Conversion Design of Solar Houses from Active to Passive

Ken-ichi Kimura

International Research Institute on Human Environment, Tokyo, Japan
Professor Emeritus, Waseda University, Tokyo, Japan

ABSTRACT: Two examples of architectural design of converting active solar house to passive solar house together with some considerations about the consequences are presented. The first one is MIT Solar House IV built in 1957 and the data acquisition was completed in 1961, when the house was determined to be sold as an ordinary house. The author was engaged in making the conversion design by removing 55 m^2 of solar collector to provide a partial extension of living room with south facing opening for direct solar heat gain. The second one is K Solar House built in 1972 with 16 units of sliding vertical solar collector of 1.6 m^2 each. These were replaced by glass block wall and sliding insulation panels with a low emissivity glass pane. The wood framings of original collector units were reused and the original aluminium framings for glass as collector glazing cover were unchanged.

Keywords: conversion design, solar house, passive, active

1. INTRODUCTION

Façade design of solar houses are no doubt important irrespective of passive or active ones, as it should perform the primary functions of collecting solar energy and express the essential beauty of the functions at the same time.

In early days of solar house development physical functions of collecting solar energy was much stressed to forget about the façade design as the main features of architecture. While nice looking buildings often failed to perform as solar buildings.

MIT Solar House IV constructed in 1957 was one of the unique examples of active solar house with well designed mechanical system yet expressing the large collector surface covering the entire 60 degree tilt roof. The author was engaged in the data reduction of this solar house and asked to design the façade removing the collector and providing a sun space instead after enough data were obtained in 1962.

Another example is K Solar House in Tokorozawa, Japan, which was designed by the author and has been lived by the author's family from 1972 to present. The sliding doors with collector panels on the south façade made it possible to invite direct solar gain, when partially opened, through glass cover of ordinary aluminium sash. After 33 years they had to be replaced by glass block in part and movable insulation panels behind the reused aluminium sash with a pane of new reflecting glass.

This paper introduces these two examples of façade design conversion from active to passive with some considerations from both view points of aesthetics and energy performance.

2. MIT SOLAR HOUSE IV

2.1 Original façade design of MIT Solar House IV

The outside view of the original MIT Solar House, built in Lexington, Massachusetts, U. S. A., is shown in Fig.1. The entire south façade of 60 degree tilt is occupied by flat plate solar collector of $60m^2$ against the total floor area of $135m^2$.

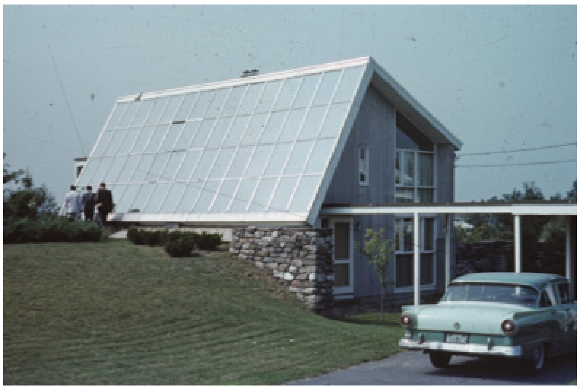

Figure 1: Outside view of MIT Solar House IV

The solar energy project of MIT (Massachusetts Institute of Technology) was supported by Godfrey Cabot Fund initiated in 1940s and this house was preceded by three experimental houses. MIT Solar House III, destroyed by fire, had direct gain south window and collector on the roof. Since the collector area was a little too small and it was found difficult to determine the energy supplied by solar energy as the amount of direct solar heat gain could not well estimated.

It was the reason why Solar House IV intentionally avoided providing direct gain features so that a quantitative amount of solar contribution could be identified by detailed analysis with a large amount of measured data.

2.2 Outline of thermal system

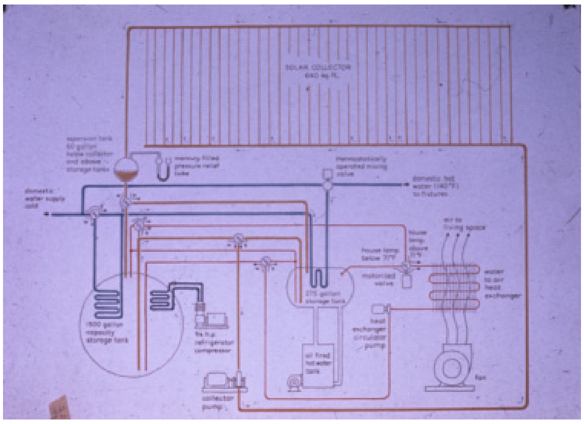

Figure 2: System diagram of MIT Solar House IV

As shown in the system diagram of Fig. 2, solar energy collected is fed to the solar tank and the warm water is supplied by a circulating pump to the heat exchanger where warm air is produced for space heating. The auxiliary tank heated by the oil furnace is provided for the case of less solar energy available. Domestic hot water is supplied by passing the city water through the heat exchanger within the solar tank topped up by the auxiliary tank.

The flat-plate collector was consisting of copper tubing clamped with blackened aluminium plate by galvanized iron channel and double pane glass covering fastened with wooden framing. It was found after three years' operation that, horizontal wood framing was slightly rotated because of the weight of the glass as shown in Fig. 3 and some rain water leakage caused some deterioration within the collector. Thus the collector performance turned out being degraded.

Figure 3: Closer look at the collector

This was the main reason why the committee decided to remodel the solar house into an ordinary house on the ground that sufficient data has been obtained by three full years of measured data.

2.3 Conversion design of MIT Solar House IV from active to passive

It was sometime in 1962 when I was asked to propose a conversion design of the house.

Since the area behind the large collector was living room with the window only to the west, it was considered necessary to provide a large opening to the south. Much larger sun space could have been provided, but excessive glass area might cause a large amount of heat loss in winter and the remodelling of the house was completed as shown in Fig.4.

Figure 4: Outside view of the remodelled house

All area of the collector was taken away and finished with shingles. The protruded portion with cantilever is identified by an extension of living room. Behind the east of the protruded portion there is a staircase, where window was regarded unnecessary.

Soon after the completion, the house could be sold to an engineer's family and they were quite satisfied with the house.

The original house was so designed with heavy insulation and double glazing. Only small windows are openable. This means that the remodelled house is regarded a low energy house, thus conversion design from active to passive could be achieved.

It may well be noted that the word neither "active solar" nor "passive solar" was not exist in those days.

3. K SOLAR HOUSE

3. 1 Original façade design of K Solar House

The outside view of K Solar House is shown in Fig.5. It took a few years to design the solar house based on the experience at the solar energy project of MIT. This house with the total floor area of 145m^2 was completed in March 1972, one and half year before the oil crisis. The collector panels were installed in the middle of March 1973.

The main decision made for the façade design was to take the south vertical surface for the collector, because the total amount of solar radiation during the winter months on the south vertical surface was found only 10% less than that on the tilted surface of the most optimum tilt angle. This could allow for easier house plan.

Since the optimum tilt angle for solar collector of domestic hot water supply was about 45 degrees for the latitude of 35 degrees, where this house is located, the collector for the domestic hot water supply was determined to be installed afterwards.

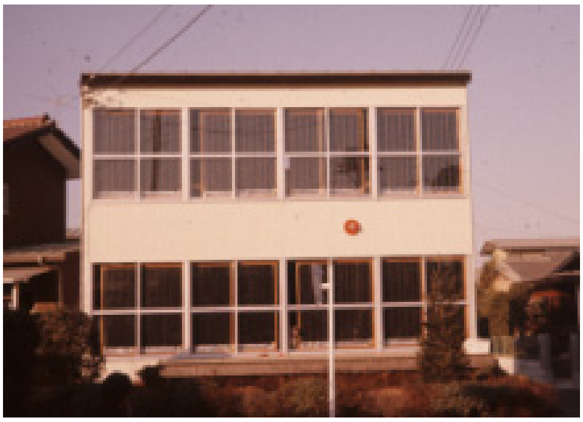

Figure 5: South side view of original K Solar House

Another feature of this façade design was to take direct solar heat gain from the south opening in the daytime of winter when the sliding collector panels were partially opened as shown in Fig.6 as well as in Fig.5. Because of the enough sunlight from these small openings the rooms inside were blight enough. On sunny days in winter no heating was necessary owing to the stored heat in the concrete floor kept warming by panel heating during the preceding night.

As seen in these photographs, the opened areas look blacker than the black-painted collector surface. This means passive direct solar heat gain is more effective in collecting solar energy.

Figure 6: Collector of sliding doors partially opened (left) and inside view of them closed, where connecting rubber hoses can be seen (right)

The right hand side picture of Fig.6 shows the rubber hoses connecting the inlet of collector panels to the header below as well as to the collector on the above floor. These flexible hoses allow for the doors to be slid sideways to open in the sunny daytime and to shut during the night when the collector panels function as insulated panels.

However, these ugly looking hoses obstruct the curtains to be drawn and have been disliked by all family members. This was another reason why the remodelling project of the house was started.

3.1 Solar space heating system

The remodelling had to be made because a large amount of scale had been produced inside of the iron pipes in the collector loop for the 33 years of operation, though the copper tubes in the collector remained clean and could have been used more.

Figure 7 shows the system diagram of the solar space heating and domestic hot water heating system.

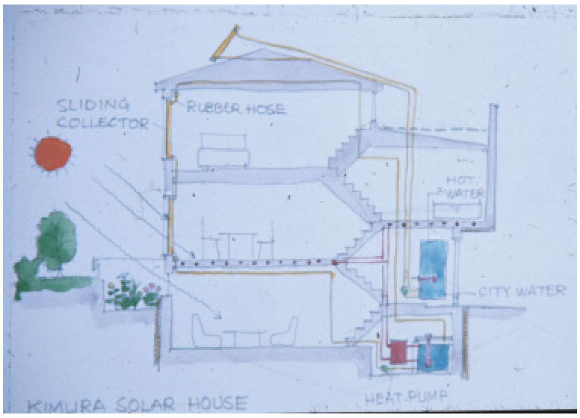

Figure 7: Solar heating system

The solar energy collected by the collector panels of 24 m^2 in total is brought into the solar tank of 1 m^3 made of concrete in the basement. The water-to-water heat pump of 1.5kW takes the solar water out of the tank to warm up and to supply the warm water into the pipes embedded in the concrete floor. This allows for the panel heating to the spaces above and below.

This operation is performed during the night, thus storing solar energy in the concrete slab. In the early morning the water temperature in the storage tank goes down to as low as 4 degrees C so that solar collection will be made with higher efficiency on next day.

Figure 8: Solar water heaters on the roof

The life expectancy of this small size heat pump was regarded around less than 10 years. But this heat pump has been used for more than 30 years, being used only for winter months. As the time passes, the performance has been gradually degraded and replacement had to be considered.

Solar domestic water supply was originally made by forced circulation system with an array of flat plate collectors of $8m^2$ in total connected to the heat exchanger within 380 litre water tank with a built in electric heater as shown in Fig. 7.

Later it was replaced by passive type of solar water heater placed on the roof from which solar water was topped up by another 380 litre water tank with built in electric heater connected in series as barely shown on the roof of Fig.8.

3.3 Renovation project of K House

After 33 years have passed, renovation was planned in 2005 with the main part of façade design. The collector panels were determined to be removed, but wooden doors themselves were kept to be reused with plywood face board instead of collector plate and insulation replaced. Aluminium sashes were reused with panes of glass replaced by low emissivity coated glass. Thus, the function of insulation during the winter night remains the same.

Out of 8 pairs of the original collector panels mounted sliding doors, 2 pairs were replaced by glass block walls of 1.8m wide and 1.8m high each of the first floor as shown in Fig. 9.

Figure 9: South view after conversion

Figure 10: Laying work of glass block; finishing of joints from outside (left) and view from inside with allocating steel bars (right)

Workers were carefully laying many pieces of glass block with reinforcement steel bars in between as shown in Fig.10.

Glass block itself has mortar joints on top and bottom as well as right and left so that it can function just as overhangs and side fins of egg crate type of louvers to intercept direct solar radiation and yet to allow diffuse light into interior spaces. Of course it has air space between two thick glass faces with some thermal insulation characteristics.

Photovoltaic panels of 2.25kW are installed on the roof in 2003 to assist electricity requirements of the all electric house. A new floor heating system using air source heat pump was installed with the prefabricated panels with polyethylene tubes backed up by insulation to replace the old system, whose copper pipes embedded in the concrete slab seemed to be deteriorated.

4. DISCUSSION

The case of MIT Solar House IV seems quite straightforward as it was an experimental house lived by the family and the budget of the solar energy project could not afford to continue to maintain the house.

The case of K Solar House may be identified as a representative of the old system that had to be replaced after 33 years to make a better performance in accordance with the new energy rating plans of electric company. Even ordinary houses would have been reconstructed after lived by family because of a change in occupants.

How to make the façade design maintaining or improving the energy performance and yet giving an impressive appearance as a solar house is quite difficult and therefore quite interesting in comparison with the case of designing a new solar house.

5. CONCLUSION

Conversion design of solar house from active to passive is presented with the two examples that the author experienced and the following conclusions may be drawn.

1. It is of primary importance to try to maximise the energy performance considering aesthetics in the façade design of a solar house.
2. The façade having any kind of moving parts, like water flows, would eventually terminate in use, while passive solar features would remain longer.
3. Passive solar system would not be able to suffice the occupants' needs fully and some kind of auxiliary energy systems would be necessary.

REFERENCES

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APPENDIX

Table 1: Collector efficiency of MIT Solar House IV

Period	ρ_u(%)*	ρ_c(%)*	ρ_o(%)*
Oct.1958-Apr.1959	68.8	40.9	28.1
Oct.1959-Apr.1960	76.2	43.9	33.4
Oct.1960-Apr.1961	79.3	39.8	31.6
Jul.1959-Jun.1960	62.1	42.0	26.1
Jul.1960-Jun.1961	68.5	37.7	25.8

*ρ_u = total solar radiation while pump operating / total solar radiation
ρ_c= collection / total solar radiation while pump operating
ρ_o = collection / total solar radiation

Table 2: Percentage Solar of periodical and annual total energy requirements of MIT Solar House IV

Period	space heating (%)	DHW heating (%)	overall (%)
Oct.1958-Apr.1959	30.1	74.3	34.5
Oct.1959-Apr.1960	46.3	57.4	48.2
Oct.1960-Apr.1961	57.3	54.7	56.8
Jul.1959-Jun.1960	48.2	70.9	53.1
Jul.1960-Jun.1961	58.2	67.4	60.8

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