Study on the utilization of heat in the mechanically ventilated Trombe wall in a house with a central air conditioning and air circulation system

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HIGHLIGHTS

\begin{itemize}
  \item A mechanically ventilated Trombe wall with additional windows in the storage wall was introduced.
  \item This Trombe wall was used for a house with a central air conditioning and air circulation system.
  \item The effective method of heat utilization of the Trombe wall was concluded.
  \item Airflow from the Trombe wall to the air conditioning room reduced the heating load.
\end{itemize}

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ABSTRACT

This paper presents a study on a mechanically ventilated Trombe wall that adds additional windows to the storage wall. The mechanically ventilated Trombe wall is located on the south side of the house with a central air conditioning and air circulation system. To reduce the heating load, during the heating period, the heat from the Trombe wall air channel is sent to the air conditioning room, from where it is then distributed and stored throughout the house by way of air circulation. Taking a house located in Miyazaki, Japan as an example, we conducted an actual survey to understand the situation of heat utilization of the Trombe wall and used numerical simulations to examine the effective method of heat utilization of the Trombe wall. Results showed that in all-day air conditioning, even when sending the air in the Trombe wall to the air-conditioned room, the temperature of the Trombe wall remained high. The heating load was reduced by sending the air from the Trombe wall to the central air-conditioned room and installing the large heat capacity material on the floor in the Trombe wall.

1. Introduction

Building energy consumption accounts for a great part of regional and global energy needs. Building energy consumption for cooling and heating accounts for 18–73\% of overall energy consumption. Heating energy consumption occupies 32–33\% of the overall building energy consumption [1]. Therefore, the use of renewable sources such as solar energy for building heating is an effective method. One of the easiest and cheapest methods of using solar energy is the Trombe wall, consisting of a transparent glazing panel, the air channel, the vent, and the storage wall [2]. Solar heat is stored by the storage wall during the day and released into the room at night. However, the traditional Trombe wall has several disadvantages such as low aesthetic value, changeable heat transfer, reverse thermo-siphon phenomena, and low thermal resistance [3].

Many scholars modified the traditional Trombe wall and found that the improved Trombe wall was more effective than the traditional Trombe wall. Rabani et al. [4] carried out an experimental analysis on the heating performance of an improved Trombe wall, which can obtain solar irradiance from the directions of south, west, and east. The results showed that the improved Trombe wall can increase the maximum temperature of absorbers 10\°C higher than the traditional Trombe wall. Yu et al. [5] presented a study on the formaldehyde degradation performance and heating performance of a TC-Trombe wall combining the
Trombe wall with the thermal catalytic technology. The results indicated that the TC-Trombe wall can save the formaldehyde degradation energy and space heating energy up to 33.1 kWh/m² and 64.3 kWh/m², respectively. The zigzag Trombe wall [3] was invented to reduce glare and unnecessary heat increase, which comprises the southeast part, the southwest part, and the south part. The southeast part and southwest part form an inward “V”-shaped wall. The south part and southwest part are traditional Trombe walls; the southeast part is a window. Duan et al. [6] studied the thermal performances of two types of Trombe walls through a mathematical model, depending on the position of an absorber plate on the storage wall. They found that Trombe walls with absorber plates placed between the glass cover and the thermal storage wall are better than Trombe walls with the absorber plate pasted on the thermal storage wall. The particular exergy destruction, owing to absorption of the absorber plate is the largest and a higher absorber plate temperature is preferable in decreasing the total exergy destruction and increasing exergy efficiency. A non-ventilated Trombe wall with an additional window in the storage wall was proposed by Bellows et al. [7]. The results showed that the new non-ventilated Trombe wall can transfer the solar heat into the interior quickly, resulting in indoor temperature rising from noon to afternoon. Leang et al. [8] used the Dymola/Modelica software to study the energy performance of a composite Trombe wall. They compared a M_PCM (mortal phase change materials) composite Trombe Michel wall with a concrete composite Trombe Michel wall. The results showed that the M_PCM composite Trombe Michel wall has a great heat recovered capacity, which can recover 50% more energy than the concrete composite Trombe Michel wall. Hu et al. [9] carried out a study on the performance of three types of photovoltaic Trombe wall systems that can generate electricity and provide cooling/heating. Type 1 is photovoltaic-blinds-integrated Trombe wall (PVBTW). Type 2 is photovoltaic cells attached to massive wall (PVMWT). Type 3 is photovoltaic cells attached to glass (PVGWT). The results showed that the type 1 (PVBTW) system can save 45% of the total electricity consumption and reduce the CO2 emission by 1.5 times compared with type 2 (PVMWT system) or type 3 (PVGWT system). Tunç and Uysal [10] conducted a numerical simulation study on the performance of the fluidized Trombe wall, in which the air cavity channel is fluidized by using low-density and highly absorbent particles. The results showed that fluidized Trombe walls gain more heat than traditional Trombe walls. Adams et al. [11] presented an experimental analysis on the performance of the water Trombe wall with three different water storage wall thickness levels (3 in., 6 in. and 9 in.). The results showed that the 9-in. and 6-in. water storage walls present better than the 3-in. water storage wall. The 3-in. storage wall did not adjust the temperature as well as the 9-in. and 6-in. water storage walls. The 9-in. and 6-in. water storage walls lagged a longer time than the 3-in. storage wall, which appeared to store and release the heat more efficiently. Sodha et al. [12] carried out a numerical study on the thermal performance of the solar transwall, which consists of a semi-transparent plate and glass walls. The results showed that the thermal performance of the solar transwall increases by increasing the water column thickness. Melero et al. [13] carried out an experimental study on the energy performance of a hybrid prototype Trombe wall integrated with a ceramic evaporative cooling system. They concluded that the hybrid prototype Trombe wall can improve the comfort of interior in summer and winter. Taffesse et al. [14] developed a mathematical model of SVPT-TW (semitransparent photovoltaic thermal Trombe wall) for the heating of a room by using the MATLAB R2013a software. They concluded that 0.4 m is the optimal thickness of the SVPT-TW for thermal load leveling.

There are various components to help improve the efficiency of the Trombe wall such as insulation, fans, shading devices, vents, glazing type, the storage wall’s materials and thicknesses, coating materials, and air cavity depth. Ji et al. [15] proposed a numerical study on the thermal performance of the outer insulated Trombe wall. Results showed that the outer insulated Trombe wall performs more efficiently than the traditional Trombe wall, which can improve the operating efficiency of Trombe walls up to 56%. Ma et al. [16] used the software of THERB for HAM to study the thermal energy efficiency of a double-layer Trombe wall assisted by a fan. Results revealed that the double-layer Trombe wall assisted by the fan can increase the double-layer Trombe wall efficiency close to 5.6% and reduce heating demand by 0.6 kWh/m². Soussi et al. [17] studied the energy performance of the Trombe wall by using the TRNSYS software. Results showed that the total energy demand is reduced by using the movable solar overhangs, internal shading devices, and low-e Argon glazing. Briga-Sâ et al. [18] studied the energy performance of the non-ventilated and ventilated Trombe wall with various thickness in the storage wall. Results showed that for the non-ventilated Trombe wall, the heat gains increased with the decreasing of the thickness of the massive wall. However, for the ventilated Trombe wall, the heat gains decreased when the thickness decreased. Liu et al. [19] carried out a numerical and experimental analysis on the closing and opening the air vent of the Trombe wall. They concluded that it is best to close the vent one hour before sunset and open the vent two hours or three hours after sunrise. Mohamed et al. [20] conducted a numerical simulation and experimental study on the performance of the Trombe wall in Tunisia. Results showed that in the periods of the highest solar radiation, the room temperature reaches 25°C for the single glazed Trombe wall but does not exceed 22°C for the double glazed Trombe wall. The single glazed Trombe wall allows a good transmission of energy and improves the comfort level of the interior. However, Stazi et al. [21] concluded that the Trombe wall performance increased with the use of double glazing and low-e single glazing in term of global warming potential. Rabani et al. [22] studied the heating duration of a room with various materials of the Trombe wall in periods of non-sunny days. Results indicated that the heating duration of a room with the paraffin wax wall was 8 h and 55 min, the salt wall was 8 h 30 min, the brick wall was 8 h 11 min, and the concrete wall was 7 h 12 min. Zhou and Pang [23] performed an experimental analysis of the thermal behavior of a PCM (CaCl2H2O) storage wall. The results showed that the surface temperature of PCM (CaCl2H2O) performs speedy–slow changes during the 17.5-hour discharging process and rises speedy–slowly during the 6.5-hour charging process. Bojić et al. [24] studied the environmental and energy performance of Trombe walls that have various thickness of the storage wall. Results showed that for natural gas heating, the optimal thickness of clay bricks is around 0.25 m. For the electrical heating, the optimal thickness of clay bricks is around 0.35 m. Nwosu [25] conducted an analysis of the heat transmission balance of a Trombe wall. The results showed that the highly absorptive coating materials can improve the storage capacity of the Trombe wall. Burek and Habeib [26] conducted an experimental study on the mass flow rate and heat transfer in the Trombe wall. The results showed that the mass flow rate increases by increasing the heat input and air cavity depth. If the heat input is as high as 1000 W/m², the air cavity depth has no effect on the Trombe wall’s efficiency.

Based on the author’s review, the characteristics of the Trombe wall are summarized, including 12 different types of Trombe walls and various components that can help to improve the efficiency of Trombe walls. However, there is no study on the utilization of heat in the Trombe wall in a house with a central air conditioning and air circulation system. This paper presents a mechanically ventilated Trombe wall that adds additional windows to the storage wall. The use of additional windows can partly solve the Trombe wall’s aesthetic problems and increase natural daylighting in the room. In addition, this configuration allows a portion of the solar radiation to heat the interior directly. The mechanically ventilated Trombe wall is located on the south side of the house with a central air conditioning and air circulation system. To reduce the heating load, during the heating period, the heat from the Trombe wall air channel is sent to the air conditioning room, from where it is then distributed and stored throughout the house by way of air circulation. The numerical calculations are done with the
software of THERB for HAM, which is valuable calculation software especially for situations where the air inside the Trombe wall needs to be sent to the air conditioning room. The house in Miyazaki, Japan is a case study, and we are going to understand the situation of heat utilization of the Trombe wall by the actual survey to examine the effective method of heat utilization of the Trombe wall using numerical calculation.

2. Overview of the building

2.1. The house description

The house is located in Miyazaki, Japan and had a Trombe wall with an extra window in the storage wall installed on the south of the house, mainly for the purpose of reducing the heating load. The house is a wooden structure. Fig. 1 shows the building exterior and the air channel of the Trombe wall. Fig. 2 shows the floor plan of the building in millimeters. The outside window area of the Trombe wall is 9 m². The storage wall of the Trombe wall is 6.29 m². The window area on the storage wall is 7.29 m². The construction details of the house are given below (see Tables 1–12):

2.2. Central air conditioning and circulation system

External air is sent to the central air-conditioning machine room through air filters and a total heat exchanger. The air in the central air-conditioning machine room is then sent to each room after its temperature and humidity are adjusted by a residential heat pump air-conditioning unit. The air in the rooms returns to the central air-

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Table 1
Specifications for the house.

<table>
<thead>
<tr>
<th>Location</th>
<th>Miyazaki, Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area classification of energy saving standard</td>
<td>7 region</td>
</tr>
<tr>
<td>Area classification of solar radiation in the heating season</td>
<td>3</td>
</tr>
<tr>
<td>Total floor space</td>
<td>115.5 [m²]</td>
</tr>
<tr>
<td>Total building skin space</td>
<td>350.9 [m²]</td>
</tr>
<tr>
<td>Direct gain opening space</td>
<td>8.1 [m²]</td>
</tr>
<tr>
<td>Trombe wall opening space</td>
<td>9 [m²]</td>
</tr>
<tr>
<td>Window glass Trombe wall room (outside)</td>
<td>Pair glass</td>
</tr>
<tr>
<td>Other</td>
<td>Triple Shannon IIS</td>
</tr>
<tr>
<td>Skin heat transmission coefficient average (UA)</td>
<td>0.26 [W/m²K]</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>There are a household air-conditioner of heat pump unit in the bed room of second floor (cooling capacity 4.0 kW heating capacity 5.0 kW), DC motor, the central air conditioning and circulation system</td>
</tr>
<tr>
<td>Ventilating equipment</td>
<td>Total enthalpy heat exchanger</td>
</tr>
</tbody>
</table>

Table 2
Constructions with their layers used in ground.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness (m)</th>
<th>λ (W/m K)</th>
<th>ρ (kg/m³)</th>
<th>cp (J/kg K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>0.27</td>
<td>1.2</td>
<td>2200</td>
<td>840</td>
</tr>
<tr>
<td>Rigid polystyrene foam</td>
<td>0.1</td>
<td>0.035</td>
<td>32</td>
<td>1470</td>
</tr>
</tbody>
</table>
conditioning machine room through vent layers in the wall and duct. Part of the air is discharged to the outside by a total heat exchanger. The rest of the air is sent back to the rooms after going through the central air-conditioning machine room again. To reduce the heating load, during the heating period, the heat from the air channel of the Trombe wall is sent to the central air-conditioning room, from where it is then distributed and stored throughout the building by way of air circulation. Further, during the cooling period, the cooling load can be reduced by opening the windows on the outside of the Trombe wall and using the roof and wing walls to provide shade from the sun (see Fig. 3).

3. Method

We investigated the thermal effects and operation methods of the Trombe wall by using measurements and numerical simulations.

3.1. Experimental procedure

In the measurement, the RTR-503 device is used to measure the temperature and humidity in the Trombe wall air channel and the room space. The sensors are located in the Trombe wall air channel center and the room center. The Vantage Pro2 Console device is used to measure the solar radiation, wind direction, wind speed, temperature, and humidity outdoors. The experimental work introduced here mainly focuses on the analysis of the performance of the Trombe wall, when the air is sent to the air-conditioned room from the air channel of the Trombe wall.

3.2. Calculation details and conditions

In this study, we ran a numerical simulation using THERB for HAM
dynamic heat load computation software to investigate effective methods of using the heat from inside the Trombe wall, as well as possible structural improvements. THERB for HAM (Simulation Software of the Hygrothermal Environment of Residential Buildings for Heat, Air, and Moisture) is a dynamic calculation software that can calculate the temperature, humidity, heating, and cooling loads for multi-zone buildings [27]. Akihito Ozaki developed the software of THERB for HAM initially. The calculation result of THERB for HAM was validated throughout the building energy simulation test (BESTEST) in Japan. The features of THERB for HAM are as follows [28]: (1) Combined calculation of heat and moisture transfer and airflow; (2) Prediction of the hygrothermal environment (Temperature, humidity, predicted mean vote, standard effective temperature); (3) Temperature and humidity control or predicted mean vote control; (4) Considering time variation of convective heat and moisture transfer; (5) The forced and natural heat and moisture transfer coefficient are calculated for each part based on the dimensionless equation; (6) Strict geometric calculation of sunlit and shading areas of outside and inside; (7) Multi-layer window model; (8) Multiple reflections of transmitted solar radiation through window; (9) Nonlinearity of radiation heat transfer; (10) Mutual radiation between inside surfaces; and the (11) Network airflow model. Ozaki et al. [27] compared the monitored and calculated data of a building with a Trombe wall and verified the accuracy of THERB for HAM.

Table 13 gives the air conditioning schedule for each method of air conditioning and Table 14 gives an overview of the numerical simulation models. As the table shows, we developed nine models with different combinations of air conditioning methods, amounts of airflow from the Trombe wall to the air conditioning room, presence or absence of a thermal storage medium, and open or closed windows. “C” shows that a thermal storage medium (concrete) was installed as the foundation of the floor inside the Trombe wall. The concrete thickness was 100 mm. The concrete has a length of 4.1 m and width of 0.91 m. The thermal conductivity of the concrete was 1.6 W/m K. The concrete specific weight was 2300 kg/m³. The specific heat of concrete was 880 J/kg K. “w” shows that the window in the second-floor bedroom bordering the Trombe wall was left open. We also assumed that air was only sent from the Trombe wall to the air conditioning room between 12:00 and 18:00. The simulated work presented here mainly focuses on the analysis of the performance of the Trombe wall under the following three different air conditioning methods.

(1) In the condition of using the air conditioning all day, we compared the effect of the amounts of airflow on the heating load reduction (model I, model II and model III). We also compared the effect of the thermal storage medium on the heating load reduction (model II and model IIc).

(2) In the absence of air conditioning, we investigated whether it was
possible to keep the Living/dining/kitchen area at a comfortable
temperature by only using the air flow from inside the Trombe wall
(model V, model VI and model VIc). We also investigated the ef-
effectiveness of keeping the window open in the second floor bed-
room bordering the Trombe wall and letting the heat from the
Trombe wall circulate into that room (VIc, VIcw and VIcw 24 h).

(3) In the condition of using intermittent air conditioning, we studied
the effect of the airflow on the living room/dining room/kitchen
temperature (model IV).

4. Results and discussion

4.1. Measurement results

Fig. 4 shows the temperature of the air in the Trombe wall within
two months. The highest daily temperature of the air in the Trombe
wall was higher in February than in March, and in early February there
were days when the temperature rose to 40 °C or more. It seems that
even in early February, the coldest outside temperatures, sending air
from the channel of the Trombe wall to the air conditioning room was
an effective way of reducing the heating load. However, the fact that
the maximum daily air channel temperature of the Trombe wall
dropped to 20 °C or less on days with little solar radiation indicates that
air inside the Trombe wall cannot be sent to the air conditioning room
every day.

Fig. 5 shows the variation in the temperature of each room when air
is being sent from the channel of the Trombe wall (without air con-
ditioning). The heat collected from the Trombe wall is sent to the air-
conditioned room from 12:00 to 18:00 and then distributed to each
room. Airflow from inside the Trombe wall resulted in an approximate
1 °C temperature rise in the air conditioning room. In Japan, the
minimum air exchange per hour is 0.5. The volume of the Trombe wall
air channel is 12.9 m³. The ventilation from the Trombe wall into the
air-conditioned room is 500 m³/h. The Trombe wall temperature
growth rate decreased after the beginning of airflow at 12:00. The
Trombe wall temperature reduction rate decreased after the end of
airflow at 16:00. The temperature of the Trombe wall is affected by the
outdoor air temperature and solar radiation. The outdoor air tem-
perature is not changed so much from 13:00 to 16:00 and the Trombe
wall has a significant delay effect on the air temperature fluctuations.
As a result, even if the amount of solar radiation decreases, the tem-
perature of the Trombe wall continues to increase. However, the tem-
perature rises a little in the living/dining/kitchen area and the tem-
perature inside the Trombe wall remained high even after airflow to the
air conditioning room commenced and this air could potentially be used
to provide further heat.

4.2. Simulation results

4.2.1. Verify the accuracy of the simulation software

In order to verify the model by experiment, the measured meteor-
ological data of Miyazaki is configured as a data input file of the si-
mulation program based on the state of the demonstration house. The
time step is ten minutes. The experiment was carried out with air
conditioning all day. Fig. 6 is the calculated data and monitored data of
the temperature inside the Trombe wall. Fig. 7 is the calculated data
and monitored data of the temperature of the child room. The fact that
the simulated temperatures roughly match the actual ones con-
firms that the simulation software is highly accurate.

4.2.2. Reduce heating load by using heat collected from the Trombe wall

Fig. 8 shows the monthly heating load in Models I, II and III, and
Table 4 shows the monthly heating load reduction ratio. The unit of
load reduction ratio is percentage (see Table 15).

In all months, airflow of 500 m³/h or 1000 m³/h from the Trombe
wall to the air conditioning room reduced the heating load more than
airflow of 0 m³/h, confirming that airflow from the Trombe wall helps to reduce the heating load. However, the heating load reduction ratio was extremely low in March, when sending air from inside the Trombe wall to the air conditioning room did not have any effect on the heating load because there are many cloudy days causing the Trombe wall temperature to not be very high. Further, comparing airflow of 500 m³/h from inside the Trombe wall to the air conditioning room with airflow of 1000 m³/h, the fact that the difference in heating load reduction ratios was about 1% throughout the period indicates that 500 m³/h, the volume currently used, is sufficient. For real application, we can change the amount of airflow to 500 m³/h.

Fig. 9 shows the variation in the temperature inside the Trombe wall on sunny days in Models I, II and III. The temperature inside the Trombe wall was lower when there was airflow from the Trombe wall to the air conditioning room (Models II, III) than when there was no airflow (Model I). However, in all models the temperature inside the Trombe wall was high, at 30 °C or more, indicating that investigation is needed into more effective ways of using the heat collected inside the Trombe wall.

Fig. 10 shows the yearly heating load in Models II and IIc. The yearly heating load in Model IIc, where a thermal storage medium was installed under the floor inside the Trombe wall, was reduced by about 5% to approximately 250 kWh, lower than that in Model II where there was no thermal storage. This demonstrates that using high heat capacity flooring materials inside the Trombe wall further enhances the heating load reduction effect of airflow from inside the Trombe wall to the air conditioning room.

Fig. 11 shows changes over two days in the temperature inside the Trombe wall in Model II and Model IIc. Given that the temperature inside the Trombe wall drops more slowly at night when a thermal storage medium is installed in its floor, it may be possible to further reduce the heating load by extending the period of airflow from the Trombe wall to the air conditioning room.

Fig. 12 shows the heating loads in Models II and IIc over two days when the period of airflow from the Trombe wall to the air conditioning room was extended. The airflow period was extended to last from 10:00 to 24:00. It can be concluded that extending the duration of airflow had a greater impact on the heating load ratio in the presence of a thermal storage medium because of using high heat capacity flooring materials. For real application, we can add high heat capacity material to the existing storage wall and extended the airflow period.

### 4.2.3. Investigation without air conditioning

We investigated whether it was possible to keep the LDK (living room/dining room/kitchen) area at a comfortable temperature without the use of heating by only using the airflow from inside the Trombe wall. Fig. 13 shows temperature distribution in the LDK (living room/dining room/kitchen) areas of Models V, VI and VIc from December to March. In this study, a comfortable interior temperature was defined as being between 18 °C and 22 °C [29]. It comes from one of Japan’s thermal comfort standard in winter. In all models, temperatures were below the comfortable range at least 90% of the time, showing that it is difficult to keep the LDK (living room/dining room/kitchen) area at a comfortable temperature without using heating.
As one method of making effective use of the air inside the Trombe wall, we investigated the effectiveness of keeping the window open in the second-floor bedroom bordering the Trombe wall and letting the heat from the Trombe wall circulate into that room. Fig. 14 shows the second-floor bedroom’s temperature and Trombe wall temperature over one day in models VIc, VIcw, and VIcw 24 h. Note that Model VIcw 24 h is the same as Model VI except that the window was left open for 24 h. Because the open window in the second-floor bedroom allowed the collected heat to directly enter the room, the temperatures in the Trombe wall were lower in models VIcw and VIcw 24 h than they were in Model VIc, where the windows were closed. Further, when the windows were open, the second-floor bedroom reached a comfortable temperature (18–22 °C) between 17:00 and 20:00, with the temperature in Model VIcw 24 h remaining approximately 1 °C to 3 °C higher than in Model VIc. These results demonstrate that by opening the window next to the Trombe wall, the heat inside the Trombe wall can be used efficiently and the second-floor bedroom can, at times, reach a comfortable temperature. However, the time of day when the open inside window to the Trombe wall allowed the second-floor bedroom to reach a comfortable temperature was between approximately 17:00 and 20:00, a time when the second-floor bedroom was unoccupied. It can be concluded that if the LDK (living room/dining room/kitchen) area was positioned on the second floor next to the Trombe wall, opening the window of the Trombe wall would allow the LDK (living room/dining room/kitchen) area to be kept warm without the use of heating for more of the time that the area is occupied. For real application, we can add the Trombe wall to the south of living/dining/kitchen area.

4.2.4. Investigation with intermittent air conditioning

Because it is difficult to keep the LDK (living room/dining room/kitchen) area warm without heating, we ran a simulation with intermittent air conditioning. Fig. 15 shows changes in temperature over one day in the LDK (living room/dining room/kitchen) area of Model IV. The fact that the temperature stayed at more or less 20 °C even after the air conditioning was stopped indicates that, on days when the temperature inside the Trombe wall is high, the airflow from the Trombe wall is enough to keep the area at a comfortable temperature in the afternoon. For the real applications, the air conditioner can be turned off when the heat is sent from the Trombe wall to the air conditioning room on sunny days.
5. Conclusions

This paper presents a mechanically ventilated Trombe wall that adds additional windows to the storage wall. The use of additional windows can partly solve the Trombe wall aesthetic problems and increase the natural daylighting in the room. In addition, this configuration allows a portion of the solar radiation to heat the interior directly. To reduce the heating load, during the heating period, the heat from the mechanically ventilated Trombe wall air channel is sent to the air conditioning room, from where it is then distributed and stored throughout the house by way of air circulation. We conducted an actual survey to understand the situation of heat utilization of the Trombe wall and used numerical simulations to examine the effective method of heat utilization of the Trombe wall. These are our findings:

(1) When air conditioning is used all day, the heating load can be reduced by combining heat collected inside the Trombe wall with duct-style central air conditioning. However, we confirmed that,
under normal use, the temperature inside the Trombe wall remains high even if the air is circulated, resulting in overheating. (2) Raising the Trombe wall’s ability to store heat leads to a gentler drop in its nighttime temperature, enabling an extension of the period during which airflow is circulated in the air conditioning room.

(3) When air conditioning is not used, there are times when the rooms bordering the Trombe wall can be heated to a comfortable temperature by opening the windows to the Trombe wall during the daytime; it can, therefore, be concluded that it is preferable to position the main living areas next to the Trombe wall.

(4) When intermittent air conditioning is used, on sunny days, the

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**Fig. 12.** The heating loads over two days when the period of airflow from the Trombe wall to the air conditioning room was extended (II and IIc).

**Fig. 13.** Temperature distribution in the LDK (living room/dining room/kitchen) areas from December to March (V, VI, and VIc).

**Fig. 14.** The second-floor bedroom temperature and Trombe wall temperature over one day (VIc, VIcw, and VIcw 24 h).
living room/dining room/kitchen area can be kept at a comfortable temperature even after the air conditioning has been stopped by only using the airflow from inside the Trombe wall.

For future work, we propose studying the optimum thickness of various materials, the optimum thickness of the ventilated air channel, and the optimum window area of the storage wall. Using a temperature controlled fan to supply air based on the Trombe wall air temperature should be further studied.

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