SUDee2018 Workshop

Sustainable House Development in Japan
– From Vernacular to Passive Solar, to Zero Energy House

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ABSTRACT Overview of solar house development in Japan – from vernacular to passive solar, to zero energy house is described with a focus to sustainable features of various solar houses. Japanese vernacular houses are basically climate oriented as seen in thatched roof houses and open style houses. After a brief review of active solar houses, a significant importance of various sustainable features of passive solar houses is stressed with different examples towards a modern development of zero energy houses.

1. Introduction

Climate of Japan

Japanese archipelago ranges from cold to subtropical areas.

In central mild areas, rainy season starts in the second week of June and continues for more than one month.

In the middle of winter lots of snow falls in the north facing Japan Sea, while lots of sunshine in the south facing Pacific Ocean.

Summer is hot and humid except in Hokkaido. Most parts of Japan belong to seasonally hot-humid region.

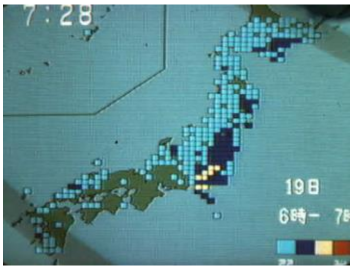

Fig. 1 Weather forecast for Japanese archipelago (JMA)[1)]

Fig. 2 Ancient Tateana house with thatched roof

Fig. 3 Open style house in Iso Park, Kagoshima

2. Vernacular Houses

2.1 Japanese Vernacular Houses have two Basic Types

(1) Thatched Roof House of Tateana Built 竪穴造 2000-3000 years ago with dark interior

(2) Open Style House of Shinden Built 寝殿造 after 1000AD with bright interior.

(3) Basic Principle in house design: Deep eaves, Natural ventilation

Fig. 4 Yucatan house

2.2 Thatched Roof House [1]

Thatched roofs soak rain water to be evaporated by strong solar radiation afterwards, which is called evaporative cooling. They are 40-60 cm thick to be a good thermal insulation. When the moisture is released, the surface temperature is lowered by evaporation. This principle is the same as Yucatan house in hot and humid Yucatan peninsula of Mexico.

2.3 Open style house

Open style house invites a lot of natural ventilation to give thermal comfort from nice breeze against hot and humid conditions outside. This is called

Fig. 5 Chiran house of open style

ventilative cooling or adiabatic cooling. Moisture is absorbed by straw mat floor and clay walls and board ceiling, which then may be cooled by evaporation. Thus, the mean radiant temperature of the interior space is 1-2 degree C lower than room air temperature. Nice breeze comes in though garden in hot and humid summer.

Fig. 6 Hakogi heritage house in Kobe

2.4 Hakogi Heritage House as the oldest existing house preserved in Japan.[2],[3]

The main house with a thatched roof on the right built 600 years ago is quite cool in summer just like an ancient house.

The attached house on the left built 300 years ago and nice breeze can come through the inside spaces just like open style house. Wooden board ceiling, clay wall, paper screen and straw mat floor in different characteristics of moisture regulation.

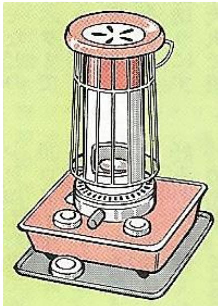

Fig. 7 Fireplace of Sonehara House, Azumno (left) Kerosene oil heater (right)

2.5 Construction components with passive characteristics

Thatched roofs soak rain water to be evaporated by strong solar radiation afterwards, which is called evaporative cooling. They are 40-60 cm thick to be a good thermal insulation.

2.6 Soil floor gives large thermal mass to keep cool the interior spaces. In rural houses a large area is occupied by soil surface backed by the stable temperature of underground. It absorbs and desorbs moisture depending on the humidity conditions. When the moisture is released, the surface temperature is lowered by evaporation.

Fig. 8 Clay walls of Hakogi house

Fig. 9 Interior of detached house, Hakogi house

2.7 Clay walls are extensively used as interior finish. Like soil floor, clay walls tend to show lower temperature than room air temperature.

2.8 Moisture regulation by interior surfaces of detached house with straw mat floor. Wooden board ceiling, clay wall and paper screen so that different characteristics of moisture absorbing and desorbing.

Raised floor avoids moisture from ground.

Fig. 10 Tamugimata House, Tsuruoka

Fig. 11 Nishi House, Tsuwano

2.9 Combination of Both Types

- Tamugimata House

Upper floor has thatched roof. Lower floor is of open type. Thus, both merits are combined.

Another combined type - Nishi House built 100 years ago Large roof surface receives strong solar radiation so that the average amount of absorbed solar radiation can be less than flat roof.

Open type was inherited to modern age with passive solar characteristics.

Raised floor gives coolness to interior space with high crawl space to avoid moisture from ground. Strong solar radiation is invited during winter, while it is protected by deep eaves in summer.

2.10 Tiled Roof House 1500 – 1970

Since thatched roof is flammable, tiled roof has been widely used replacing thatched roof because of frequent occurrence of fire in urban districts. As the shape of roof tiles is curved and the minute air space between sheathing board and roof tile heated by solar radiation would be expelled to outside as well as evaporative cooling effect by the wet tiles soaking rain water.

Fig. 12 Tiled roof house
Photo by author

2.11 Quite Cold in Winter

In winter minimum temperature in Tokyo area is as low as 0℃. Before Oil Crisis in 1973. Japanese Houses had No Insulation for walls and ceilings. People enjoyed around traditional fireplace of charcoal burning. Kerosene oil heaters are widely used for heating living space only in the daytime.

Fig.13 Japanese traditional fireplace photo by author

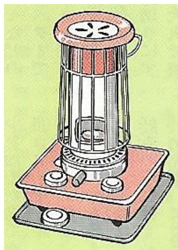

Fig.14 Kerosene stove Wikipedia

3. EnergyConservation Period 1970s – 1980s

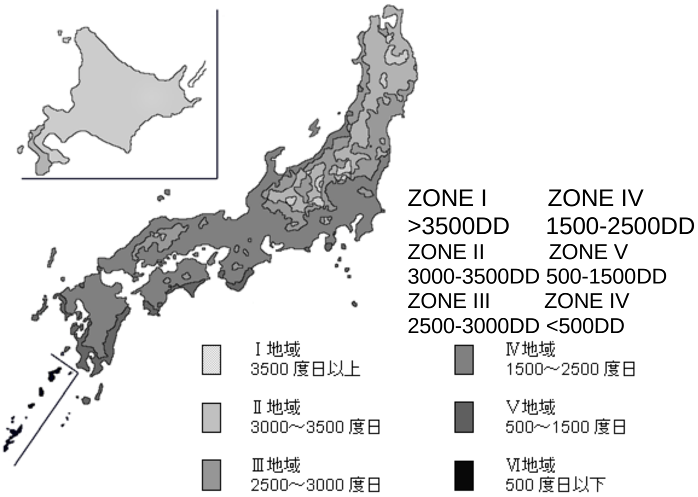

Fig. 15 Climatic zones of Japan for Building code of energy conservation

People were accustomed to wear heavy clothes in putting up with poor conditions regarding thermal comfort and indoor air quality.

Oil crisis in 1973 called for improving insulation and air tightness for residences, as most of Japanese houses had no insulation for walls and roofs tradition to build houses mainly for summer conditions.

Japanese government set up a new regulation standard and Building Codes which stated for 5 different climatic zones of Japan.

4. Various Attempts of Harnessing Solar Energy

4.1 Solar Water Heaters

A large number of solar water heaters of different types prevailed nationwide in Japan.

Fig.16 Solar water heater of gravity circulation type

4.2 Early Active Solar Heating Project

(1) MIT Solar House IV 1958-1961 [4]

Solar heat collector of tube-in-plate type, heat storage tank, auxiliary heat source, Solar heat supplied to living space together with auxiliary heat. PV system was not yet ready for practical use.

The author spent two years from 1960 at Solar Energy Project of MIT (Massachusetts Institute of

Technology) to build experimental and habitable solar house

(2) Yanagimachi Solar House 1959~

Mr. Yanagimachi used four heat pumps to collect solar heat from the roof mounted panel of aluminum roll bond, to supply heat to the radiant ceiling panel and to use for domestic hot water supply in his own unique solar house.

Fig.17 MIT Solar House IV

4.3 Solar Heating and Cooling in Japan's Sunshine Project

Solar cooling system developed with Sunshine Project started in 1974 by the Japanese Government. Absorption type of refrigerating machine was developed.

Solar collector of high temperature including evacuated tubular collector came into the market. Hirakata Solar House was built as a test house with solar cooling. Sseveral solar buildings were constructed for practical use and operated successfully from the technical point of view.

Fig.18 Hirakata Solar House with Solar Cooling

However, active solar cooling house turned out very expensive and most of solar cooling system for buildings did not work efficiently and had to be abandoned.

4.4 Solar Desiccant System

Solar regeneration by liquid desiccant was proposed as an alternative semi-passive cooling system

Mechanical desiccant system with wheel type of heat exchanger is working nowadays as promising.

5. Passive Solar Heating 1976~

5.1 Basic Features of Passive Solar Houses

After International Solar Energy Congress in 1975, a new movement of passive solar house rose among architects and building physicists against mechanical solar components and systems mostly proposed by engineers. Since 1976 passive solar conferences were held worldwide and passive solar heating flourished.

They classified important passive solar components into the followings:

Fig. 19 Direct solar gain absorbed by floor slab photo by author

(1) Direct solar heat gain falls on the heavy floor slab to store solar energy naturally.

(2) Thermal storage wall stands behind the glass pane with air space where the room air is introduced from the bottom hole of the wall and flows upward by natural convection to be introduced to the room space through the top hole in the wall so called Trombe Wall. Japanese Government subsidizes this system for houses.

(3) Natural convection process is interesting when solar energy collected at a lower place is delivered to the living space by natural convection when both places are connected by air flow route.

Fig. 20 Attached greenhouse photo by author

(4) Attached greenhouse to the living space acts as natural solar heat storage and often used very effectively.

(5) Roof pond absorbs solar radiation to be covered by insulated boards in winter during night and emits long wave radiation to the sky in summer night to reflect daytime solar radiation from the cover board in the daytime, presenting a unique idea to be applicable for both winter and summer.

Passive solar houses are represented by Kodama Solar House, Odeillo Solar House, Balcomb Solar House.

By definition, Passive solar house is the one in which building materials and components work as they collect heat, store heat and release heat.

Fig. 21 Kimura Solar House, Tokorozawa photo by author

5.2 Hybrid Solar Houses [5]

The solar components and systems so far developed were called active solar against passive solar. The author recognized the importance of both and designed Kimura Solar House and constructed it in 1972.

When the movable collector panels of tube-in-plate type installed in sliding doors partially open, direct solar heat gain comes in to interior spaces.

Fig. 22 Sagara Solar House, Inagi photo by author

The author designed several solar houses in collaboration with other architects and engineers. Among them Sagara Solar House completed in 1979 was a quite successful one with total floor area 120m^2, a large glass of direct solar gain, flat plate collector 24m^2, no auxiliary heat for space heating, heat storage tank for hot water, heat storage within underground soil, all electric house, to be resulted in annual electricity use 5MWh. [6]

Fig. 23 TEPCO Solar House of All electric house, Tokyo photo by author.

A passive solar house of TEPCO with heavy insulation, direct solar gain from 2 storeyed window, greenhouse, earth contact floor, rock bed storage was designed by a team led by the author in combination with heat pump system for domestic hot water, space heating and cooling and constructed in Tokyo with extensive mearsuring system for three years from 1983.

6. Passive Solar Cooling with cool heat sink (negative suns)[7]

Learning from vernacular architecture, evaporative cooling, ventilative cooling, earth contact floor, nocturnal radiation and night purge are found quite effective as passive solar cooling. evaporative cooling with grass covered roof, ventilative cooling, underground coolness or earth contact floor, vertical ventilation from basement to top opening, nocturnal radiation, night purge with cool outside air as represented by Okinaw house as shown in Fig. 24.

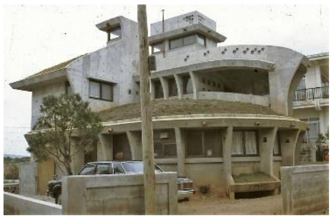

Fig. 24 Okinawa Solar House of Passive cooling. photo by author

5.1 Passive and Low Energy Architecture (PLEA)

Founded in Bermuda in 1982 led by Prof. Arthur Bowen. The author presented a paper on the experiment with thatched roof at this First PLEA Conference as shown in Fig. 25..

International PLEA conference being held annually in different places worldwide.

Most recent PLEA Conference was held in Edinburgh in 2017.

Next one 34th PLEA Conference will be held in Hong Kong 10-12 December 2018.

Fig. 25 Representative participants at First PLEA Conference in Brmuda 1982 Photo by autor

7. Toward Zero Energy House

6.1 Gradual Development of Photovoltaic System [8], [9]

Government support system started for residential use of PV system from 1994. Large-scale PV system made effective in 2000s with FIT (feed-in-tariff) process.

Fast spread of PV house has been seen in 2010s and the author presented some studies with PV integration into house design. [8]. [9] PV system is suitable to be combined with passive solar house toward Zero Energy House

6.2 Basic Requirements for Zero Energy House (ZEH)

Passive solar heating systems of different types are available.

Domestic hot water supplied by heat pump from outside air as heat source PV system mandatory for use of electricity in lighting, cooking and household appliances

6.3 Sustainable House Projects for Zero Energy House

Domestic hot water load can be minimized by solar water heater combined with CO_2 refrigerant type of heat pump. Electricity for lighting, cooking heaters, refrigerators and other electrical appliances can be supplied by photovoltaics. Space heating load can be reduced by heavy insulation and low-E double glazed windows.

Government subsidiary is being implemented.

Energy efficient houses tend to be inferior in aesthetical appearance. Sustainable houses of good design can be seen in recent years.

Application of vernacular technologies to modern architecture is an important issue [10], [11].

6.4 Life Cycle Carbon Minus House (LCCM House) [12]

This house is a demonstration house designed and built by the project in the Building Research Institute of Japanese government at Tsukuba City, north west suburb of Tokyo as a two storied detached house with low energy and photovoltaic systems so that generated energy on site can be equal or greater than consumed energy in the house. Principal architect is Professor Masao Koizumi.

Photo shows summer version (above), winter version (below).

Photovoltaic panels on the roof can be seen. A full height of south facing large glass window can invite winter solar radiation directly into living space through enclosed Engawa, buffer space. The venetian type of sun shades is provided on the entire south façade to control solar radiation effectively, for which simulation study was carried out to analyze life cycle energy taking acc

Fig. 26 LCCM House, BRI, Tsukuba
Above: Winter version
Below: Summer version
Principal architect: Masao Koizumi
Source: BRI 2014

Results of measurement under virtual occupancy for one week each of s seasons shows annual values of domestic energy use against photovoltaic power generation as follows.

Annual production of CO2: 899kg hot water, 27kg space cooling, 998kg space heating,172kg ventilation, 277kg lighting, 956kg appliances, 3781kg total.

Annual Reduction of CO2: 6585kg by photovoltaic energy.

Difference in CO2 emission: -2804kg / year, realizing a minus carbon house.

8. Conclusion

Overview of solar house development in Japan – from vernacular to passive solar, to zero energy house is described with a focus to sustainable features of various solar houses.

Traditional vernacular technologies are applicable to modern house design even to zero energy house design.

It is very important to try to reduce energy requirements as much as possible in the first place.

Phtovoltaics application is mandatory to make realize zero energy house.

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