# STUDY ON INDOOR THERMAL ENVIRONMENT AND SENSITIVITY ANALYSIS OF A PASSIVE METHOD WITH SOLAR HEAT UTILIZATION HOUSE

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## ABSTRACT

In this paper, we clarified the effectiveness of the heating load reduction, based on measurement results by calculating the amount of heat accumulated by passive techniques. The accuracy of the numerical simulation was confirmed using the actual measurement data. Then we clarified the impact of some passive method such as window area, window specification, double skin and trombe wall. In recent years, the demand for highly efficient insulation and airtightness in a detached house has steadily been increasing. In addition, the utilization of solar heat attracts attention as an efficient method to reduce the conventional heating load. In our project, we proposed a method, which collects and provides solar heat using a passive heating technique in the central air conditioning and circulation system. We set 6 buildings in 6 areas for verification of the heating load reduction effect by utilization of solar heat. These 6 test houses were designed based on a numerical simulation. In addition, it is necessary to mention that these houses have two characteristics: first, the heat exchangers were introduced; second, the air conditioning system for the entire house, including the bottom floor, consisted of only a common heat pump air conditioner. For each house, external temperatures, room temperature and humidity, and the energy consumption used to run these houses were measured starting February, 2015.

## KEYWORDS

Numerical simulation, Solar heat utilization, Heat load, Passive method, Air circulation

## INTRODUCTION

Reduction of energy for heating and hot water supply is required because these account for about 60 percent of energy use in a whole house. We develop a new air-conditioning system with a combination of passive and active methods, and propose effective operations. The purpose of this study is to reduce more than 50 percent heating and hot water supply energy consumption by utilization of solar heat. We chose 6 regions of the different climate characteristics and verified by

measurement of 6 test houses, to construct the system regardless of the region. From July 2014 to January 2015 we developed the system, studied passive and active methods, planned and constructed the test houses. Then, from February 2015, started measurement of various data. The purpose on this research is to verify our systems work effectively in each regions. By analysis of the data obtained and the measurement and results of numerical simulations we clarify the performance of these test houses, the effect of heating and hot water supply energy consumption reduction and the efficient operation of systems.

## SOLAR UTILIZATION HOUSE

We describe outlines of test houses, passive-active heating method and air circulation systems. The Passive house which we proposed has systems for solar heat collection and air circulation with central air conditioning. The heat which is collected by the solar heat system and the air from the central air conditioning unit is circulated throughout the whole building by the air circulation system. Figure 1 shows image of the air circulation system. We constructed a small room with insulation for the air conditioning and circulation units in the attic or elsewhere, and installed a heat pump

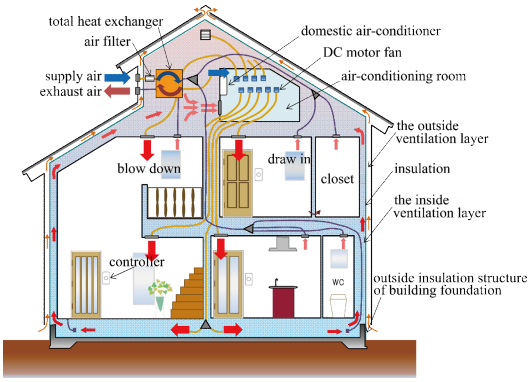



*Figure 1. Air circulation system*

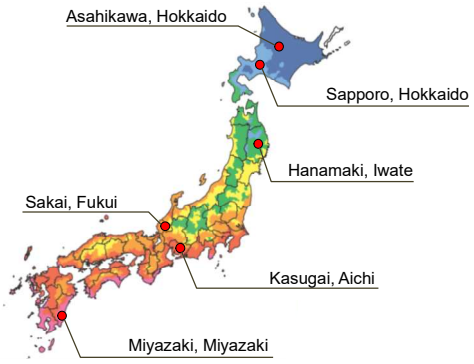



*Figure 2. Location of test houses in 6 regions*

*Table 1. Architectural outlines*

| | | Hokkaido (Asahikawa) | Hokkaido (Sapporo) | Iwate | Fukui | Aichi | Miyazaki |
|---|---|---|---|---|---|---|---|
| Climate conditions* | Area classification | 1 | 2 | 3 | 5 | 6 | 7 |
| | Amount of solar radiation division in winter | H2 | H2 | H3 | H1 | H5 | H3 |
| | Amount of solar radiation division a year | A2 | A2 | A2 | A3 | A4 | A4 |
| Building | Total floor areas [㎡] | 121.3 | 118.7 | 127.02 | 149.4 | 118.4 | 115.5 |
| | Double skin areas<br>Trombe wall areas<br>Direct solar heat gain areas<br>**Total [㎡]** | 5.4<br>9.0<br>15.2<br>**29.6** | 11.0<br>0.0<br>13.9<br>**24.9** | 6.5<br>2.6<br>16.3<br>**25.4** | 13.5<br>3.0<br>6.3<br>**22.8** | 11.6<br>0.0<br>8.4<br>**20.0** | 9.0<br>0.0<br>8.1<br>**17.1** |
| | Total of envelope areas [㎡] | 320.0 | 344.0 | 393.4 | 461.1 | 360.5 | 350.9 |
| | Q Valie<br>(Standard) | 1.26<br>(1.60) | 0.93<br>(1.90) | 1.01<br>(2.40) | 1.12<br>(2.70) | 1.07<br>(2.70) | 1.08<br>(2.70) |
| | UA Value<br>(Standard) | 0.36<br>(0.46) | 0.21<br>(0.46) | 0.27<br>(0.56) | 0.28<br>(0.84) | 0.27<br>(0.87) | 0.26<br>(0.87) |
| | ηA Value<br>(Standard) | 2.56<br>(-) | 2.07<br>(-) | 2.02<br>(-) | 2.61<br>(3.0) | 2.13<br>(2.8) | 1.72<br>(2.7) |
| Hot water supply system | Panel areas [㎡] | 16.0 | 16.0 | 20.4 | 20.0 | 12.0 | 16.0 |
| | Storage tank capacity [L] | 460 | 460 | 370x2 | 370x2 | 300x2 | 370x2 |

*The Japanese energy conservation standard 2013

Asahikawa, Hokkaido

Sapporo, Hokkaido

Hanamaki, Iwate

Sakai, Fukui

Kasugai, Aichi

Miyazaki, Miyazaki

*Figure 3. Exterior photos of test houses*

air conditioner. Air was forth ventilated through the total heat exchanger and the air filter. The air was send by ducts to each room after temperature and humidity conditioning. Using one heat pump air conditioner this system could central air condition and maintain temperature and humidity environment uniformly by air circulation. We introduced 3 types of passive heating methods and 1 active heating method, are introduced : passive methods are direct solar heat gain (large window), double skin and trombe wall; the active method is using the surplus heat in the solar hot water system as an energy source for heating by fun coil unit. Air circulation systems for double skins and trombe walls are independently and automatically controlled depending on the air temperature. For example, it can use warm air only while the air temperature is higher than the thermostats setting. A concern of passive methods is overheating because controlling the amount of solar radiation is difficult, however this problem can be solved through the air circulation system. 6 test houses were constructed in 6 regions with different climate characteristics, Asahikawa Hokkaido, Sapporo Hokkaido, Hanamaki Iwate, Sakai Fukui, Kasugai Aichi and Miyazaki Miyazaki. Figure 2 shows location of test houses with area classification of the Japanese energy conservation standard 2013. Table 1 shows architectural outline of test houses, Figure 3 shows exterior photos, Each test house is planned with a south side orientation for solar heat gain, direct solar heat gain and double skins are also included. Furthermore, the 3 test houses in Asahikawa, Iwate and Fukui have trombe walls. All test houses have deep eaves to avoid increasing the cooling load in summer. These test houses were designed based on the numerical simulation using “THERB for HAM”.

## STUDY OF HEAT LOAD REDUCTION EFFECT

Simulation Software of the Hygrothermal Environment of the Residental Buildings

"THERB" is dynamic simulation software which can estimate temperature, humidity, sensory index, and heating/cooling load for multiple zone buildings and wall assemblies. The heat and moisture transfer models used in THERB such as conduction, convection, radiation and ventilation (or air leakage) are based upon the detailed phenomena describing actual building physics, and can be applied to all forms of building design, structure or occupant schedules, etc. All the phenomena are calculated without simplification of the heat and moisture transfer principles of any building component or element.

The calculation conditions are as below. 3 cases for calculation are examined: in case one "energy conservation standard" (case 1) has equivalent performance to the Japanese energy conservation standard 2013; in the second case "air circulation" (case 2) added air circulation system to case 1; in the third case "solar heat utilization" (case 3) added solar heat utilization to case 2. Here, heating load, cooling load and hot water supply energy are examined by numerical simulation. The standard weather data in each region was used for input data, where the set-point for air conditioning temperature is 20/27 (heating/cooling) degrees with natural humidity and constant indoor ventilation 0.5 times/hour all day. In case 1 the space conditioning for each room is intermittent confirming to the schedule a family of 4; rooms are conditioned only when in active use. In case 2 and 3 space conditioning is active all day for the whole house. Figure 4 shows a change in time (representing three days) for room temperature and heating load for case 2 and 3 in winter for Miyazaki (Top: Case 2 Bottom: Case3). Figure 5 show the sum of heat load throughout period and case. In comparing

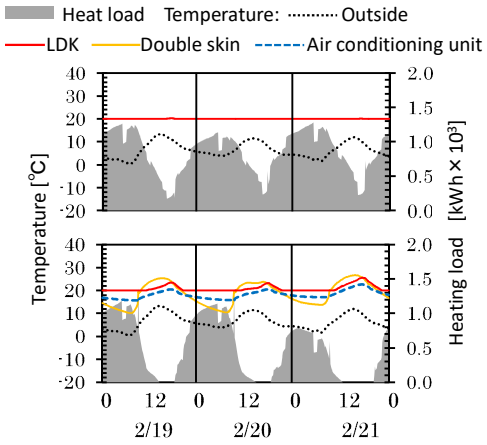



*Figure 4. Temperature and heating load for case 2 and 3 (Miyazaki)*

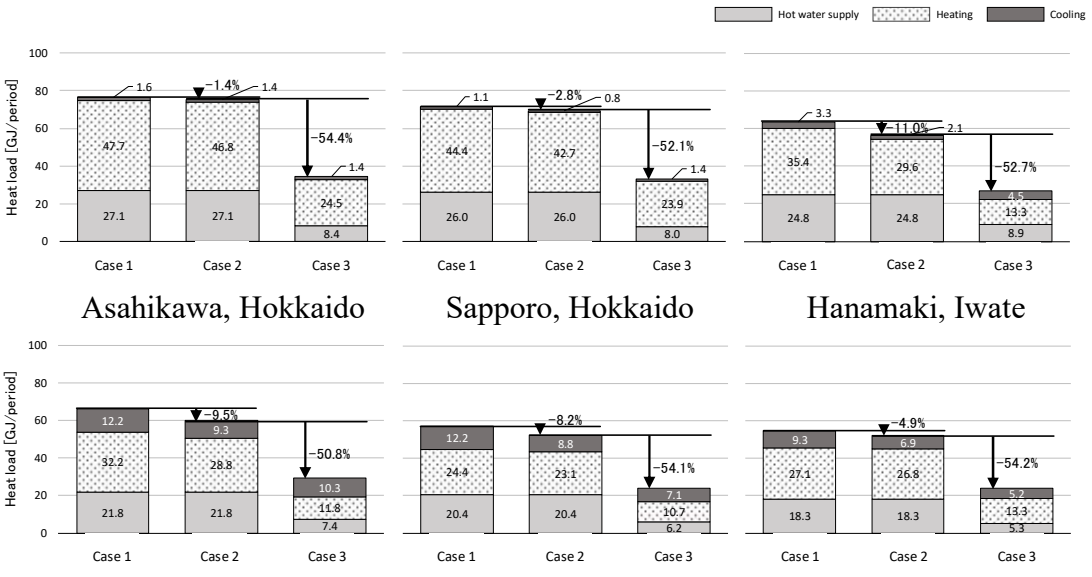



*Figure 5. Sum of heat load in winter*

case 2 and 3, heating load is reduced in all areas because temperature of double skins rise during the daytime by absorbing solar radiation, and the temperature of the air conditioning unit and LDK (living, dining and kitchen) area rises too. Due to this, it is clear that the air heated by solar radiation in the double skins contributed to heating load reduction. It has possibility that reduction of heat load become more over, depending on the hours, the temperature of air conditioning unit has exceeds setting temperature. Comparing case 2 and 3 see Figure 5, the heat load reduction is -54.4% in Asahikawa, -52.1% in Sapporo, -52.7% in Iwate, -50.8% in Fukui, -54.1% in Aichi and -54.2% in Miyazaki. The efficiency of energy conservation calculated using numerical simulation was over 50% at each location.

## EFFECTIVENESS OF HEAT LOAD REDUCTION

Figure 6 shows the thermal energy collection, daily integrated value of heat load (Top) and the quantity of hot water heat storage provided by the solar heating system (Bottom) for obtained at the Fukui location. Similar data were obtained at the 5 remaining locations. In particular, on days with a large quantity of sunlight, the amount of thermal energy collection is more than the heating load required for the day. In addition to that, on days with a little sunlight the increase in heating load is

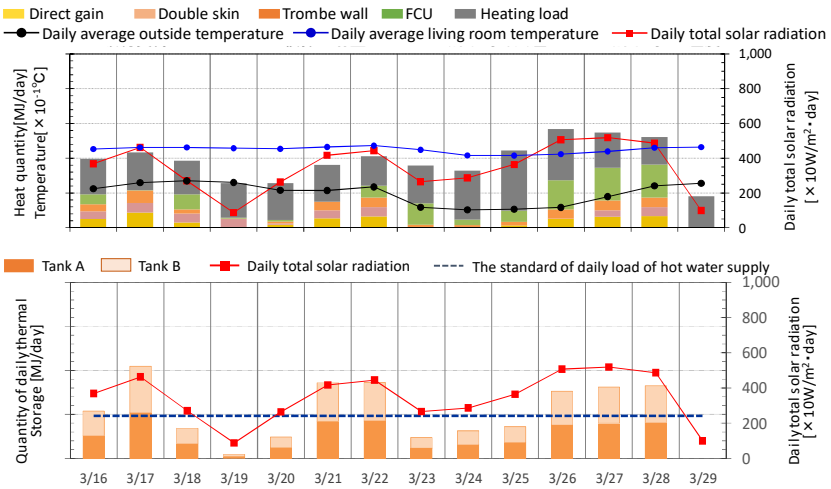
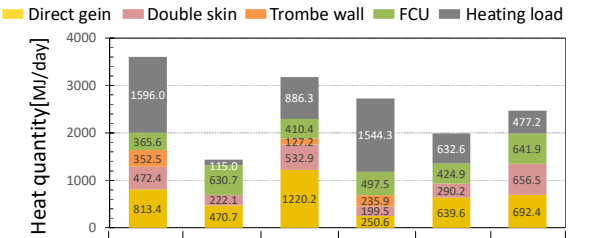



*Figure 6. Thermal energy collection, daily integrated value and quantity of hot water heat storage (Fukui)*




| | Asahikawa 3/29-4/11 | Sapporo 3/25-4/7 | Iwate 3/16-3/29 | Fukui 3/16-3/29 | Aichi 3/17-3/30 | Miyazaki 3/8-3/21 |
|---|---|---|---|---|---|---|
| Heating load | 44.3 | 8.0 | 27.9 | 56.6 | 31.8 | 19.3 |
| Solar heat utilization | 55.7 | 92.0 | 72.1 | 43.4 | 68.2 | 80.7 |

[%]

*Figure 7. Thermal energy collection for 14days*

suppressed because of heat storage throughout the structure. We also confirmed that sufficient heat was released by the fan coil unit and verified that it reduces heating load. In all houses, it is confirmed that this system can serve all the standard hot water supply load per household a day (It is assumed a standard family consisted of four persons) only from hot water by solar heat. Figure 7 shows that the thermal energy collection for 14days for each houses, and it is confirms the solar heat utilization in this system. In addition, the quantity of thermal energy accumulated for 14 days using solar heat exceeded the heating load at 5 locations (Asahikawa, Sapporo, Iwate, Aichi and Miyazaki).

## ARITHMETIC PRECISION OF SIMULATION SOFTWARE

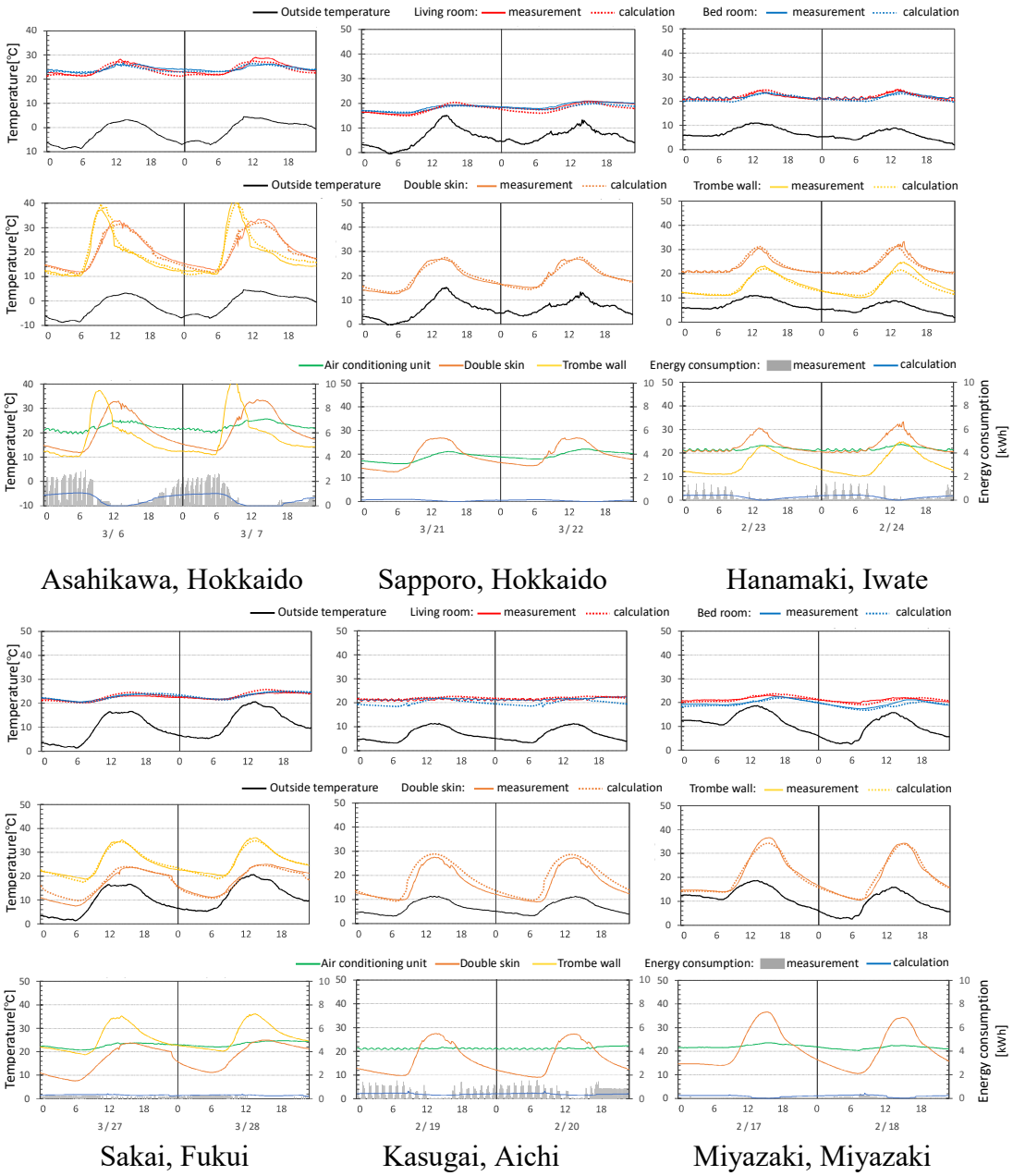



*Figure 8. Measured and calculated values*

The accuracy of THERB is verified by comparing the measured and calculated values for the house. Figure 8 shows the measured and calculated values (Top: The temperature in the living room, master bed room and outside, Middle: The temperature in the double skin, trombe wall and outside, Bottom: The energy consumption by a heat pump air conditioner and the temperature in the Air condition-circulation unit, double skin and trombe wall). The value of the calculation essentially agrees with the measured value.

## PARAMETRIC ANALYSIS OF HEAT LOAD

6 test houses were equipped with some passive method for solar heat gain such as large and high specification window, double skin and trombe wall. The impact for heat load by passive methods combined with air circulation system can be evaluated using numerical simulation. The heat load in winter (January and February) was verified by parametric analysis. The parameters for passive methods are listed in Table 2 (for details of the test houses refers to Table 1). The weather data used in calculation was an Expanded AMeDAS, The houses were ventilated all day with half of the air volume exchanged every hour (0.5 times per hour). There was no inner heating and moisture generation. The results of parametric analysis are as follows. Increase of window area from 50 to 80 percent: heat load reduction of -1.3 - -4.0% in Asahikawa, -1.1 - -3.3% in Fukui and -5.5 - -16.4% in Miyazaki. Comparing window specification double low-e glazing, triple low-e glazing and vacuum multiple glazing, the heat load reduction is -1.8 - -6.0% in Asahikawa, -2.2 - -8.4% in Fukui and -6.0 - -12.1% in Miyazaki. Comparing without or with trombe wall, the heat load reduction is -1.3% in Asahikawa and -3.9% in Fukui.

*Table 2. Parameters and these values*

| | parameter | value |
|---|---|---|
| 1 | window area [%] | 50, 60, 70, 80 |
| 2 | window specification | double low-e glazing, triple low-e glazing, vacuum multiple glazing |
| 4 | trombe wall | with / without |

## RESULTS

In this paper, we clarified the effectiveness of the heating load reduction, based on measurement results by calculating the amount of heat accumulated by passive techniques. The accuracy of the numerical simulation was confirmed using the actual measurement data. Then the impact of air circulation, window area, window specification, double skin and trombe wall was analyzed. The results of the simulation and measurement led to the following conclusions:

- The efficiency of energy conservation calculated using numerical simulation was over 50% at each location.
- The quantity of thermal energy accumulated for 14 days using solar heat exceeded the heating load at 5 locations (Asahikawa, Sapporo, Iwate, Aichi and Miyazaki).
- The results of numerical simulation agreed with the empirical values.

## ACKNOWLEDGMENT

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