# Analysis on Passive Dehumidification and Ventilation System based on Thermodynamic Energy

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## ABSTRACT

This paper demonstrates the principle of Passive Dehumidification and Ventilation System (PDVS) system based on the thermodynamic energy "water potential". Furthermore, the effectiveness of this system is verified by Hygrabe which is a simulation software of the hygrothermal analysis of building envelops. Water potential is a thermodynamic energy based on the principle of the chemical potential of an element of a mixed gas, which is defined as the driving force of gaseous phase water flux. Supposing that temperature rises in equal absolute humidity change, because relative humidity is decreased, the difference between the saturated water and unsaturated water becomes larger and water potential becomes smaller than the original state. Considering the deviation from the equilibrium state as the driving force of the moisture flux, the difference in water potential between the interior of the room and the inside of the wall becomes the driving force, thus, dehumidification can be performed in PDVS systems. Dehumidification is performed by providing a ventilation layer to the outer-air side (single ventilation layer), generating water vapor transfer from the interior to outside air by causing a water potential gradient using solar thermal energy. In addition to the outdoor air ventilation layer, a double ventilation layer provided with one more ventilation layer on the interior side is used for the system in order to reduce the desorption.

## KEYWORDS

Water potential, Moisture absorption and desorption, Latent heat load,
Dehumidification, Ventilation layer

## INTRODUCTION

Houses tend to be highly airtight and insulated for the purpose of improving the indoor thermal environment and reducing heating and cooling loads. Moreover, airtight and thermal insulation have been increasingly strengthened by the Japanese Energy Conservation Standards for Housing (Law Concerning the Rational Use of Energy) and the construction of the Housing Performance Indication System. In association with those trends, the dwelling performance demands quantitative

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evaluation by numerical values, not a conventional qualitative description. However, the passive method using natural energy has not been reflected; as a result, high levels of insulation and airtightness have been spurred. Currently, about 30~40% of residential energy consumption is used for heating and cooling according to the official report by the Ministry of Land and the Infrastructure and Transport and tourism and the Ministry of Economy, Trade and Industry in Japan. In particular, an effective reduction method is not found with respect to the latent heat load during summer cooling. It is required to reduce the latent heat load in order to aim ZEB·ZEH in the future. In this study, the basic concept of PDVS (Passive Dehumidification and Ventilation System) envelope system for heat load control by using solar energy in the roof and walls is introduced, and the reduction effect of the latent heat load is examined.

## PDVS SYSTEM USING SOLAR ENERGY

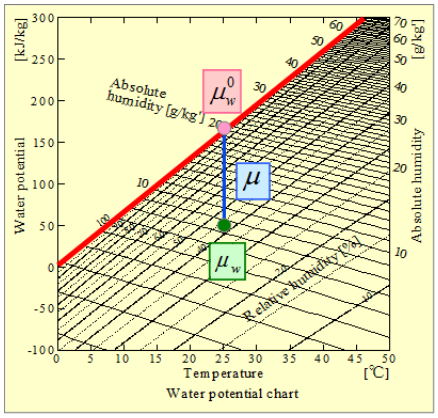



***Figure 1**. Water potential*

Figure 1 shows the graph of Water potential (Ozaki 2005). Water potential is a function of non-equilibrium thermodynamic energy based on the principle of the chemical potential of an element of a mixed gas, which is defined as the driving force of gaseous phase water flux. Water potential of a certain temperature and humidity state is represented as the sum of the saturated water potential and unsaturated water potential. Figure 2 shows the change in temperature, humidity, and water potential inside the ventilation layer. Supposing that temperature rises in the equal absolute humidity change, because relative humidity is decreased, the difference between the saturated water and unsaturated water becomes larger and water potential becomes smaller than the original state. Thus, the thermodynamic energy of dry air is low, and generating the moisture flow from the high-humidity air can be understood. Therefore, considering the deviation from the equilibrium state as the driving force of moisture flux, the difference of water potential in the room and the inside of the wall become the driving force (Ozaki and Watanabe 1996), by which dehumidification is performed in PDVS envelop system.

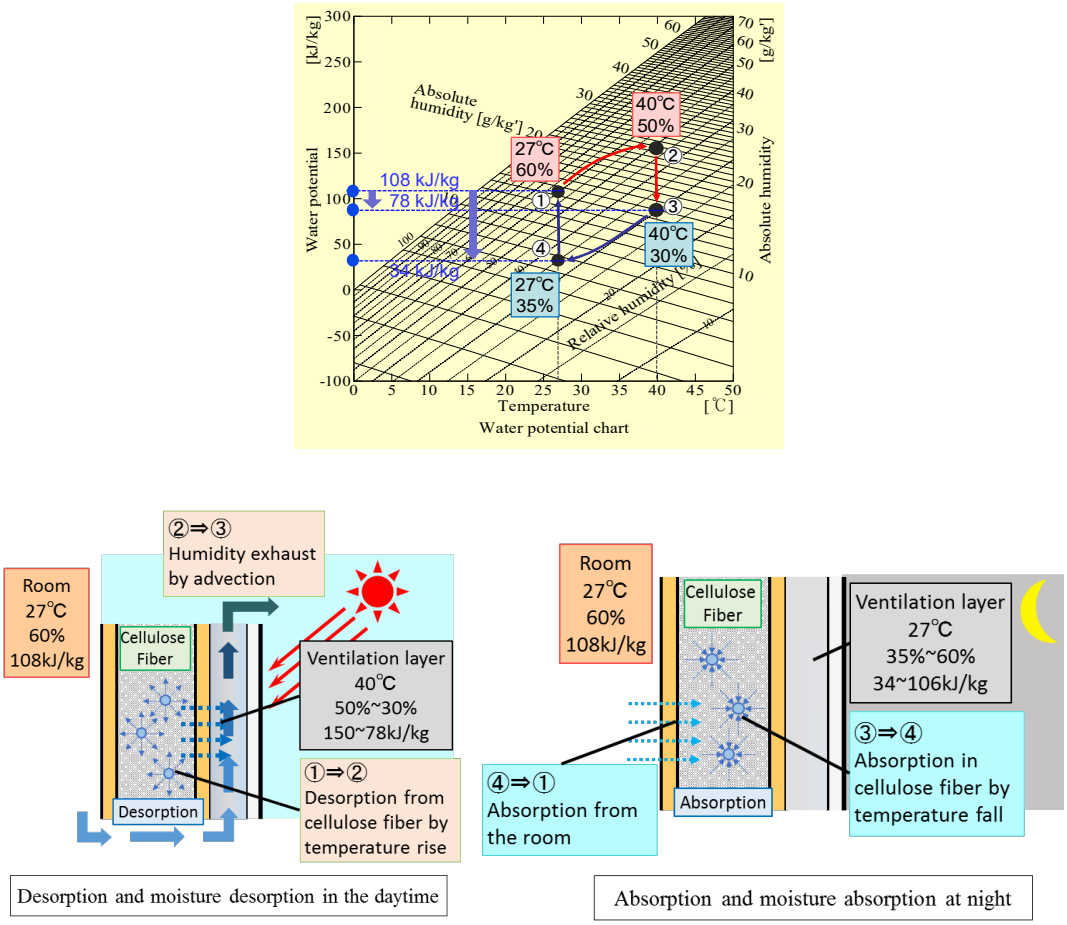



***Figure 2**. Moisture absorption and desorption in summer*

Assuming that the advection of the ventilation layer is ignored, due to desorption and diffusion of water vapor from the fiber-based insulation material according to the temperature rise by irradiated solar heat in the daytime, the absolute humidity of the ventilation layer is increased to the same extent as the thermal insulating material. Because the indoor air is originally circulated to the ventilation layer, the absolute humidity is reduced. As a result, water potential difference occurs between the room and the ventilation layer, by which moisture flow from the interior to the ventilation layer occurs. On the other hand, at night, because the thermal insulation material absorbs moisture in accordance with the outside air temperature decline, the absolute humidity in the wall, including the ventilation layer, is reduced and the water potential is maintained at a lower state than the room. For this reason, water vapor penetrates from the room to the inside of the wall; however, absolute humidity increases with the passage of time. All day dehumidification is possible from the room to the inside of the wall by repeating the above process in the periodic steady state of a one day cycle. This is the basic concept of the system.

## SYSTEM CONFIGURATION

### Single ventilation layer

The case of providing the ventilation layer only in the outside of the wall (hereinafter "single ventilation layer") is shown in Figure 3. Water vapor transfer is generated

from the room to the outside air by causing a water potential gradient in the room and outdoor air ventilation layer using solar thermal energy; therefore, dehumidification is performed. Ventilation is carried out only in the daytime through the ventilation layer and does not efficiently perform dehumidification at night.

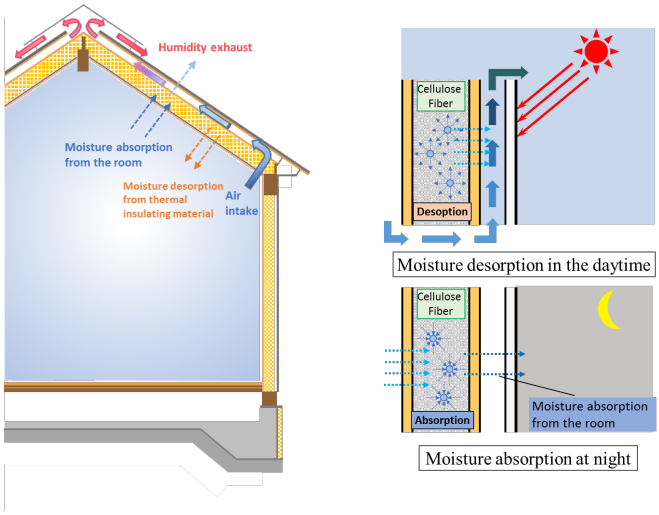



***Figure 3**. PDVS system of the single ventilation layer*

**Double ventilation layer**

Desorption which occurs during the daytime from the thermal insulating material to the room is concerned. Therefore, in addition to the outside ventilation layer, a double ventilation layer, installing an inside ventilation layer, is used for the system in order to reduce the desorption. Figure 4 shows the system diagram. Hardly any water potential difference is generated between the room and the inside of the wall. By providing an inside ventilation layer, the amount of moisture absorption is reduced at night in comparison with the single ventilation layer, however, a more comfortable indoor space can be made because the amount of moisture desorption is greatly reduced in the daytime.

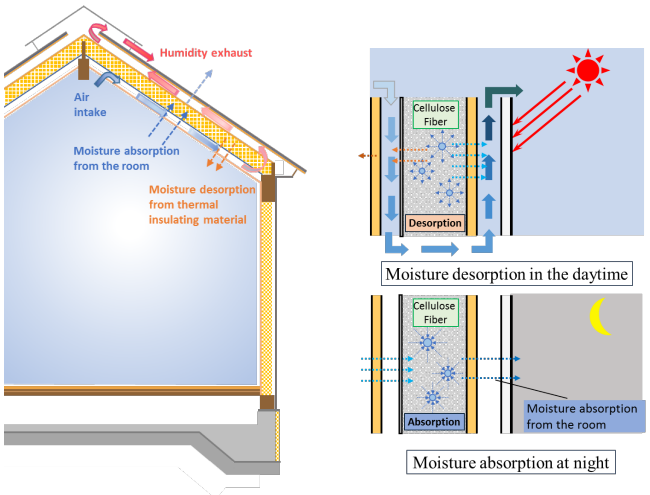



***Figure 4**. PDVS system of the double ventilation layer*

## CALCULATION OF THE DEHUMIDIFYING AMOUNT IN THE WALL AND ROOF SURFACE

### Calculation contents and conditions

Table 1 and Table 2 present the wall construction and calculation conditions, respectively. Parameter sensitivity analysis related to the dehumidification of the wall was performed by Hygrabe (Ozaki et al. 2004), which is a non-steady state heat transfer analysis tool.

***Table 1.*** *Wall composition*

| **Single ventilation layer** | **Double ventilation layer** |
|---|---|
| Galvalume | Galvalume |
| Roofing material | Roofing material |
| Waterproof plywood | Waterproof plywood |
| Ventilation layer | Ventilation layer |
| Moisture-permeable & Airtight sheet | Moisture-permeable & Airtight sheet |
| Structural plywood | Structural plywood |
| Cellulose fiber | Cellulose fiber |
| Base material | Ventilation layer |
| Plaster board | Base material |
| | Plaster board |

***Table 2.*** *Calculation conditions*

| | **Overview** |
|---|---|
| Calculation object | South-facing wall and roof |
| Meteorological data | Expanded AMEDAS weather data (Fukuoka) |
| Calculation software | Hygrabe |
| Preliminary calculation | 15 days |
| Computation period | July 20 ~ August 19 |
| Indoor temperature and humidity | 27℃ , 70% (constant) |
| Solar absorptivity | 0.7 |
| | **Parameter** |
| Ventilation | Yes (time: 9-16, 10-17, 11-18, 12-19), No |
| Insulation water capacity | 0, CF, CF` |
| Interior material water conductivity | Low, Standard value, High |
| Flow rate in ventilation layer | 0.1, 0.2, 0.3, 0.4, 0.5 m/s |

### Calculation result

The examples of calculations are shown in Figure 5 and Figure 6. The moisture absorption from the room is represented by a positive value, and a negative number represents the moisture desorption into the room. The amount of moisture released into the room decrease in proportion to the flow rate. Moisture absorption from the room is increased when air flow is below 0.2 m/s in the cases of both the single and

double ventilation layer. However, when air flow is above 0.3 m/s, the moisture absorption is decreased. It is considered that the air temperature is prevented from rising in the ventilation layer. On the other hand, the moisture absorption from the room in the case of the double ventilation layer is approximately 70% compared with the single ventilation layer, and moisture desorption into the room is reduced up to about 50%. Thus, the usefulness of this system can be confirmed.

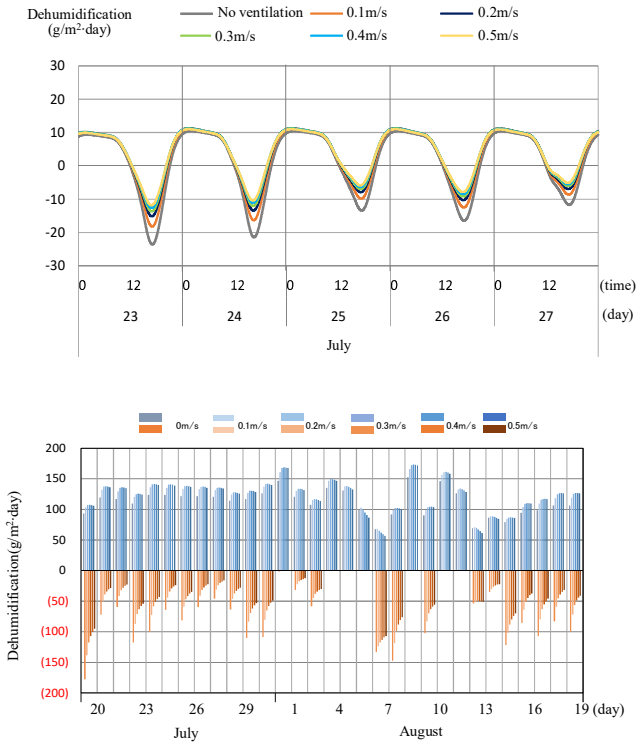



***Figure 5**. Influence of flow velocity in roof surface (single ventilation layer)*

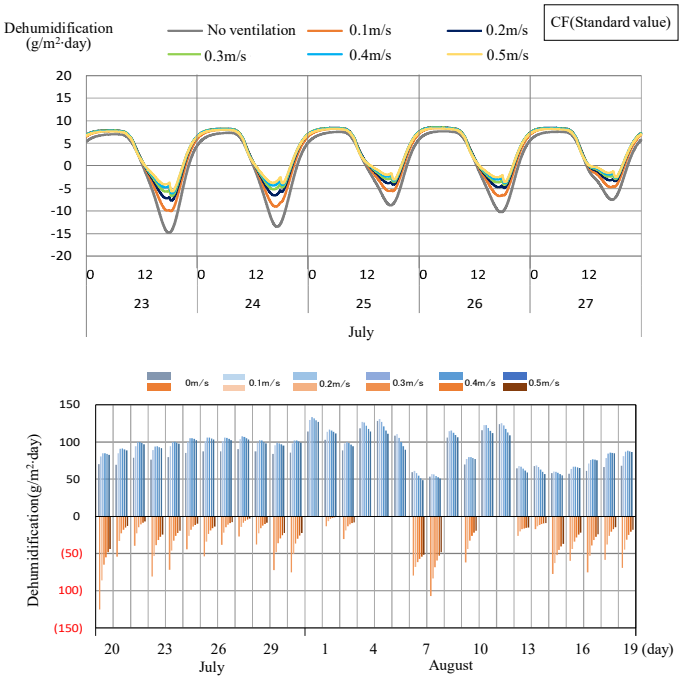
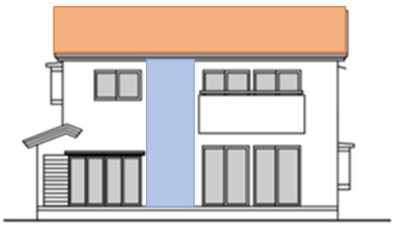



***Figure 6**. Influence of flow velocity in roof surface (double ventilation layer)*

## REDUCTION EFFECT OF LATENT HEAT LOAD BY PDVS ENVELOP SYSTEM

### Calculation contents and conditions

Table 3 shows the system configuration. Based on the amount of dehumidification calculated in the previous chapter, a comparison is performed with the water vapor content which enters into the room. The water vapor is evaluated by indoor absolute humidity, ambient air absolute humidity, and the specific gravity of ambient air for verifying the reduction effect of latent heat load of this system. An IBEC standard house is used for the calculation model shown in Figure 7.



| | | |
|---|---|---|
| Total floor space | 120.07 $m^2$ | |
| Floor height | 2.825 m | |
| Area of system | Wall | 10.20 $m^2$ |
| | Roof | 31.77 $m^2$ |

***Figure** 7. Calculation model*

***Table 3.** System configuration*

| | Case number | Wall | Roof (solar absorptivity) |
|---|---|---|---|
| System configuration | 1 | Single ventilation layer | Single ventilation layer (0.7) |
| | 2 | | Single ventilation layer (0.9) |
| | 3 | Double ventilation layer | Double ventilation layer (0.7) |
| | 4 | | Double ventilation layer (0.9) |

### Verification of the dehumidifying effect

The amount of dehumidification and the reduction effect of the latent heat load are shown in Figure 8. Cellulose fiber (CF) as moisture capacity of the thermal insulation material, the standard value as moisture conductivity of the interior material, and the flow rate of 0.2 m/s are adopted for the calculation conditions. Compared to moisture absorption and desorption in the wall using CF and water vapor content in the room from the outside, a dehumidifying effect of about 30%~40% is obtained. The higher dehumidifying effect is obtained by reducing the moisture capacity of the wall such as that of CF, which is possible because moisture desorption from the wall is increased during the day as moisture capacity is larger.

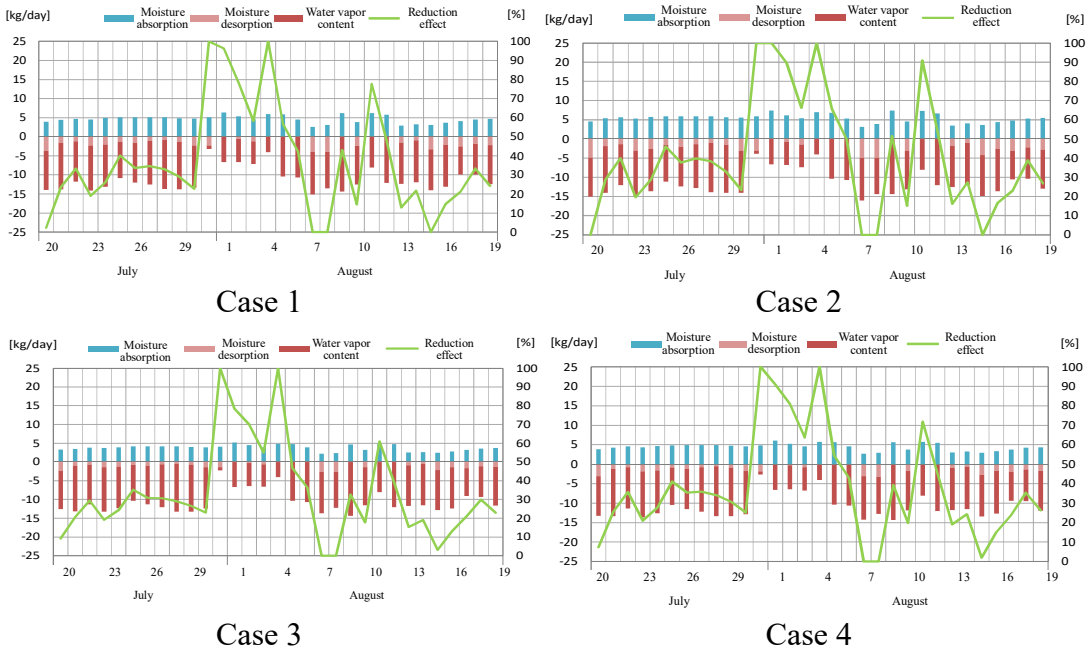



***Figure 8***. *Reduction effect of latent heat load: (Case 1)* Single ventilation layer × Single ventilation layer (0.7), (Case 2) Single ventilation layer × Single ventilation layer (0.9), (Case 3) Double ventilation layer × Double ventilation layer (0.7), (Case4) Double ventilation layer × Double ventilation layer (0.9)

## CONCLUSION

In this paper, the effectiveness of this system and the reduction effect of the latent heat load are confirmed by performing numerical simulations using Hygrabe, which is a non-steady state heat transfer analysis tool for building envelops. However, at the present stage, because calculation of the dehumidifying amount in the walls and roof is discussed only in certain indoor conditions, henceforward, investigations which are considered actual indoor conditions, such as moisture generated inside the room, are necessary in changing ventilation layer thickness or insulation thickness.

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