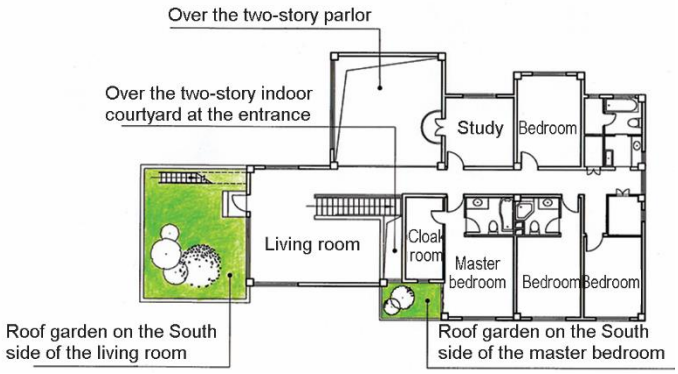

Figure 2. Second floor plan

Shown in fig. 3, the parlor is two floors high, with double-insulated floor-to-ceiling windows on the South. The top high window can be opened and closed, and a mechanical exhaust device is installed. Double-floor floor-to-ceiling windows increase the direct heat in the living room in winter to get more solar energy. In addition, the two-story parlor, floor-to-ceiling glass and high windows that can be opened and closed on the top also create conditions for the natural ventilation of the building driven by the greenhouse effect and the chimney effect.

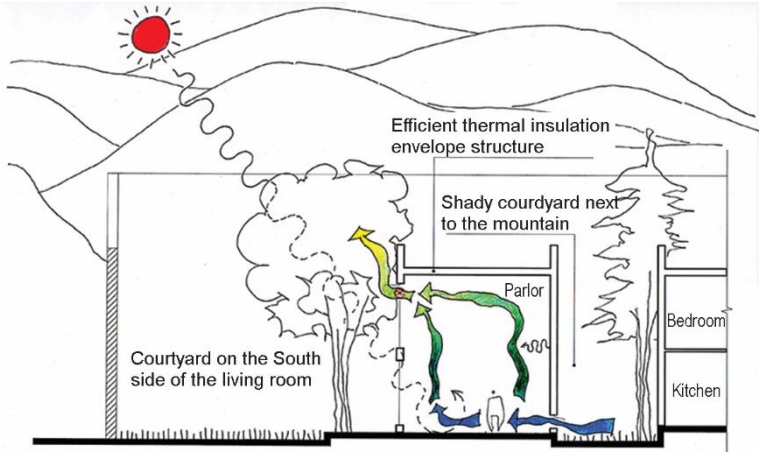

Figure 3. Operating mode in summer daytime of the parlor

As is described in fig. 4, the upper part of the main entrance porch is provided with a glass roof daylight room protruding from the roof and the top surface is inclined. The North side façade of the sunlight room is provided with high windows that can be opened and closed, and mechanical ventilation devices are installed at the high windows. The sloping glass top surface reduces the angle of incidence of the Sun and captures more solar energy [6]. The high windows that can be opened and closed, the high-rise porch and the glass roof together constitute the greenhouse effect and the chimney effect. While improving sunlight and obtaining more solar energy in winter, it is also beneficial to natural ventilation in summer [7-9].

A small greenhouse inner courtyard is set at the entrance to improve the building's microclimate [10]. As shown in figs. 1 and 4, the top of the small courtyard is equipped with a glass-topped daylight room, with natural soil floor, planted with evergreen shrubs and small trees. Elegant climbing vines climb up the gravel wall on the South side of the courtyard, directly reaching the low wall of the open living room on the second floor. The warm indoor courtyard introduces nature into the building, effectively purifies the air, increases the oxygen content, and improves the indoor microclimate.

A shady courtyard is organized in the North of the living room and the West of the dining room. Openable and closable ventilation holes are provided at the bottom of the exterior wall of the building adjacent to the courtyard. Metal nets to prevent rats and snakes, *etc.* are installed outside the holes, as shown in figs. 1-3. During the day, because of the surrounding walls and mountains, the courtyard is shaded all year round, and only receives short-term solar radiation around noon. Because the mountains have huge thermal inertia, the air in the courtyard and the surrounding interface are cold, and the hot air above the courtyard cannot enter the courtyard, only generating eddies over the courtyard. At night, the temperature in the valley decreases, and the air in the courtyard is gradually replaced by the cold air that sinks from the night sky. Cold air accumulates in the courtyard and gradually penetrates and cools the surrounding walls and cliffs. Therefore, this shady courtyard forms an air-cooling source outside the house.

The walls, doors, and windows adopt an efficient thermal insulation envelope structure.

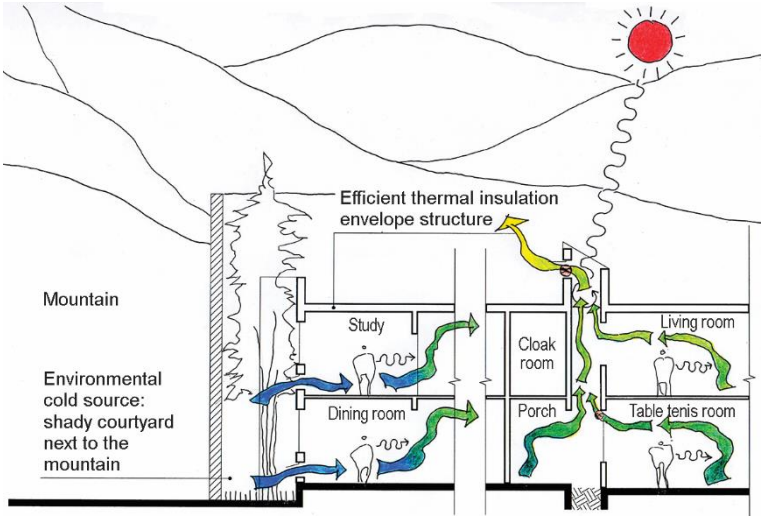

Figure 4. Operating mode in summer daytime of the dining room and the porch

Deciduous trees are planted outside the parlor. The trees are lush in summer, blocking the Sun. The leaves fall in winter, the branches are sparse, and the house has good sunlight [11].

Using the huge thermal inertia of the mountain, a cave-type storage space is dig and built in the mountain.

Working mode of passive solar ventilation system in summer

In summer, the house organized natural ventilation through the aforementioned passive solar building strategy to reduce dependence on mechanical air conditioning, as shown in figs. 3 and 4. The working mode of the building's passive ventilation system is different during the day and at night.

Working mode in summer day

During the daytime in summer, solar radiation in the mountains is strong. Building exterior walls, doors and windows are made of high performance thermal insulation materials. Closing doors and windows can effectively block heat conduction and solar radiation to the wall. Tall deciduous trees are planted outside the floor-to-ceiling windows on the South side of the parlor. The trees are dense in summer, which can block a lot of solar radiation and reduce the greenhouse effect in summer.

In addition, the courtyard North of the parlor and West of the dining room is shady, next to the mountain, and it is a cold source outside the building [11]. The two-story vertical space above the roof at the entrance and the two-story parlor can form a chimney effect, which promotes natural ventilation. The fresh cold air that is continuously cooled by the mountain in the shady courtyard is continuously introduced, and the building is ventilated and cooled.

Specifically, the external doors and windows of the house are closed, the ventilation holes at the bottom of the outer wall of the room adjoining courtyard are opened. Cold air

penetrates the parlor and dining room from the courtyard. The lower part of the floor-to-ceiling window is closed, and the top high window is opened in the parlor. The high window on the North side of the daylight room at the top of the porch opens. The cold air infiltrating into the building is heated by solar radiation and radiation from the human body, furniture, walls, *etc*., and slowly rises to form a chimney effect, which is discharged from the high windows at the top of the parlor and the porch. The air at the bottom of the building is under negative pressure, and cold air will flow into the room continuously. The glass bevel on the top of the porch absorbs solar radiation, which also enhances the chimney effect and drives air-flow.

Summer night working mode

In summer nights, it is very cool in the mountains. Opening convection is the most convenient cooling mode at night. However, the area is dominated by the South-East wind in summer, and the buildings are mainly East-West. After the evening, when there is no wind or the wind direction does not match the direction of the building, the outdoor cool air often cannot quickly penetrate into the building, and the indoor cooling time is delayed. At this time, the chimney effect can be fully utilized to accelerate the replacement of indoor and outdoor air [12, 13].

Specifically, while keeping the high windows in the living room and the top of the hallway open, open the doors and windows in the building as much as possible. Due to the chimney effect, the indoor air is heated by radiation from the human body, walls, and furniture, and then discharged from the high windows of the parlor and the high windows of the sunlight room over the porch. Due to the heat pressure, the cool outdoor air will be drawn into the room. If necessary, open the mechanical exhaust device at the high window to strengthen the chimney effect and accelerate the air-flow.

At night the outdoor cold air enters the room to cool down the building. During the day the windows and doors are closed, and the highly efficient thermal insulation envelope structure can still keep the room cool to a large extent.

Passive solar heating mode in winter

In winter, the house uses a direct heating solar house and other strategies to passively heat the building and minimize the use of mechanical air conditioning. The specific working mode is as follows: First of all, the building is flexibly laid out under the adverse influence of retreat, and the courtyard or roof garden is organized on the South side of the parlor, living room and master bedroom, so that these important spaces are laid out Southward. The efficient thermal insulation envelope structure greatly reduces the heat loss of the building. Secondly, the courtyard on the South side of the living room is 11 m deep from the North to the South, the height of the cliff on the South side of the courtyard is low. The parlor is two stories high, with large glass windows on the South side. During the daytime in winter, the parlor enjoys sufficient sunlight, forming a direct heated solar room. Large glass windows are also set on the South-facing walls of the living room and the bedroom on the second floor to allow more solar radiation during the day. All South-facing rooms of the house get directly heated through large glass windows during the daytime in winter. The sunlight entering the room directly heats the air, and the heated air circulates and penetrates inside the building, heating the building.

In addition, the ground, floors, walls, and furniture absorb and store a certain amount of solar radiation heat during the day. At night in winter, when the indoor air temperature is

lower than its surface temperature, these heat storage objects become low-temperature radiators, which provide radiant heating to the room.

Conclusion

The mountain house has a flexible layout under the unfavorable land boundaries. Through architectural design, structural design, greening, and other means, it makes full use of solar energy, wind, courtyards, and mountains with great thermal inertia to form direct heat solar rooms, shade cold source next to the mountain, greenhouse effect, chimney effect, *etc.* It passively heats and cools the building and reduces the use of mechanical air conditioning. The passive solar building strategy adopted in it has important reference value for mountain houses and public buildings.

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