OPTIMAL DESIGN OF PASSIVE SOLAR BUILDING

by

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A passive solar building cannot only save cost and reduce energy consumption, but also benefit the harmonious development of society. This paper introduces an optimal design strategy by taking into account its external environment, the building layout, the shape coefficient, the building envelope, and the building structure. An example is given to reveal various concepts and their applications.

Key words: *passive solar building, optimal design strategy, Fangzhu*

Introduction

Due to rapid urbanization, half of the world's population now lives in cities. This has led to the global energy crisis. Global energy consumption is predicted to have increased by 53% in the next 10 years [1]. Energy demands in developing countries will be especially severe due to the rapid growth of construction industry [2]. At present, renewable energy only accounts for 9% of the global energy consumption [3]. Of these sources, the solar energy is the most abundant source of the renewable energy available today. Many researchers have been focusing on the use of solar energy in the buildings to improve their thermal performance and to reduce the energy consumption from fossil fuels. According to the Solar House Action Plan [4, 5], many passive solar buildings have been designed and constructed in various places. After a long-term theoretical research and much practical experience, much progress has been made in the solar energy building, and a *passively based, actively supplemented* model was gradually formed.

Design principle of passive solar building

The design of the solar energy building can generally be divided into active and passive types. The active building mainly harvests the solar energy mechanically, and the collected solar energy is then converted into cooling or heating capacity for use in the building through specific equipment. The provided energy of the passive solar building does not use any mechanical equipment. It collects and stores the solar energy through a reasonable layout of surrounding environment, building site selection, ingenious treatment of building space, proper selection of building envelope and building structure, *etc.*, and carries out natural heat conversion by conduction, convection and radiation, so as to achieve comfortable thermal en-

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vironment. Compared with the active solar building, the passive solar building is energy-saving, environment-friendly and low investment cost. In the early stage, the architecture needs to be designed professionally. However, in the later stage, the income is considerable, which greatly reduces the use of mechanical equipment and maintenance management costs.

The optimal design strategy of the passive solar building

External environment

The solar radiation is an important factor that cannot be ignored in the building environment. The passive solar building is closely related to its external environment. It should be selected in the area with abundant solar resources after fully considered the local natural environment and climate condition.

- Different landforms have different effects on the passive solar building. In order to obtain more solar radiation, the building should be placed on a sunny flat or a sloping area instead of a concave area. In a hot area, the building should be close to a lake or a river, where the summer breeze skims over the water into the building makes people feel refreshed and comfortable.
- Considering local climatic conditions is the basic method of the ecological architecture. Only active adapting to the local climate characteristics, the building will be humanized, better integrated into nature, and better energy conservation. In the optimal design of the solar building, the climate conditions such as sunshine, solar altitude angle, humidity, degree of hotness or coldness and dominant wind direction should be considered. Sometimes, the impact of microclimate should also be considered. For example, planting deciduous trees in the south of the building can reduce the solar radiation in summer, and it does not hinder the building from receiving the solar radiation in winter duo to the falling leaves.
- The layout of surrounding buildings is an essential factor that can't be ignored during the optimal design of the passive solar building. In order to make efficient use of the solar energy, there should be an appropriate space between buildings. An excessive space will cause a waste of land resources. Narrow space between buildings will lead to blocking out each other. In general, the building interval is generally 1.1 times higher than the height of the adjacent building in the south direction. At the same time, the layout design, retreat and enclosure can be considered to obtain more solar radiation.

Building layout

The plane and space layout of buildings can also efficiently utilize solar energy throught ingenious treatment. The plane should be simple, and the depth should be short, which is conducive to the natural lighting and ventilation inside the building. In order to make rational use of the solar energy, the heating rooms that are used frequently should be arranged in the south, and the non-heating rooms should be arranged in the north. Space design can be combined with the design of the door and window design to achieve better lighting and ventilation.

Shape coefficient of building

The shape coefficient of a building refers to the proportion of the surface area above the ground that is contacted by the outdoor air and the building volume. When the building volume is constant, the larger the building surface area is, the more the solar radiation of the building absorbs. However, the large heat loss increased. For example, an earth-covered

building in a cold region reduces the heat dissipation area, while a stilt building in a hot region increases the heat dissipation area. Therefore, a balance point should be found in the design to optimally control the shape coefficient in an appropriate range.

Building envelope

Good thermal performance is an important factor for the building envelope. The wall should be made of materials with good heat preservation performance. In addition, it can also consider a green plant. In summer, when the sun's elevation angle is high, the heat preservation and insulation of the roof are particularly important because the roof receives a lot of solar radiation. The integrated design of the building roof and the photovoltaic device not only collects energy, but also makes sunshade. In addition, planting roof, double ventilation roof and other forms can also be adopted. In winter, it is extremely necessary to pay attention to the heat preservation of doors and windows and other components because the heat dissipation is large [6].

Building structure

At the beginning, it should consider the technology of building structure and skillfully apply it to the architectural design, which cannot only make the rational use of the solar energy, but also can enrich the facade of the building, giving the architectural characteristics of the times and unique aesthetic feeling.

- *Direct solar type:* the room absorb the sunlight through the south-facing window and transparent roof, so that the building is heated. The larger the area of the south-facing window is, the more solar energy will be radiated. At the same time, the north-facing window should be opened as little as possible. In order to increase the area of the south-facing window, the area ratio of window to wall can reach 0.4 and the sunshine depth is generally 2.5 times of the window height after taking thermal insulation measure. Therefore, the depth of the room can be controlled and the height of the window can be set reasonably. The lighting and heating effect of a transparent roof is better than that of vertical windows. But in summer, the indoor temperature is easy to be high due to the strong sunlight. Therefore, the building can choose sunshade glass and insulating glass, or change the height of the building roof and strengthen ventilation to decrease the indoor temperature. In addition, as for the roof form, the sloping roof is easier to receive sunlight radiation than the flat roof. Therefore, the design of the appropriate roof form can be considered.
- *Sunspace-attaching type:* It can be roughly divided into three types. Firstly, the south of the building is enclosed by transparent glass to form a large space. Secondly, the roof of the atrium is made of transparent glass. Thirdly, the space is enclosed by the south balcony and window. A winter garden has a buffering effect and can regulate the indoor climate. It can reduce the heat loss in the building in winter and delay the heat conduction to the room in summer. The winter garden can follow the principle of the hot pressure ventilation and reasonably set the position of air inlet and outlet, which can enhance the effect of indoor ventilation, fig. 1.
- *Thermal storage wall:* the thermal storage wall can collect and store the solar energy. A solid thermal storage wall is painted with black paint on the surface, and glass is installed outside the wall. The outer wall stores heat, while the surface of the interior wall radiates heat to the room. However, it is difficult to control the indoor temperature, fig. 2. In convection loop type, a tuyere is set on the external wall or window. In winter or when the room temperature is low, the tuyere on the thermal storage wall is opened to circularly

heat the indoor cold air by using the solar radiation. In summer or when the room temperature is high, the *chimney effect* is used to open the summer ventilation port on the glass to extract the hot air, fig. 3. The convection loop type is better to control the indoor temperature.

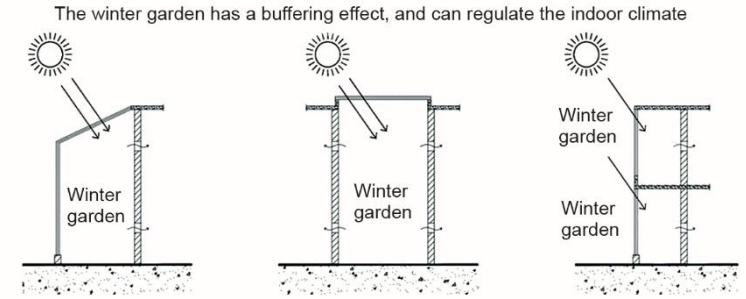

Figure 1. Three forms of additional winter garden

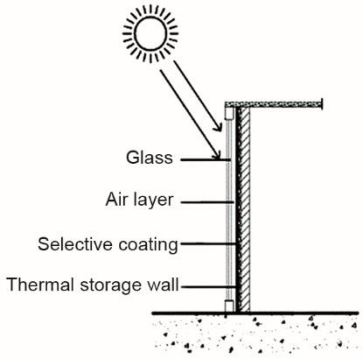

Figure 2. Solid type

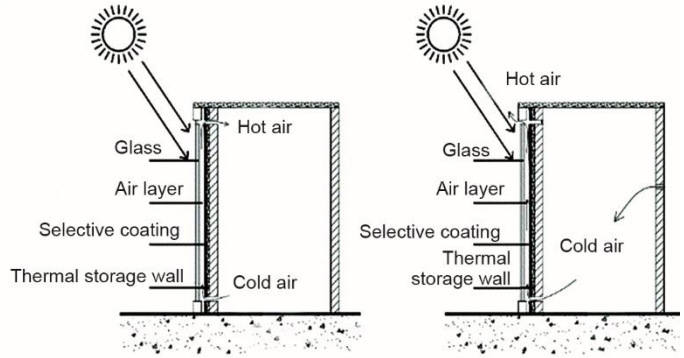

Figure 3. Convection loop type in winter and summer

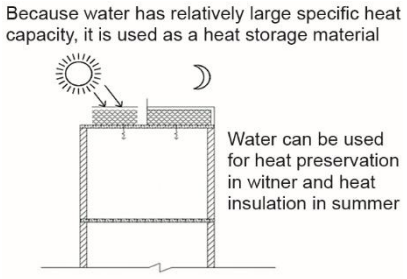

Figure 4. Rooftop pool type

– *Rooftop pool type:* The pool on the roof can be installed with a push-pull thermal insulation board, which uses the high heat capacity of water as the heat storage material. In winter day, the thermal insulation board is pushed to make the water absorb the solar radiant heat. At night, the thermal insulation board is covered to reduce the heat loss. The operation is opposite in summer. The impounded roof has the function of heat preservation in winter and heat insulation in summer, fig. 4.

– *Combined type:* The type is the combination of the above construction technologies, which makes the passive solar building more energy-saving and cost-effective.

Optimal design and application analysis of passive solar building

Taking the atrium as an example, it combines several design strategies to explore its application in passive solar building design. The atrium with a transparent glass roof known as a buffer space uses solar radiation to improve the building environment. Natural ventilation is the result of heat pressure and wind pressure. The sunlight through the transparent glass roof makes the atrium get heat energy. At this time, the heat pressure generated in the atrium promotes natural ventilation. If the wind pressure is reasonably designed and optimally utilized, the natural ventilation will be greatly enhanced, and the energy conversation effect will be better [7].

In summer, the sunshade can effectively block the direct sunlight, and has the function of a thermal buffer, making the atrium as a comfortable cool shelter. In spring and autumn, the air vent at the top of the atrium can promote indoor natural ventilation. In winter, its closed buffer space has the function of heat preservation and energy conversation [8], fig. 5. According to the previous analyses, an optimization problem can be easily established considering various factors.

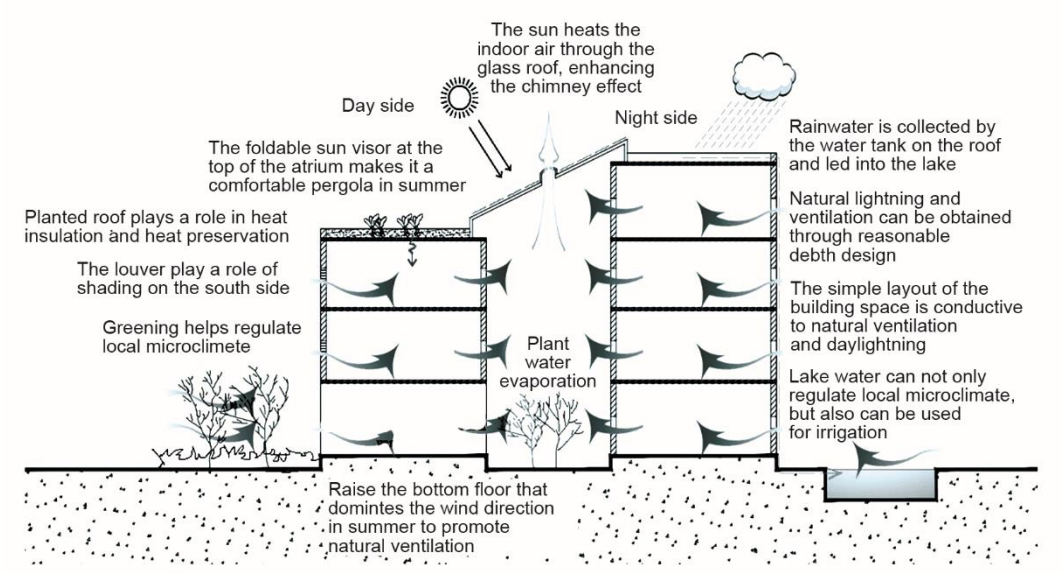

Figure 5. Combined application of multiple passive solar design strategies

Discussion and conclusion

Recently the mechanism of Fangzhu for the passive atmospheric water harvesting was revealed [9], and the incorporation of Fangzhu's passive water collection from air into the passive solar building makes the future building industry much promising.

The passive solar building accords with the development needs of the new age, which is of great realistic significance to reduce costs, save energy, and protect the environment. It should be promoted and applied vigorously. Architects should realize their responsibility and consider the technology from the source of the optimal design to promote the development of the passive solar building.

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References

[1] Song. Q., *et al.*, Towards to Sustainable Energy-Efficient City: A Case Study of Macau, *Renew. Sustain. Energy Rev.*, *75* (2017), Aug., pp. 504-514
[2] Aditya, L., *et al.*, A Review on Insulation Materials for Energy Conservation in Buildings, *Renew. Sustain. Energy Rev.*, *73* (2017), June, pp. 1352-1365
[3] Jones, G. A., *et al.*, The 21st Century Population-Energy-Climate Nexus, *Energy Policy*, *93* (2016), June, pp. 206-212
[4] Chandel, S., *et al.*, Implementing Passive Solar Housing Technology in Mountains, in: (Saman, W. Y., Charters, W. W. S,. eds.), *Bringing Solar Down to Earth, Proceedings of ISES, Solar World Congress, Adelaide, Australia*, 2001, pp. 183-189
[5] Chandel, S., Strategy for the Promotion of Passive Solar Housing Technology in Western Himalayas, *Int. Energy J.*, *7* (2006), 4, pp. 273-277
[6] Younes, C., *et al.*, Air Infiltration Through Building Envelopes: A review, *Journal of Building Physics*, *35* (2012), 3, pp. 267-302
[7] Chwieduk, D., *et al.*, Solar Energy in Buildings, *Encyclopedia of Physical Science & Technology*, *106* (2014), 21, pp. 111-126
[8] Hamdy, I., *et al.*, Passive Solar Ventilation, *Renewable Energy*, *14* (1988), 3, pp. 381-386
[9] He, C.-H., *et al.*, Passive Atmospheric Water Harvesting Utilizing an Ancient Chinese Ink Slab, *Facta Universitatis-Series Mechanical Engineering*, *19* (2021), 2, pp. 229-239

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