Development of Energy-Efficient Houses Equipped with Central Duct Space-Conditioning System and Solar Collector

Myonghyang Lee [1]*, Akihito Ozaki [1], Mikako Maeta [1]

[1] Department of Environmental Sciences, Graduate School of Life and Environmental Sciences, Kyoto Prefectural University, Kyoto, Japan

ABSTRACT

In recent years, due to the enforcement of the "Energy Conservation Standard for Housing" and the "Housing Performance Indication Law" in Japan, insulation and air-tightness have been all the more emphasized and have drastically advanced, and a duct central space conditioning system has been often introduced. This system is thought of as a useful measure to various problems in living environment, such as heat shock and sick house syndrome. However, the current central space conditioning system usually has a concern with an increase of energy consumption compared to individual space conditioning. Therefore, for the spread of this system, evaluation of the system performance is necessary.

In this study, the combinational effect of the central duct space conditioning system equipped with personal circulation fans, which blow warm or dry cool air into each room from the air-conditioned space by the direct current fans, and the solar collector such as a double-skin façade and direct gain on energy saving is examined by numerical simulation utilizing the simulation software 'THERB'. This system enables individual control of blast volume into each room and distribution of collecting solar heat to whole building. Calculation results are verified through the comparison with monitoring results of the actual house. Then it is clarified that this system is superior to the individual space conditioning system equipped with each room on energy saving and can even out the temperature and humidity in whole buildings.

KEYWORDS

The Central Duct Space Conditioning System, Insulation and Airtight House, Energy Saving, Solar Collector, Double-skin Façade, Direct gain

INTRODUCTION

In recent years, energy conservation measures are needed to more promoting in the residential and architecture fields for realizing a low-carbon society. Therefore, insulation and airtight houses in Japan tend to increase year after year. These high performance houses are often adopted the central duct space conditioning system (CDSCS) that are unified the ventilation and the cooling and heating system.

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* s811732001@kpu.ac.jp

However, energy consumption of the CDSCS increases much more than an individual space conditioning system with each room. So, this system is required further energy conservation. The evaluation of the entire system, such as comfortable thermal environment and high-efficiency of air-conditioning equipment, is needed to spread this system.

In this study, the central duct space conditioning system which is adopted the direct current fans designed to energy saving, individual control of blast volume into each room and distribution system of collecting solar heat is proposed. The numerical simulation utilizing THERB clarifies about the indoor hygrothermal environment and energy saving performance of a detached house equipped with this system. Furthermore, the effect of solar heat utilization, such as double-skin façade and direct gain, is examined

OUTLINE OF DUCT CENTRAL AIR-CONDITIONING SYSTEM

Figure 1 illustrates a diagram of the central duct space conditioning system (CDSCS) for whole building. The heat pump type air conditioner for home use is equipped exclusively within the air-conditioning control space in the attic. Warm or dry cool air is supplied into each room from this space by the direct current fans designed to energy saving, low pressure loss and high blast volume, and then the air of each room is returned to the air-conditioning control space. This system can reduce temperature distribution among rooms because the temperature difference between charge air and rooms are kept small caused by high blast volume. The direct current fans which are installed in individual ducts automatically or manually enable variable air volume with low power consumption. A total heat exchanger is also adopted to this system as a ventilation fan for all day so that it decreases outdoor air load by ventilation for

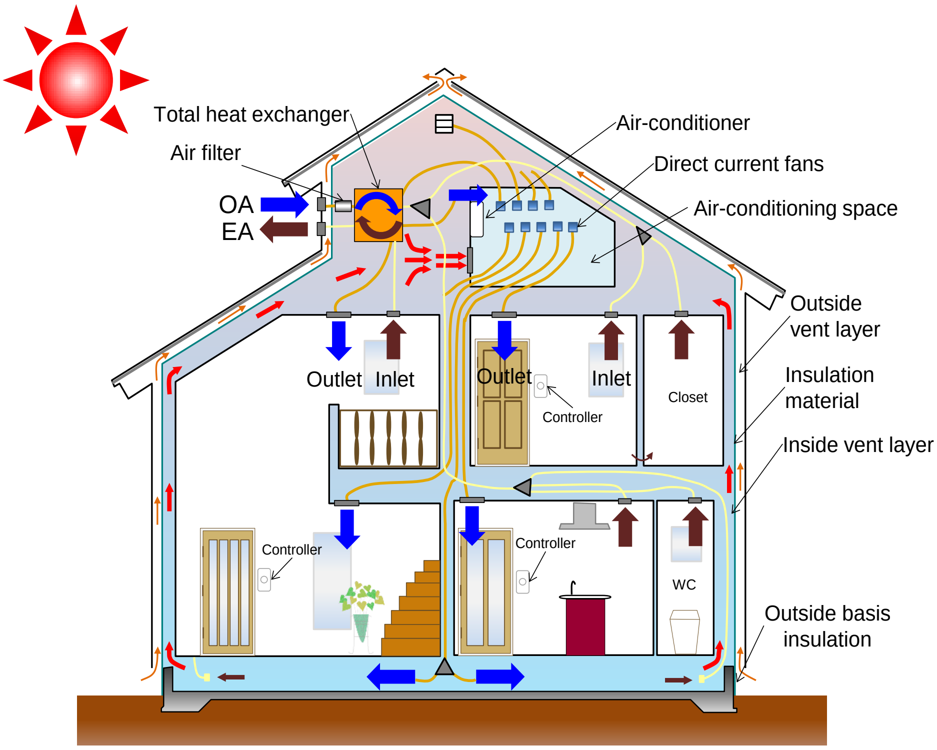


Figure 1. *Central duct space-conditioning system*

whole building space. Furthermore, it is possible to reduce heating load by using solar heat collected by the heat collecting systems such as a double-skin façade and direct gain. The collecting solar heat is distributed by the medium of the central duct space-conditioning system.

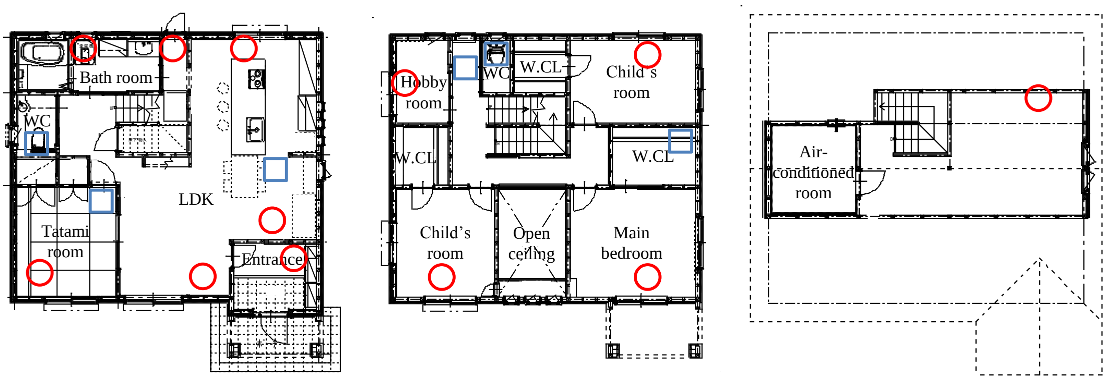
THEORITICAL FEATURE OF SIMULATION SOFTWARE ‘THERB’

A Heat, Air and Moisture (HAM) simulation software called THERB for HAM has been developed for the purpose of estimating the hygrothermal environment within buildings. This software has complete HAM features including principles of moisture transfer within walls and can estimate temperature, humidity, sensory index, and heating/cooling load for multiple zone buildings and wall assemblies (Ozaki et al. 2006). 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. All the phenomena are calculated without simplification of the heat and moisture transfer principles of any building component or element.

The followings are the prominent features of THERB. The conductive heat and moisture transfer are mathematized by Water Potential which makes it possible to combine moisture transfer with heat transfer perfectly as thermodynamic system, and take into account internal energy and external forces such as pressure increment and gravity (Ozaki et al. 2001). The convective heat transfer coefficients are recalculated at every time step on all surfaces of the exterior, interior and cavities of buildings using dimensionless equations which are derived from either the profile method for boundary layer or defined from the experimental findings according to natural or forced convection (Fujii et al. 1972, Ozaki et al. 1990). Then the convective moisture transfer coefficients on all surfaces are calculated on the basis of the analogy between heat and mass transfer. Incident solar radiation on the exterior and into the interior of buildings is calculated for all parts of the building in all directions using accurate geometric calculations of shaded and unshaded portions of the building by considering the influence of overhangs and side walls. The multiplex reflection of both transmitted direct and diffuse solar radiation among interior surfaces including re-transmission of solar radiation from the inside to the outside through the windows is calculated by using the short-wave absorption coefficients. Mutual radiation among interior surfaces is also calculated by using the long-wave absorption coefficients.

CALCULATION ACCURACY

The accuracy of THERB is verified by comparing the calculated and measured values. Figure 2 illustrates the first and second floor plan of the monitoring house in which the central duct space conditioning system is installed. The total volume of air circulation among the air-conditioning control space and whole building is 2,500m^3/h. Ventilation amount by way of the total heat exchanger is 0.5 times/h. Table 1 and 2 show building specifications and calculation conditions. Internal heat and moisture generation are assumed general conditions that follow the common Japanese lifestyle. Local weather observation data are used for calculation.



(1) The first floor(2) The second floor (3) Attic space

Figure 2. *Plan*

Table 1. *Building specifications*

	Wall assemblies		Heat conductance
Roof	Cypress Polystyrene form Plywood Asphalt roofing Air space Heat Shield sheet Roofing tile	12mm 80mm 12mm – 12mm 4mm 30mm	0.35 [W/m^{2}· K]
Exterior wall	Plaster board Vent layer Air space Wood Polystyrene form Vent layer Moisture-proof and Permeability sheet Siding	9mm 16mm 120mm 9mm 50mm 20mm – 10mm	0.56 [W/m^{2}· K]
Exterior wall (under the floor)	Concrete Polystyrene form Mortar	210mm 50mm 16mm	0.66 [W/m^{2}· K]
window	Double glazing	3mm+Air space12mm+3mm	0.34 [W/m^{2}· K]

Table 2. *Calculation conditions*

Simulation software	THERB for HAM
Building specifications	Timber construction
Weather data	Observation data
Location	Gihu in Japan
Heat and moisture generation	Following common Japanese life style
Indoor condition	without heating and cooling
Calculation term	Oct. 11 to Oct. 13

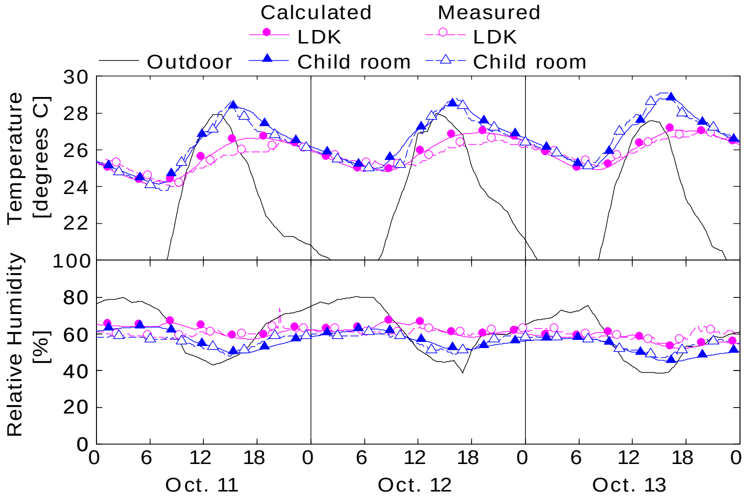


Figure 3. *Comparison of calculated and measured values*

Figure 3 shows the calculation and monitoring results of the indoor temperature and humidity (the first floor living room and the second floor child room) on October 11 to 13 in mild climate. Air-conditioning and opening and closing of windows are not performed in this term in obedience to occupant behavior. The calculation results agree well with the monitoring results. The difference of both results of temperature and relative humidity are 0.8 degrees C and 5.0% at a maximum.

THE EFFECT OF SOLAR HEAT UTILIZATION

Double-Skin Façade and Direct Gain

Figure 4 and Figure 5 illustrate the system of double-skin façade and direct gain to use solar heat. The double-skin façade is composed of exterior glazing, air cavity, window shade (solar collector), air cavity and interior glazing in order of position from outdoor. The air is circulated between the air-conditioning control space and air cavities to decrease heating load in winter when the temperature of air cavities increases depending on solar heat. Then the warm air of the air-conditioning control

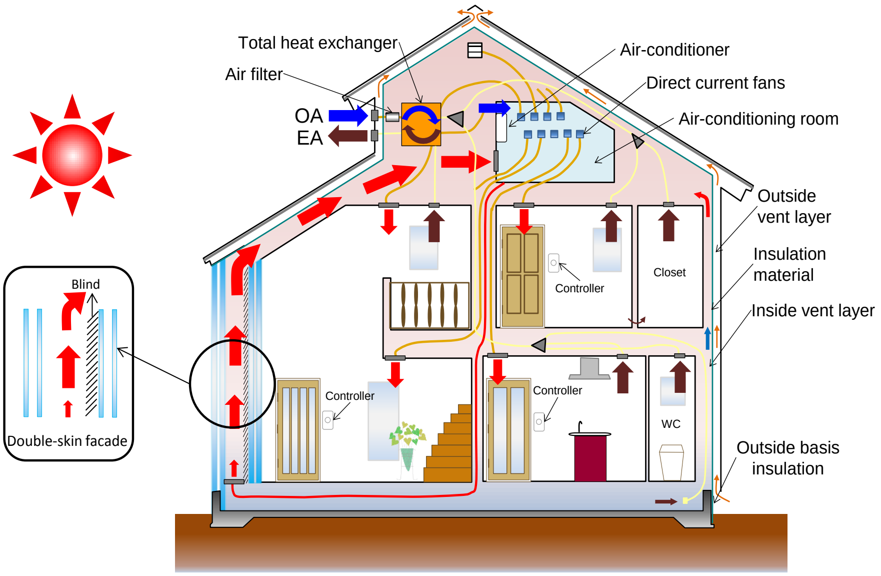


Figure 4. *Solar collection by the double-skin façade*

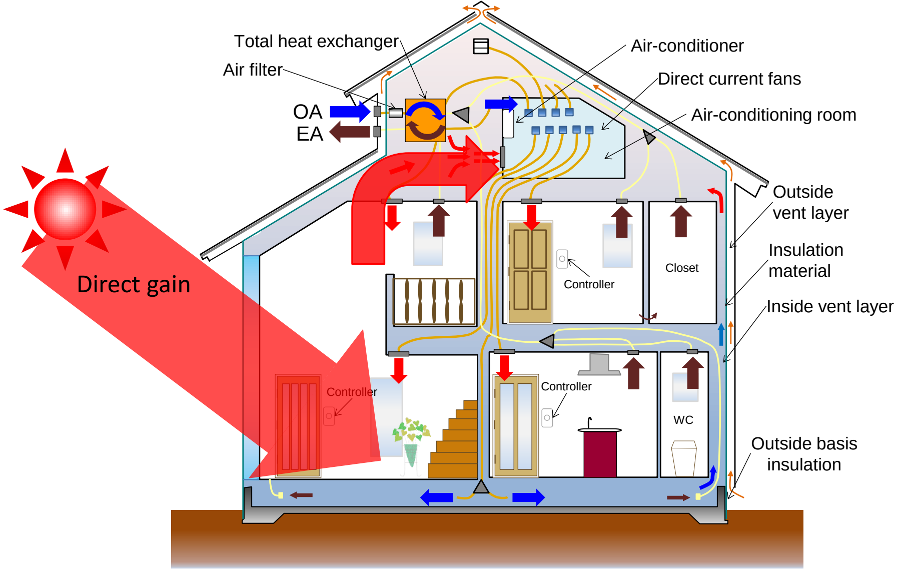


Figure 5. *Solar collection by the direct gain*

***Table 3.** Calculation condition of passive methods*

	Exterior glazing	Interior glazing	Window area of solar collector
Double-skin façade	Double-glazing	Double-glazing	17.1 m^2
	Low-e double-glazing		
	Evacuated low-e double-glazing		
Direct gain	Double-glazing	-	25.5 m^2
	Low-e double-glazing		
	Evacuated low-e double-glazing		

space is supplied to whole building. In summer, the heat load of solar radiation and heat transmission is expected to decrease due to thermal barrier of window shade and direct heat exhaust from air cavity to the outdoor by natural ventilation. While, the direct gain is one of major passive heating method that directly takes solar heat into the indoor from openings. However it suffers from the disadvantage that temperature control is difficult and overheating naturally happens many a time, particularly in insulation and airtight houses. By adopting the central duct space-conditioning system, overheating is relieved by distributing collected solar heat to whole building through air circulation with high blast volume.

Table 3 shows the calculation conditions of passive methods on the double-skin façade and the direct gain window. In here, the exterior glazing of double-skin façade and the direct gain window are assumed any one of the followings; the double-glazing, the low-e double-glazing and the evacuated low-e double-glazing. The interior glazing of double-skin façade is fixed as the double glazing. The air circulation capacity of the double-skin façade is 600m^3/h and the heat collecting area is 17.1m^2. The opening space of the direct gain window is 25.5m^2.

The Effect of the Double-skin Façade

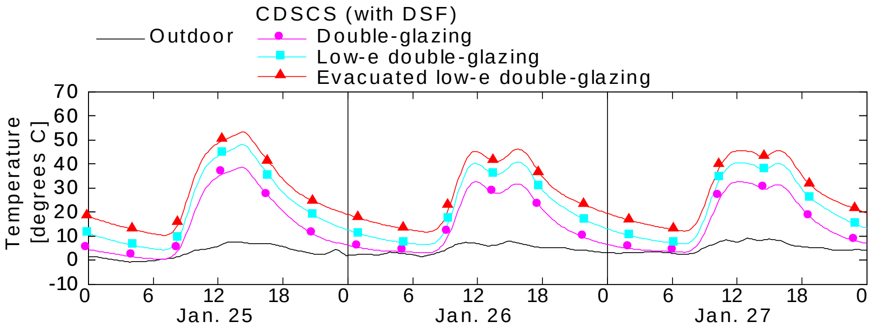
Figure 6 shows the temperature of air cavity and the heating load of whole building adopting the double-skin façade on January 25 to 27. The temperature of air cavity becomes higher in order of the evacuated low-e double-glazing, the low-e double-glazing, the double-glazing, and then the heating load becomes lower in the same order. Heating load is decreased in daytime by utilizing the collecting solar heat in the double-skin façade. Particularly in case that the evacuated low-e double-glazing is installed at exterior glazing of the double-skin façade, the heating load can be reduced to zero because of the heat loss reduction to outdoor with increasing heat-transfer resistance.

The Effect of the Direct Gain

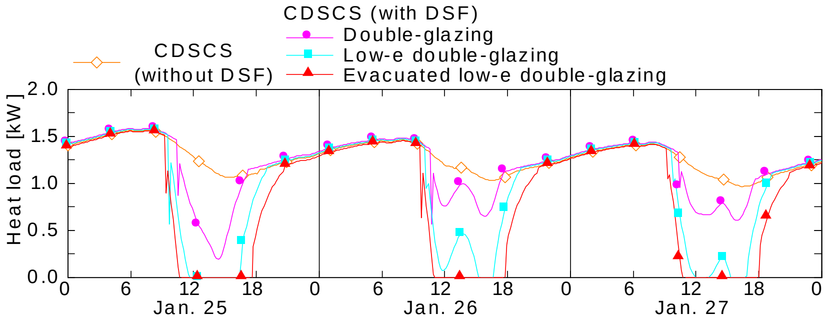
Figure 7 shows the temperature of living room without conditioning and the heating load of all day conditioning for whole building adopting direct gain on January 25 to 27. The room temperature rises too high in daytime even in natural conditions so that occupants have to do something of countermeasure to control temperature such as a curtain and window opening. However, the direct gain is expected to decrease heating load in a great measure.

The Combinational Effect of the Double-skin Façade and the Direct Gain

Figure 8 shows the annual heating load of whole building. As compared to the

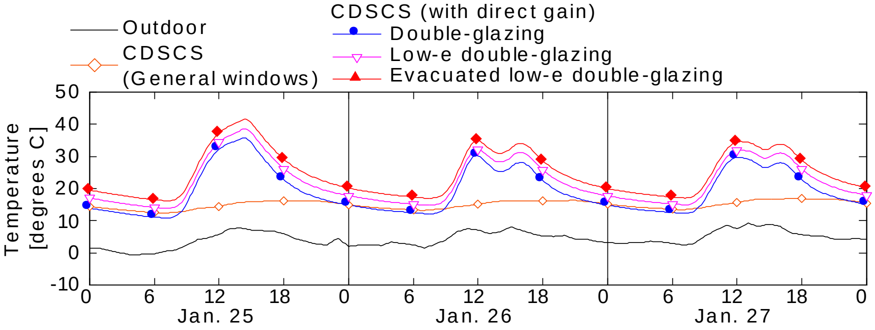


(1) Temperature of air cavity of the double-skin facade

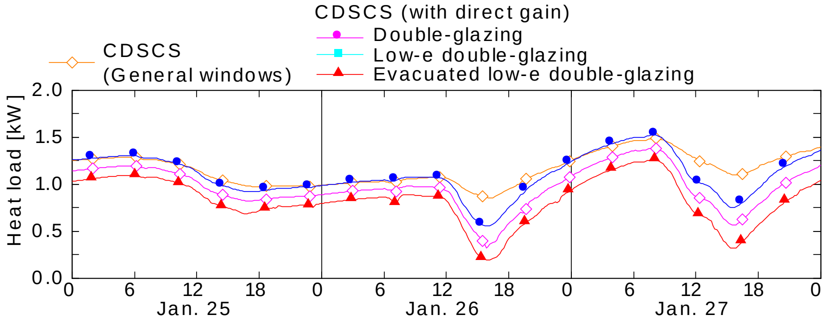


(2) Heating load

Figure 6. *Temperature of air cavity and heating load in case adopting the double-skin façade*



(1) Temperature of living room



(2) Heating load

Figure 7. *Indoor temperature and heating load in case adopting the direct gain*

individual space conditioning system (ISCS), the heating load of the central duct space conditioning system (CDSCS) is slightly decreased because surplus heat of south side rooms caused by overheating with solar heat gain is distributed to whole building by the medium of CDSCS. In case that the double-skin façade or the direct gain is combined with CDSCS, the heating load is further decreased. To compare with CDSCS, the combination system of CDSCS and the double-skin façade with the evacuated low-e double-glazing reduces by 32% of the heating load. The combination

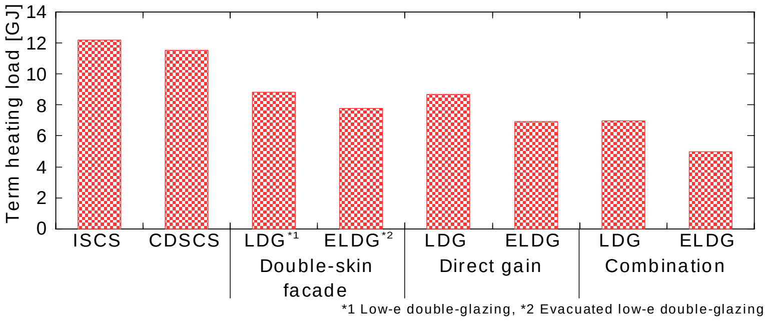


***Figure 8.** Term heating load*

system of CDSCS and the direct gain with the evacuated low-e double-glazing reduces by 39%. Furthermore, the combination system of CDSCS and both solar heat collecting system may decline by 57%. It may be possible to substantially decrease heating load through the use of solar heat by combining CDSCS with the solar collector such as the double-skin façade and the direct gain.

CONCLUSIONS

The combinational effect of the central duct space-conditioning system and the solar collector such as the double-skin façade and the direct gain on energy saving is examined by numerical simulation utilizing the simulation software ‘THERB’. THERB can predict the hygrothermal environment within whole buildings based upon the detailed phenomena describing actual building physics of heat and moisture transfer and airflow. Accuracy of THERB is verified through comparison of calculation results and monitoring results on the detached house equipped with the central duct space conditioning system (CDSCS). Then energy conservation performance of CDSCS on heating is made clear in relation to the individual space conditioning system. Furthermore, it is clarified that the combination system of CDSCS and the solar collector may substantially decrease heating load through the use of solar heat.

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