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Environment-Friendly-House Project a Case Study on Sustainable Design in the Hot and Humid Climate
节能环保住宅: 湿热气候区可持续设计的个案研究

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Abstract An environment-friendly house was carried out in Nanning, a hot and humid area of China. This building as an experimental house was designed based on the local climate and conditions of the local building materials. The solar system used in the building is the outdoor-air heat-collecting solar system. A passive cooling method has been proposed by developing a new type of ventilating brick, and a lot of architectural techniques are utilized. This paper describes the building and the design concepts. The findings from the monitored data are discussed.

Key words house heat-collecting solar system, roof exhausting ventilation, night cooling, under-floor energy storage, ventilating brick, ventilating wall

摘要　在南宁湿热地区建成一栋节能环保实验住宅,实验房引进日本的太阳房技术,结合当地气候条件和建筑材料资源,研制开发了新型空心砖,采取多种被动式降温手法和建筑节能措施。介绍实验房设计思想及系统工作原理,给出各种实测数据分析结果。

关键词　住宅太阳能采热系统　屋面通风排热　夜间辐射致冷　地板蓄能　隔热空心砖　通气保温墙
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To improve the living environment in the southern regions, the families are apt to buy an air-conditioner for cooling as soon as they can afford. It is a fact that the energy consumption at homes is greatly increasing with the spread of home air-conditioner during the past few years. A crisis in the domestic electricity supply has become a serious problem to be settled as soon as possible. It is urgent to suggest an appropriate instruction for improving the living environment from an environmental and conservation point of view. Therefore it is significant to construct energy-saving and environment-friendly buildings where a healthy and comfortable living environment can be created with less help of air-conditioning system. To construct this type of the building, however, it is lack of the actual examples available, especially in the southern China. Aiming to demonstrate a viable technology of passive cooling building for the southern regions, OM Solar Association and Institute of Applied Physics of Guangxi Academy of Sciences have jointly constructed an experimental environment-friendly building named "The Nanning Sino-Japanese Friendship Solar House" in Nanning (the capital of Guangxi Zhuang Autonomous Region). Shading and insulation and ventilation are given priority to passive cooling strategies based on the climatic conditions of the locality. A new ventilating brick has been developed and used in the out finished surface of the wall for increasing natural exhausting ventilation in the walls. In the locality, brick is one of most popular building materials for a long time. However, reckless brick production has resulted in an environmental disruption. This problem will be getting worse if appropriate measures are not taken into action. Considering the situation, a new hollow brick has proposed for the better use of brick.

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1 Design conceptions

The construction location of the building, Nanning is located in the tropic of Cancer a little to the south, about 200 km near the border of Vietnam. The solar heat on the southern and western walls are great in summer. As shown in Fig. 1, the winter is short and has only two months. On the other hand, the summer is long more than a half year as well as humid. Furthermore it lacks wind. In short, Nanning has the following climates: short winter, long and hot-humid summer, lack of wind.

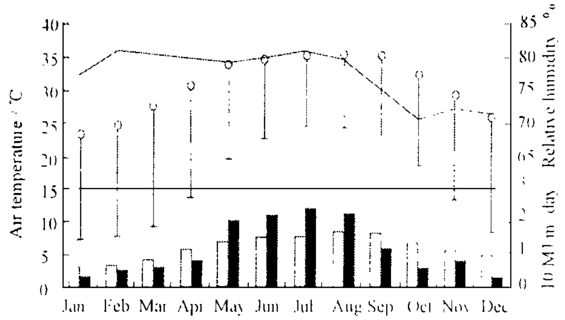

Fig. 1
▭ Daily globe radiation [MJ/m^2/day]; ■ Monthly precipitation [mm]; o Daily maximum air temperature [℃]; —— Daily minimun air temperature [℃]; —— Monthly mean relative humidity [%].

From the climatic conditions of Nanning as described above, our building was designed to be:

(1) well heat-insulated for preventing solar heat from entering the rooms as possible

(2) passive and active ventilation for exhausting the heat out of the building

(3) cooled by making good use of the environmental cooling resources

(4) built of the natural materials as possible for latent and evaporation cooling

According to the above design concepts, the following passive cooling strategies were considered:

(1) use air heat-collecting and ventilating roof

(2) build ventilating walls by bricks

(3) utilize an exhaust stack for indoor ventilation

(4) use night cooling and cool tube efficiently

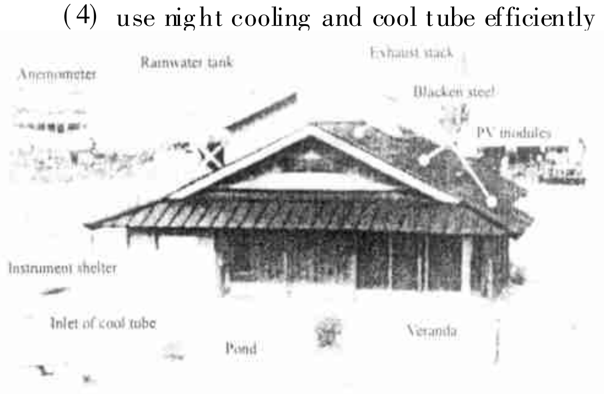

Fig. 2 Western view of the building (completed in April 1998)

Fig. 2 is a view of the building completed in April 1998. The first floor of the building is shown in Fig. 3. The building consists of two houses. The eastern one is a two-story dwelling with an open ceiling and a standard floor area (the first floor area is 60 m^2, the second floor 29 m^2). The first floor comprises a kitchen, a dining room, a shower bathroom, a bedroom and two bedrooms are in the second floor. The western house is one-storied and has a large meeting room, a traditional Japanese tea ceremony room, a bathroom with bath unit, an instrument room for the data-recorders and other equipment.

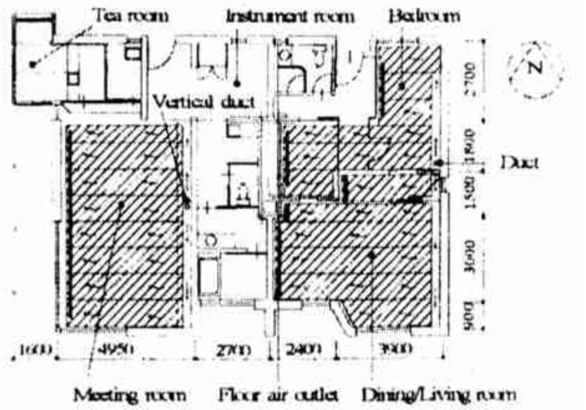

Fig. 3 The first floor plan

▨ Precast hollow concrete slab; ← Air flow under floor.

2 The solar system

A multiple solar system[1] was used in the building. The surface of the south-facing roof is a solar collector and finished with blacken stainless steel shingles. The upper part of the roof collector is covered with a sheet of glass under which there is a layer of dead air. As illustrated in Fig. 4, the outside air from inlets in the edge of eaves is drawn to flow up to the roof air chamber through the space under the roof surface by a fan installed in the air handling box. As passing in the under-roof layer of air, the air from outside is heated by the back of the shingles which becomes hot by absorbing solar heat, and the nearer to the top of roof, the higher the temperature of the air rises.

The airflow passing through the roof air chamber can follow two different ways, controlled by the dampers, depending on the adjusting mode of the system controller. In the summer daytime, the hot air gathering in the roof air chamber is exhausted outside through the exhaust duct connected with an exhaust stack. Therefore the heat from the roof into the room can be reduced. Below the under-roof air layer is an insulating layer under which there is a layer of air for natural ventilation. Under the northern roof surface there is a ventilating layer too. The air can pass through from north to south and the air passage runs to the exhaust stack whose lower part connects with the ventilation openings in each room. The hot exhaust air heats the upper part of the exhaust stack and creates a rising air current, with which the air in the room is drawn into the exhaust stack through the ventilation openings. This method enables the room to be ventilated even in the locality without wind.

If the sky is clear at night in summer, the surface temperature of the metal roof goes below the temperature of outdoor air because of the night radiation cooling effect. The air from outside is cooled by the back of metal sheet as passing in the under-roof air layer. Dew will be formed because the temperature of the roof surface is lower than the ambient air temperature and the air is humid at night. The cooler and drier air is guided down to the air space under the floor through the vertical air duct by opening the outlet damper up to the vertical air duct. Under the floor is an array of precast hollow concrete slabs within which the air space becomes passages of the cool air. At the end, the air flows up into the room from outlets near the wall (see airflow in Fig. 3). As passing under the floor, the air cools the floor slab. In the morning, the outlet damper automatically opens to the exhaust duck when the air temperature in the roof chamber is higher than the room temperature. During the day, the floor is kept cool and a radiant cooling effect can be created in the room. The effect of dehumidification may be higher than that of temperature decrease because of the latent heat being released. Due to condensation, the under-roof space may get wet at night. Nevertheless it dries quickly as the under-roof air is being exhausted out in the following day.

In the winter daytime the hot air is introduced down into the rooms following the same way as in the summer nighttime. As passing under the floor, the part of the heat in the hot air is absorbed by the floor slab. After sunset, the fan stops running automatically when solar heat is no longer available. Meanwhile, the inlet damper at the front of the air handling box shuts down and the way of airflow from the roof air chamber to the room is cut off. At night, the heat stored under the floor is released into the room through the floor, so that the room temperature falls slowly.

The wall is designed to be made of ferroconcrete with an insulating layer of polystyrene sandwiched between the concrete and an outer layer of brick tiles, as indicated in Fig. 6. The brick tile has a " 83CE" shape as shown on the right of the figure 6 and between its two transverse ridges is an air space to allow the passage of air. Inlets of the air passages are on the lowest row of brick and outlets on the uppermost row. The air in the passage rises up and brings out the heat transmitted through the brick from outside during the day. Besides, an evaporation cooling can be expected on the out walls. This reason is that the bricks are wet because of rainy and humid climate in Nanning, so that the part of solar heat shining on the wall is used to evaporate the water in the brick tile. As a result, a great deal of the heat can be prevented from entering the wall.

Another cooling method is to use the cool tube buried under the ground of the building. Its inlet is designed near the pond in the western garden and outlet is under the floor close to the outlet of the vertical air duct. The outlet of the cool tube has a lid and can be closed in winter.

In addition, the house uses an integrated hot-water system in which the hot air can be utilized to produce hot water before exhausted outside. An integrated PV roof system was also installed. In fact, the middle part of the roof is an array of PV modules which not only collects solar heat but also generates electricity.

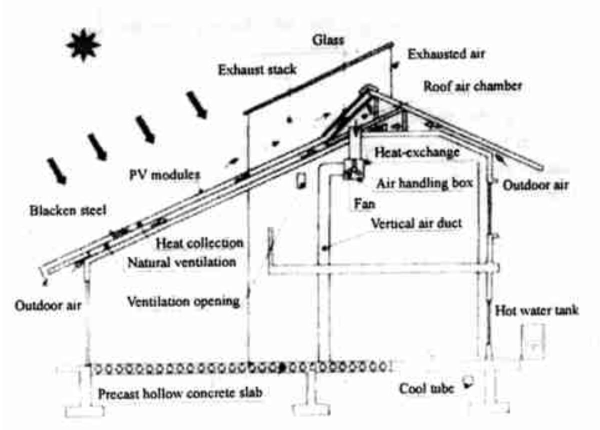

Fig. 4 The airflow in the summer daytime

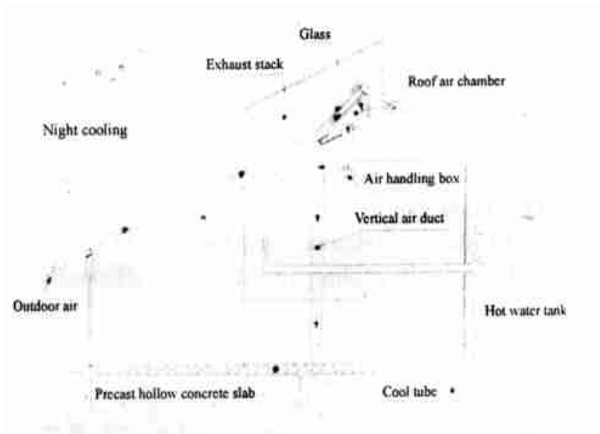

Fig. 5 The airflow in the summer nighttime

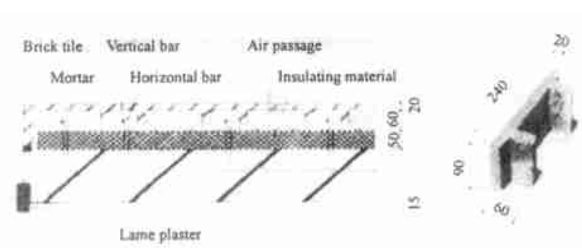

Fig. 6 Ventilating wall and view of brick

3 Results and discussions

3.1 Ventilation effect in the wall

Fig. 7 shows measurement results of temperature distribution in the western wall for three days. From the middle graphs for a clear day, it can be seen that the exterior surface temperature arrives at more than 50℃ in the afternoon. At the same time, the air temperature within the air passage is about 5℃ higher than the ambient air temperature. The air temperature of the outlet in the shade is 2℃ to 3℃ higher than that of the inlet. These results explain that the air in the air passage is rising and flowing out from the outlet. Moreover, the interior surface temperature varies within 1℃ all day long. Therefore, it can be concluded that the proposed ventilating wall has a good effect to exhaust the heat out of the wall.

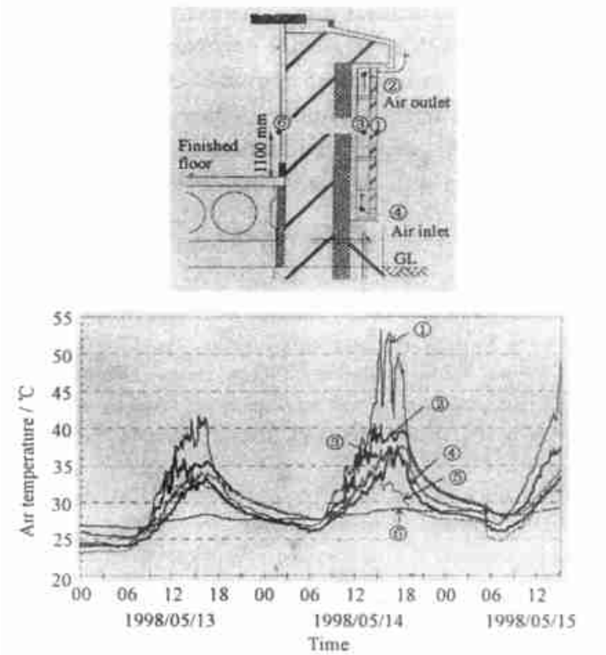

Fig. 7 Measurement points and an example of measurement results in the western wall
① Exterior surface temperature; ② Air temperature of the outlet; ③ Air temperature in air passage; ④ Air temperature of the inlet; ⑤ Outdoor air temperature; ⑥ Interior surface temperature.

3. 2 Indoor temperature

Fig. 8 gives the data recorded in the eastern house for two typical summer clear days when the door and windows were opened all day long. Although the room temperature of the first floor varies with the ambient air temperature, the former is slightly lower than the latter during the day. From the variation of the ceiling surface temperature it can be found that the roof is well-insulated. The cool air from the roof is drawn into the under-floor air space during the night. Because the floor slab is cooled at night, the surface is maintained to be about 3℃ cooler than the room temperature during the day. This result shows that a radiant cooling effect can be created.

3. 3 Internal airflow

Directions and velocities of internal airflow near windows and doors were measured. An air velocity at

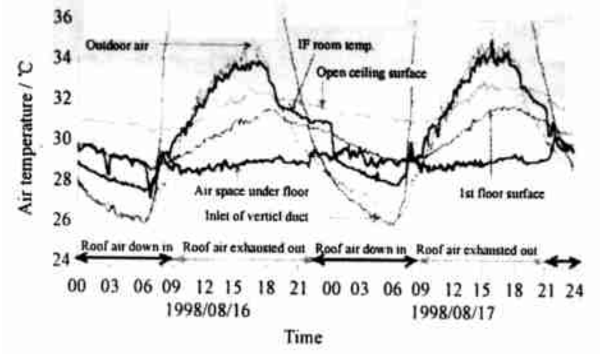

Fig. 8 Measurement results of indoor temperatures

each monitored position was measured for three minutes and its mean value was recorded. This cyclic measurement was repeated three times. As given in Fig. 9 are the three-times mean values recorded over the period 16 00 to 17: 00 on 18 August 1998. During the measurement, it was found that wind speed at a height of 8 m was around 2 m/s and the south wind was prevailing. Arrows in the figure 9 mean directions of airflow. One can see that most of the velocities are over 0. 3 m/s, the value being 15 percent of wind speed. This result indicates that a satisfactory ventilation can be obtained inside.

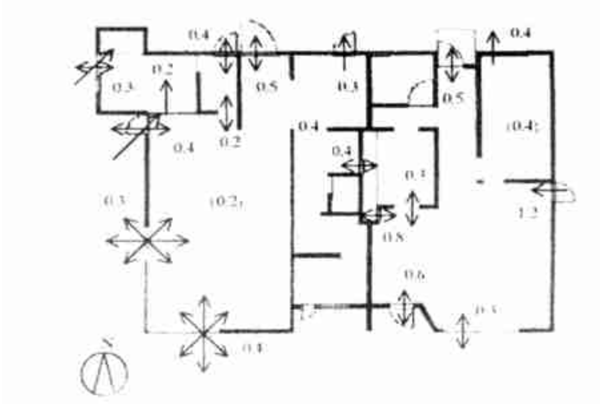

Fig. 9 Velocities and directions of internal airflow
Mean wind speed is 2 m/s at a height of 8 m during measuremen.

3. 4 Indoor radiant environment

The indoor radiant environment was measured by the spherical thermal imaging instrument[4]. Fig. 10 shows two spherical thermal images recorded in the living room at 6 37 and 14 30 on a clear day (10 August 1998). At 6 37, both the floor surface temperature and measured value of MRT (mean radiant temperature) are 30℃ or so, being nearly equal to the air temperature. Although the global solar radiation on the horizontal surface reaches 909W/m^2 at 14 30, the ceiling surface temperature is around 32℃ and the floor temperature is kept at a temperature of 31℃ ~ 32℃. At the same time, MRT is rising up to less than 33℃ with a little difference from the air temperature. The calculated value of SET * (standard new effective temperature) is 30℃ from the measured data of the air temperature, relative humidity, air velocity on condition that the quantities of clothing and metabolism are 0.3 clo (without sleeve), 1met (resting) respectively. This means that a suitable environment can be achieved.

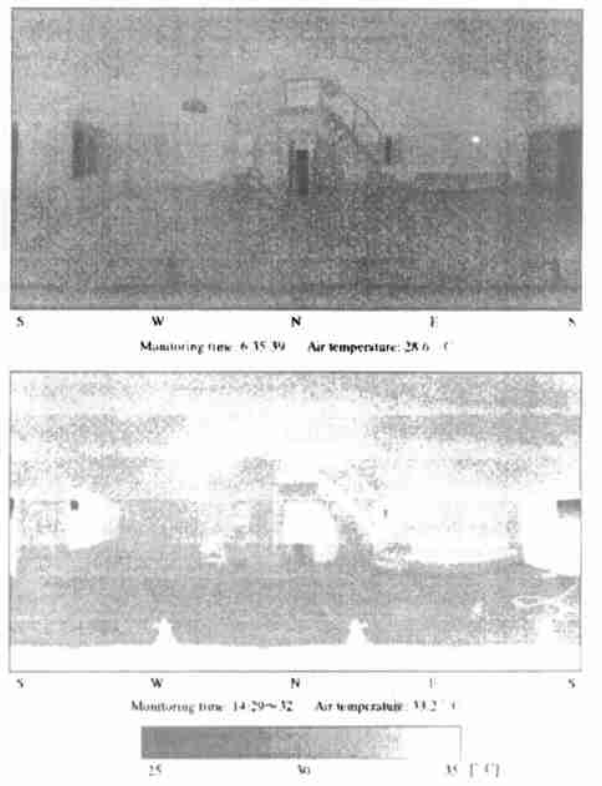

Fig. 10 Surface temperature distribution in the living room (Aug. 10)

4 Conclusions

This paper has presented an experimental environment-friendly house constructed in a city (Nanning) of the southern China where the hot and humid summer lasts over a half year. From measurements made in summer, it was found that the ventilating wall built of the proposed brick has an effect of heat-exhausting ventilation. The monitoring has shown that the indoor thermal environment of the building can be improved by utilizing the proposed cooling techniques, for instance, roof heat-exhausting, ventilating stack, openings planning, night cooling, under-floor energy storage, etc. In conclusion the presented environmentally friendly building can achieve a satisfactory thermal environment during the summer in the subtropical regions. An application to the mid-rise apartment house is being planned in our next project. A positive utilization of natural materials such as bamboo will be also considered.

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