RESEARCH AND DEVELOPMENT OF A PASSIVE SOLAR HOUSE WITH AIRFLOW SYSTEM IN BRICK WALLS

Mikiko Nakamura, Toshiyuki Watanabe, Tetsuo Hayashi
Yuji Ryu, Yasunori Akashi, Shin-Ichiro Goto, Shuho Takase
Japan Science and Technology Corporation
CREST Matsufuji Research Team
fax: 81 92 642 3368
e-mail: nakamura@beel.kyushu-u.ac.jp

ABSTRACT Research and development of new-type passive solar houses are the main purpose of this paper. The proposed passive solar houses haven an air circulation system in brick walls combined with passive heating and cooling systems. A prototype model house with a solar collector and Trombe walls was constructed and its thermal performance was measured to evaluate this new system. The efficiency on the real size model house with attached green houses is discussed through thermal performance simulations.

1 Introduction

Two reasons are mentioned against the construction of brick houses in Japan. One is its fragility for earthquakes. Masonry structures are regulated with building code in Japan. The other is condensation. The moist air of rainy early summer in Japan, the lack of ventilation caused by openings which are small because of structural reasons, low surface temperature of bricks caused by their large thermal mass result in condensation, mold, and consequent hygienic problems. The first barrier, the structural problem, can be avoided with the "Distributed Unbond Pre-stress Method" (Matufuji 1992) If the latter problem can be solved, brick houses will be popularized in Japan. The large thermal mass and capacity of brick houses can be utilized for the control of the indoor thermal environment and the reduction of air-conditioning load.

2 Passive solar house with air-circulation

A small test house was constructed and its thermal performance was measured to evaluate a new proposed air-circulation system. The air in the attic- and crawl-space circulates through the gaps in cavity brick walls and brick veneer walls.

2.1 Outline of the test house

The test house was built in November 1997 and situated in Fukuoka, southern part of Japan. Its north wall has a cavity brick structure, the east and west walls are brick veneer and the south wall is a Trombe wall. There are two windows, facing south and north. A solar air-heater, 5.4 m^2, on the roof and cool tubes at 0.5 m depth below the ground were installed as passive heating and cooling devices (Photo 1, Fig.1 and 2).
In winter, the air in the attic space is sucked into the solar air-heater, gathered into the ridge duct and sent to the air-gap in the northern cavity brick wall and the air space under the floor, driven by the electric fan installed in the air-handling box. The air reheated by the Trombe wall enters the south room, then diffuses to the north room through the openings on the partition wall. The air in the rooms goes through the lower slits on the east and west wall, goes up to the attic space through the air-gaps in the east and west brick veneer walls.

Photo.1 Outside view of test house

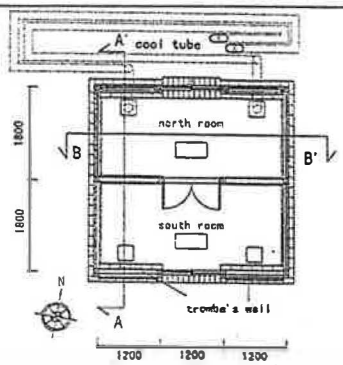


Figure 1 Floor plan [unit: mm]

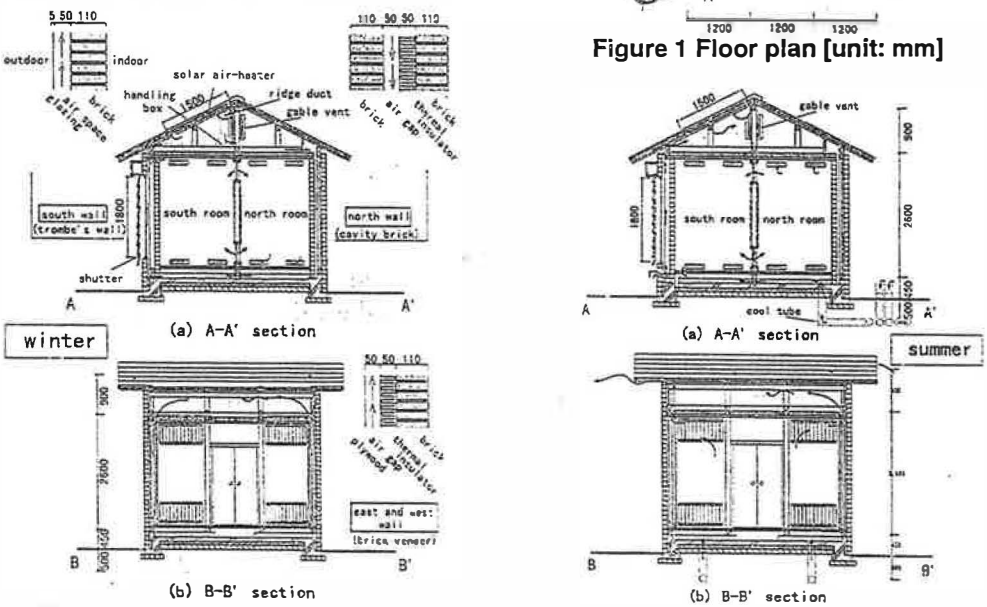


Fig.2 Sections and details of test house

In summer, the outdoor air cooled by 20 m length of earth-tubes goes into the south room, diffuses to the north room and goes up to the attic space trough the upper slits on the east and west walls. The air in the attic space is exhausted to the outdoors through the gable vents. The Trombe walls and the windows are solar-shaded by the shutter and the outdoor air entering the air-gaps in the Trombe walls and discharged into the attic space by the electric fan to prevent temperature rising.

2.2 Thermal performance in winter

The shutter on the Trombe wall was rolled up from 7 a.m. to 5 p.m., the dampers in the air-circulation circuit were opened and the electric fan in the handling box was operating to collect solar heat. The rest of the time, the shutter was rolled down, the dampers were closed and the fan was stopped to prevent heat loss. Fig.3 shows the measured air temperature fluctuation in winter. When the outdoor air temperature was 8 to 14°C, the solar heated air in the ridge duct went up to over 50°C. Its temperature went down gradually to 47°C at the inlet of the north wall, 40°C in the middle of the air-gap and 30°C at the outlet to the under floor air space, at their maximum temperature respectively. The re-heated air at the Trombe wall went into the south room, its maximum temperature was 25°C, so the air temperatures in the south and the north room was also about 25°C and no significant temperature difference between the two rooms can been seen. The radiant heat emission and convection from the north wall kept the north room air temperature 20 to 25°C in the overnight.

2.3 Thermal performance in summer

Fig.4 shows the measured air temperatures on July 19, July 22 and July 31, 1997. The outdoor air temperature on these three days exceeded 30°C. Solar shading and cool tubes were not actuated on July 19. The room air temperatures went up from the morning, reached 37°C in the north room and 36°C in the south room at 6 p.m. The night ventilation through windows cooled down the room air temperatures to 27°C. The solar shading shutter on the south wall and the cool tubes were operated from July 20. The air from the cool tube circulated in the both rooms on July 22. Though the induced outdoor air cooled 1 or 2 K by the cool tubes, the air temperature under the floor was stable all day long around 29°C. Compared with the data on July 19, the room air temperatures decreased 3 K in daytime. Since no significant difference could be found in the air temperature under floor between the operation and non-operation of the cool tubes, the decrease of room air temperature derived from the heat exhaustion caused by the air circulation. On July 31, the cooled air from the cool tubes was induced only to the south room. The air temperature in the south room was kept lower than the outdoor air temperature in the morning, restrained below 32°C in the afternoon. It was lower than that on July 22, but the air temperature in the north room on July 31 was higher than that on July 22. To utilize the insufficient cooling capacity of the cool tubes, it may be necessary to select where the cooled air is supplied.

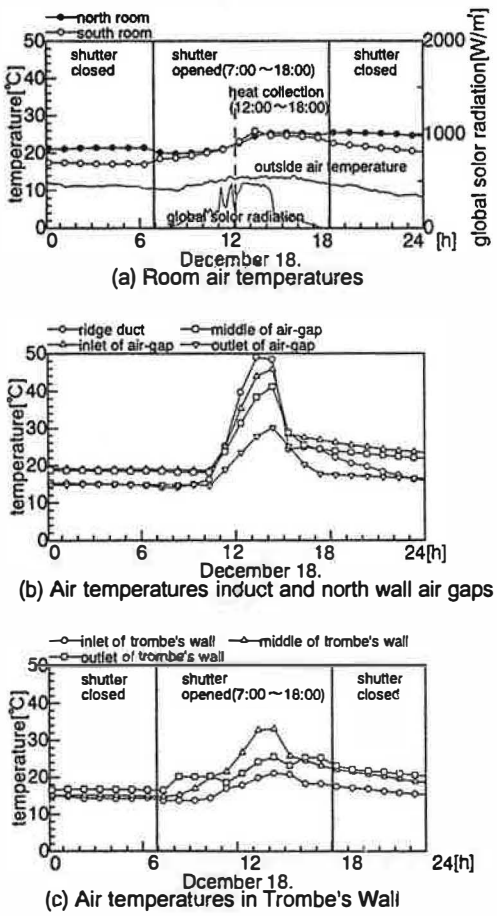


Fig.3 Air temperatures in winter

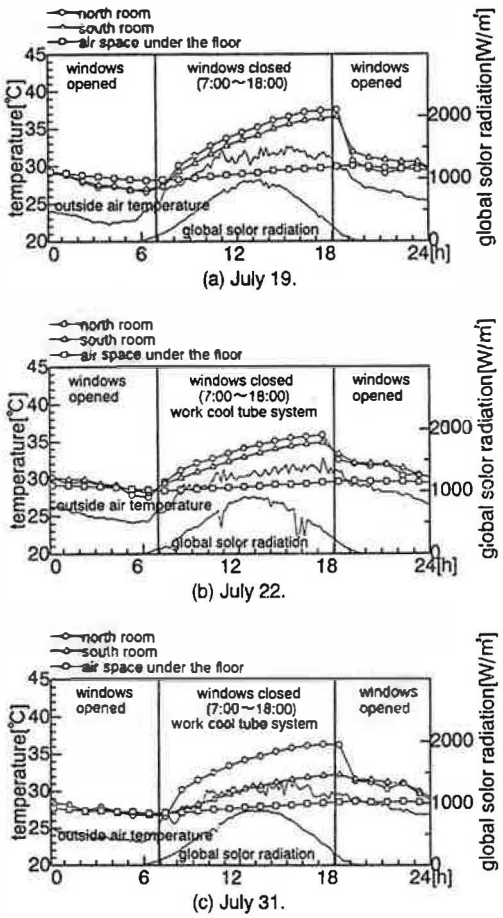
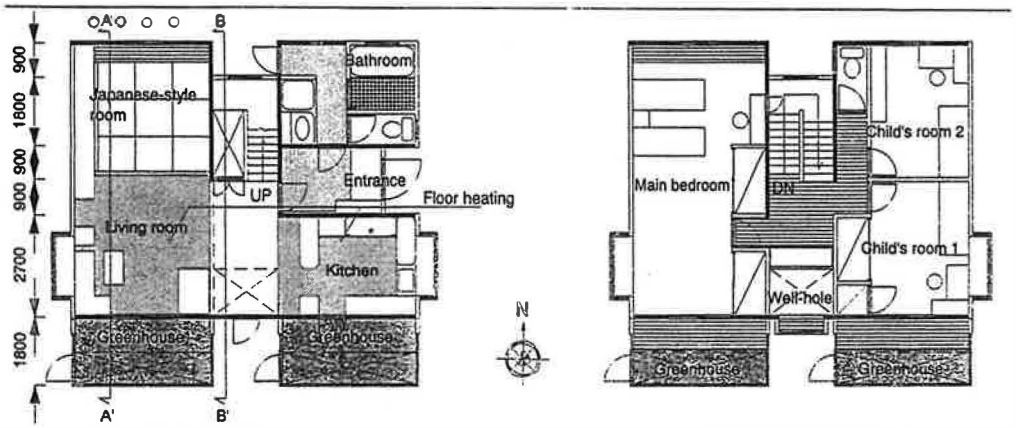


Fig.4 Air temperatures in summer



(a) Ground floor plan (b) First floor plan

Figure 5 Plans of solar house [unit: mm]

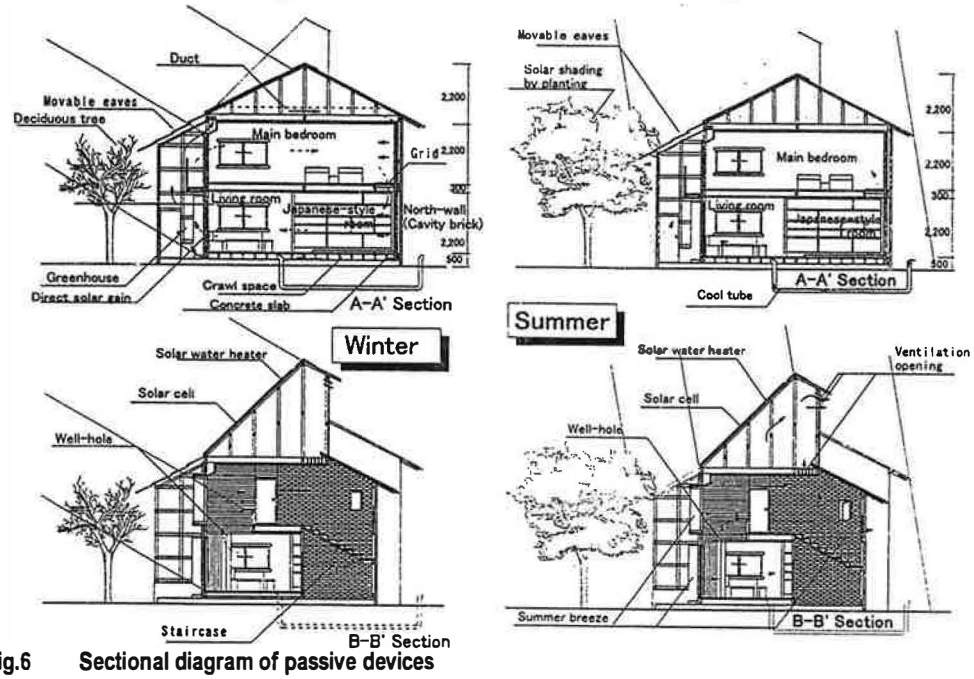


Fig.6 Sectional diagram of passive devices

3 Proposal of a passive solar house with air-circulation in brick walls

The concept of a passive solar house made of bricks is introduced and its thermal efficiency is validated with a numerical simulation. The passive solar house has air-circulation systems in brick walls, attached green houses and various openings for air-circulation and ventilation. Fig.5 is the plan of the solar house and Fig.6 shows the sectional diagram of passive systems. In winter, indoor air is heated up in the attached green houses facing to the south and sent to the air-gaps in the north cavity brick wall by the duct and fan. The air circulates from the northern air gaps to the attached green house through the air space under the floor. If the windows between the green houses and the rooms are opened, stack effect causes natural air circulation through the floor grids. In summer, the air from the cool tube goes into the air space under the floor, up to the attic space and discharged to the outdoors. The movable eaves and the planting of deciduous trees for solar shading, all-day-long opening of the southern windows for vertical ventilation prevent the over-heating of green houses.

Table 1 The conditions for simulating

- weather data : standard weather data (Fukuoka in Japan)
- simulation interval time : 1hour
- cooling period : summer July~August
- heating period : winter January~February
- cooling and heating time :
  - living room 6~9,12~14,16~22[h]
  - main bedroom 21~23[h](only winter)
  - child's rooms 16~22[h](only winter)
- setting temperature : cooling 26°C, heating 22°C

Table 2 Schedule of room occupants

Time[h]	23~6	7	8	9	10	11~17	18	19	20	21	22	23
Living room	0	3	4	1	1	1	1	1	2	2	3	1	1
Master bedroom	2	0	0	0	0	0	0	0	0	0	0	1	1
Children's rooms	1	1	0	0	0	0	0	0	0	0	1	1	1

[unit:person]

Table 3 Components of wall structures

Roof	foam polystyrene	100mm
	plywood	10mm
	clay tile	10mm
North wall	brick	110mm
	air gap	50mm
	foam polystyrene	50mm
	brick	110mm
East and west walls	plaster board	10mm
	foam polystyrene	50mm
	air gap	50mm
	brick	110mm
Inner wall A	plaster board	10mm
	air gap	50mm
	plaster board	10mm
Inner wall B	brick	110mm
GF floor	plywood	10mm
1F floor	carpet	15mm
	plywood	10mm
Japanese-style room	tatami mat	50mm
floor	plywood	10mm
Windowpane(pair glass)	glass	5mm
	air gap	10mm
GF ceiling	plaster board	10mm
1F ceiling	plaster board	10mm
	foam polystyrene	50mm
ground	concrete slab	100mm
	foam polystyrene	100mm
	mat foundation	50mm
	soil	50mm

3.1 Thermal performance simulation

A thermal performance simulation program for multi-space dwellings called "Triple P", Passive system simulation Program for Personal computers, is adopted for the simulation. Assumptions for the simulation are shown in Tables 1 to 3. Table 3 shows the components of wall structures of the proposed solar house. Three types of wall structure are examined to compare their thermal performance. One is the proposed brick wall with air-circulation system. The second has the same wall structure but no air-circulation. The third is a timber wall structure replacing the exterior wall bricks by plywood panels and no air-circulation. All have the same thickness of thermal insulation materials in the exterior walls. The cool tube combined with the air-circulation is taken as 20 m long at 3 m depth. Windows in the main bedroom and children's rooms are opened overnight in summer for noctumal ventilation.

3.2 Simulation results

Fig.7 shows the room air temperature variation in winter. No air-conditioner is operated in these simulations. Temperature rise in daytime and fall at night in the wooden house are motre pronounced. Temperature fluctuation of the brick house is much less because of its large thermal mass. The brick house with air-circulation has the highest air temperature at night and the same maximum air temperature as the wooden house in the daytime. The solar heated air and its circulation through the northern wall that has a large heat capacity in the inner bricks, keep the room air temperature high overnight.

Fig.8 shows the room air temperature variation in summer. The cool tube of the brick house with air-circulation is operated from 7 a.m. to 6 p.m. The room air temperatures overnight are the same in all three types because of the nocturnal ventilation through windows. The brick house with air-circulation has the lowest air temperature in the daytime.

Fig.9 shows the comparison of seasonal air-conditioning loads. The set temperatures shown in Table 1 are applied to these simulations. The brick house with air-circulation has less heating load by 7% and cooling load by 20% than those of the wooden house. Meanwhile, the normal brick house, with no air-circulation, gives a reduction of 3% in heating and 13% in cooling of air-conditioning load compared to the wooden house.

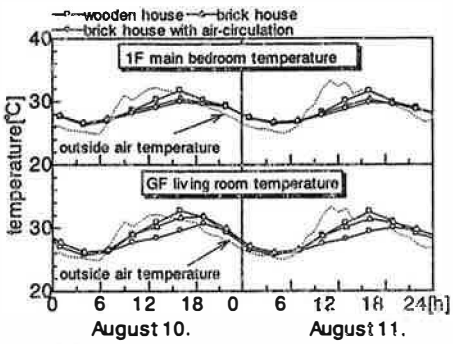


Figure 8 Room air temperatures fluctuation in summer

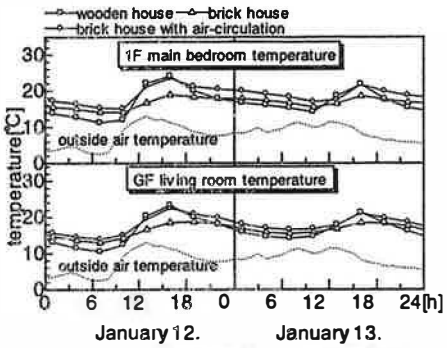


Figure 7 Room air temperatures fluctuation in winter

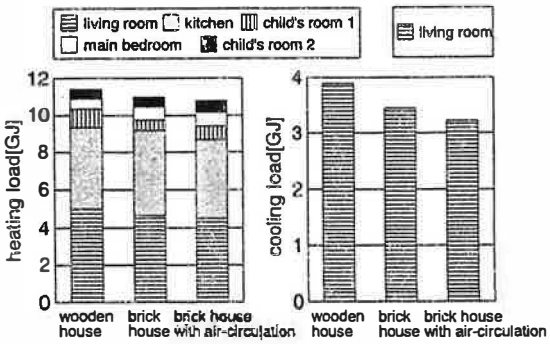


Fig.9 Comparison of seasonal air conditioning load

4 Conclusions

A passive solar house using brick walls and an air-circulation system is proposed and its thermal performance is examined. The results are the followings:

1) A small test house was constructed and its thermal performance was measured. Its room air temperature was kept higher and more stable in winter by the combined effect of the bricks' thermal mass, and the solar air heater, Trombe wall and air-circulation in walls. Heat exhaustion and ventilation caused by the induction of outdoor air is effective on the prevention of temperature rise in summer.

2) A prototype of brick solar house with air-circulation and attached green houses is proposed, its thermal performance is predicted by numerical simulations. The proposed system is more effective in regulating the indoor thermal environment and reducing air-conditioning energy consumption than the houses of ordinary wall structures.

3) Utilization of the bricks' thermal mass combined with solar heating is effective to improve the indoor thermal environment in winter. However, solar shading, heat exhaust and ventilation must be ensured for the improvement of thermal performance in summer.

5 References

T. Hayashi (1992): *Development of thermal performance simulation program for multi-space dwellings using personal computers*, Annual Report Housing Research Foundation, No.19, pp. 337-346 (in Japanese)

Y. Matufuji (1992): *Reinforced brick wall system for semi-dry brick work*, Doc. Division of Building, Construction and Engineering CSIRO (personal communication)