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Energy Management of Solar Wall with Automatic Controlled Ventilation

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Abstract—*A solar wall is an important architectural feature which provides a mechanism for the heating and cooling of buildings. A solar wall stores heat during the sunny periods and releases it with a time lag which depends on the solar wall characteristics. This articles provides description of an experimental set up to show that better energy management can be realized for a solar wall by developing an active solar energy system which includes solar wall, sensors, programmable control, and electrical actuators. Using automatic controlled ventilation, the experimental set-up provides different durations of thermal exchanges.*
Keywords— Solar wall, active solar systems, electronic control, thermal exchange, ventilation.

I. INTRODUCTION

Solar energy, along with the other energy resources, such as, hydroelectricity, biomass, and wind, accounts for most of the available renewable energy on our planet [1]. Solar energy is a resource that is not only sustainable for energy consumption, it is also renewable. It can be converted into electricity and it is also used in solar water heaters. Solar energy is used to heat and cool homes and for indoor lighting. Solar energy is a non-polluting, clean, reliable, and renewable source of energy. It can be easily deployed by residential and commercial users as it does not require a huge physical set-up. During the construction of a building, passive solar systems can be integrated into its structure to realize energy saving [2]. The architectural features such as solar chimneys, solar roofs, and solar walls provide potential mechanism for the reduction of the environmental impact of greenhouse gas emissions [3].

Solar walls represent an important architectural feature that aids in the ventilation, heating, and cooling of buildings and thus contribute to significant energy saving [4]. Solar walls have been studied for a long time as a method for heating buildings from a renewable energy source, that is, sun [5]. A key feature of solar wall configuration is the use of a sun-facing wall to heat up air for ventilation, used to provide thermal energy to buildings. The mechanism involves absorption of solar radiation during the day and release of the energy absorbed during the night [4][6]. Another salient feature of solar walls is their storage capacity. To avoid the problem of increased weight and volume of solar walls due to storage mass, phase change materials can be used which allow the storage of a large amount of energy in a small volume [5][7].

This article presents an experimental study for the energy management of a trombe solar wall using automatic controlled ventilation. The location of experimental set-up is Bethune (latitude 50° 31´ North and longitude 2° 38´ East) This set-up which is based on a solar wall prototype is maintained by the LGCGE Laboratory of the Civil Engineering Department of the University of Artois.

II. SOLAR WALL CONFIGURATION

The vertical section of the solar wall used in the experimental set-up is shown in Fig. 1 while the horizontal section is illustrated in Fig. 2. From outside, the solar wall consists of a double glazing exposed to solar irradiation during the periods of sun light. A three centimeter air gap is enclosed between the double glazing and an air-tight partition built with cement mortar. At the back, there is a ventilated layer conducted through two vents drilled in the insulated panel.

The solar wall absorbs part of the solar irradiation. Due to the greenhouse effect in the enclosed layer, the solar energy is converted to thermal energy which is transferred to the storage material resulting in a temperature rise. As the time passes, the storage material releases the stored energy through its inner surface to the ventilated layer causing the air to warm up.

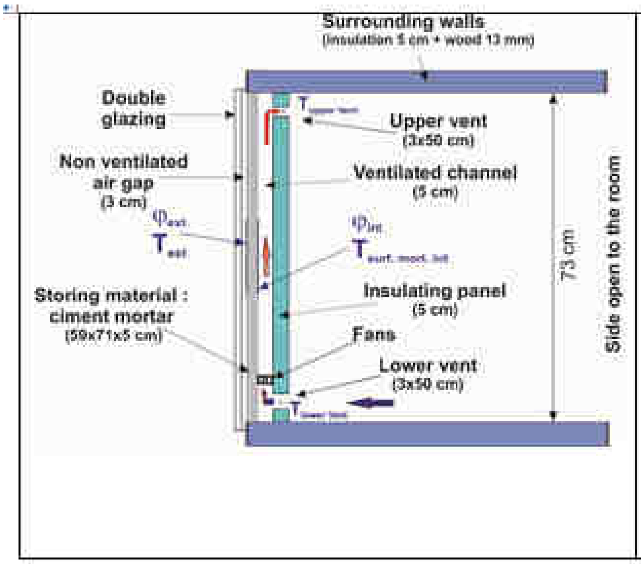

Fig 1. Vertical Section

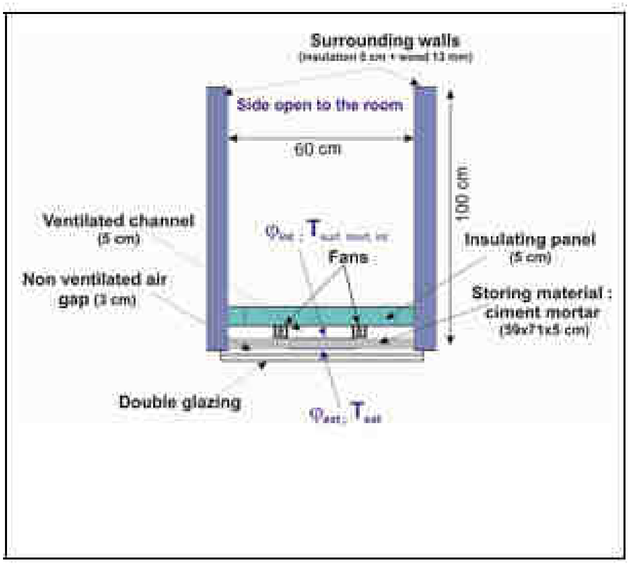

Fig 2. Horizontal section

1. Measurement and recording instruments

The instrumentation used for the experimental set-up of solar wall consists of a pyranometer, thermocouples, and tangential gradient fluxmeters. A pyranometer is a radiometer designed to measure broadband solar irradiance on a planar surface. The pyranometer is located in the vertical plane of the façade receiving the incident solar flux. Tangential gradient fluxmeters and thermocouples measure the heat flux and the temperature on each face of the storage material. T-type thermocouples with a diameter of 0.1 mm are used. The thickness of fluxmeters is 0.2 mm. The fluxmeter dimensions are 15 cm. x 15 cm. and the sensitivity is nearly 110 $\mu V.W.^{-1}m^2$. The fluxmeters are calibrated for a precision level of nearly ±3%. The fluxmeter measures the incoming and outgoing heat flux. On the ventilated channel side, the fluxmeter measures the convective and the radiative heat exchanges between the storage material and the insulated wall.

III. THE ELECTRONIC CONTROLLER

As shown in Fig. 3, a temperature sensor fastened to the inner surface of the storage material senses the temperature inside the solar wall. When the temperature becomes high, corresponding to a large amount of stored thermal energy, two electric fans are used to accelerate the air flux into the back ventilated layer. The entire energy management system shown in Fig. 3 is fully autonomous as all the energy needed by the system is provided by a photovoltaic solar panel.

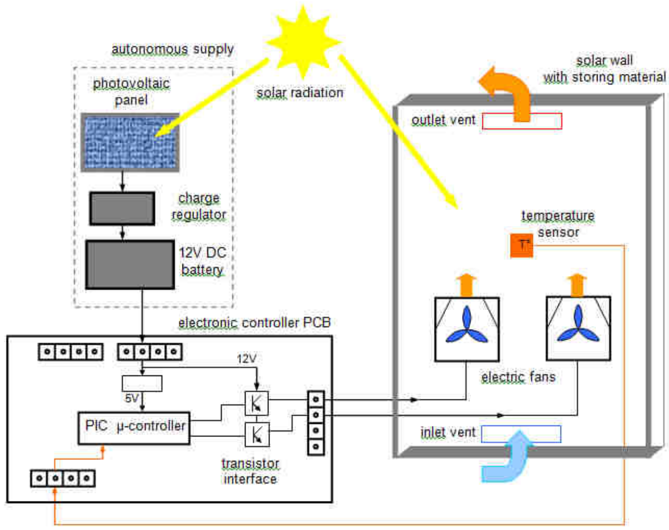

Fig 3. Block diagram of the electric controller

1. The autonomous power Supply

The electronic controller is supplied with DC current under a 12V voltage. The current for the electronic PCB equals 22 mA for its own functioning, so the electronic components need 0.26 Watt power. The two fans consume 2.9 Watts each, only when they are operating. We consider an average duration of 4 hours per day that the two fans are operating in December which is the unfavorable period with the lowest insolation. The average global consumption equals 29.44 Wh per day.

The consumption of electrical energy is very low, so it is possible to set this system autonomous by using a photovoltaic panel to collect the needed energy from the sun radiation. So, as the solar wall with the thermal energy, the electrical energy is stored in a battery to possibly ventilate when the sun light has disappeared during the evening for example. Considering a minimum storing efficiency of 80%, a lead battery providing 12V, 12Ah is sufficient for our application.

The solar panel collects the sun energy and as a result of the photovoltaic effect, converts it to electrical energy. A mono-crystalline silicon panel has been chosen for our application. It consists of a constructor SUNSET type AS55C. These characteristics are peak power 55W_p,open circuit voltage 20.7V, short circuit current 3.5A, max power point 16.9V 3.25A, dimensions (mm) 980* 450* 35.

To calculate the collected energy, the local characteristics of the solar irradiation for Bethune are used. These characteristics correspond to the physical orientation of our solar panel which is on vertical position facing south without shadowing. As the solar wall will be mainly operating during the winter season from October until May, the period with the lower insolation is considered which is December for the north hemisphere. The global solar irradiation equals 874 Wh/m^2 per day for December in Bethune.

The energy collected by the solar panel can be estimated and converted to electrical energy. The efficiency of the solar panel has been measured under the following conditions: irradiance 1000W/m^2 , Air mass 1.5, and a cell temperature 25°C. The solar panel will produce its peak power during N_e=0.874 hour per day in December. Thus on the average, it produces 48 Wh per day.

The energy produced from the solar panel is higher than the energy needed to supply the ventilation system even during the unfavorable period of low insolation. The function of the battery is just to store the electrical energy from the photovoltaic source and to allow for the functioning of the controller in the absence of direct sun light.

It is not possible to directly connect the solar panel to the battery. A charge regulator must be inserted to control the charge level to avoid overcharge of the battery and to limit the discharge. It must be calibrated according to the solar panel specifications.

2. The controller hardware

To automatically control the two fans used in this solar wall, we use a programmable electronic device realized on a Printed Circuit Board (PCB). On this PCB, the main unit is a programmable microcontroller (µC) type PIC 16F877 built by Microchip. The Fig. 4 shows the picture of the PCB.

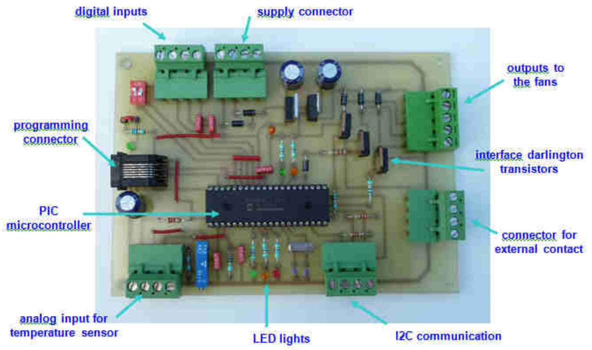

Fig. 4: Picture of the PCB

The 12V DC battery supplies the PCB, and the voltage regulator provides the +5V voltage to the microcontroller. Two digital outputs drive Darlington transistors used as interface circuit to supply independently the two fans which are assembled in the solar wall to accelerate the air flux in the ventilated layer. These fans are very small electrical actuators built by SUNON type 14CFM. As shown in Fig. 5, their size is 40 mm x 40 mm x 15 mm, consumption 2.9W, air flow 14CFM, low noise 44.2 dBA. Each fan integrates a DC brushless motor running at 12000 rpm.

Fig. 5: Picture of an electric fan

A temperature sensor is fastened to the solar wall on the inner surface of the storing material. This sensor provides a voltage proportional to the temperature. The ratio equals 10mV/°K. This signal is connected to an analog input of the µC to be converted to a numerical value.

The main task of the processor is to compare the measured temperature of the storage material T_w with different temperature references Th_{on} and Th_{off} . If T_w increases more than th_{on}, the two fans are switched on for ventilation. If T_w decreases to less than Th_{off}, the fans are stopped. To set the right values of these thresholds, we adjust Th_{off} lower than

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Th_{on} for a few degrees. So a hysteresis window is programmed to avoid fast changing of the fans' control.

In Fig. 4, it is shown that many other components are installed on the PCB. LED lights of different colours are connected to µC outputs to display events such as parameters variations or results of a special diagnostic subroutine in the µC. A 12C serial port is designed for future developments, for example remote control or communication for home automation or supervision.

IV. RESULTS

We will initially focus on the experimental results obtained on the first day of the experimental set-up period. The red curve is the variation of the global solar irradiance given from a pyranometer which is placed on the vertical frontage. The day light started at 5:45 am and finished after 10 pm.

The green curve (φ_{ext}) gives the recording of the heat flux measured on the outer side of the storage material. Just after the sun rise, this incoming fluxis positive and increasing following the sun irradiance. The solar wall starts to transfer and store thermal energy in the storing material.

The blue curve (φ_{int}) on Fig. 6 and the same on Fig. 7 show the inner heat flux from the storage material in the ventilated layer. During morning, this flux is very low corresponding to a non transfer of energy to the housing.

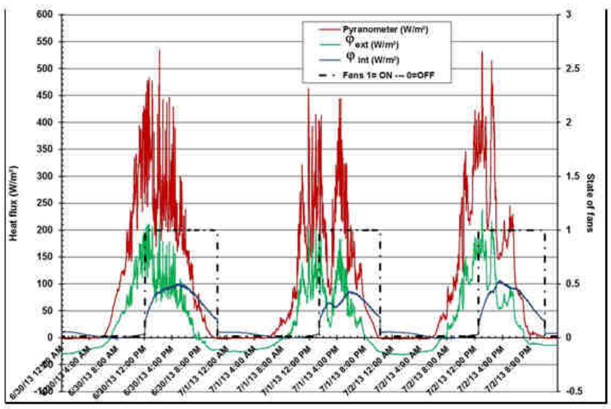

Fig 6. Recording of insolation and heat flux

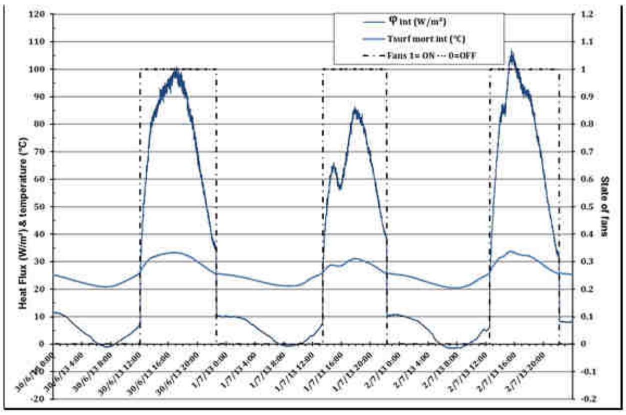

Fig 7. Recording of inner heat flux, temperature and fans' functioning

Fig. 7 shows the variation of the inner temperature on the surface of the storage material represented by the light blue curve which increases from 21°C to 26°C at midday. The dotted black line shows the on-off state of the fans. Before midday this line is at low level, and the fans are stopped.

At the end of morning, the sensor temperature reaches the threshold value Th_{on}. The electronic controller detects this change and switches on the two fans which accelerate the air circulation in the ventilated layer. It may be observed that the heat flux jumped from 5 to 35 W/m^2. As shown in Fig. 8, fresh air comes through the lower inlet vent and the difference of temperature between warm charged material and the air creates a thermal transfer. It corresponds to an extraction of energy from the storage material to the ventilated layer and warm air is injected into the housing through the upper outlet vent.

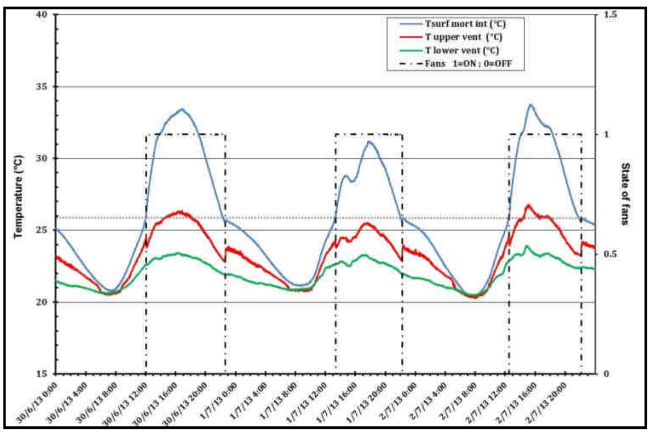

Fig 8. Recording of temperature in the ventilated layer

From the blue curves on the Fig. 7 and Fig. 8, we notice that the temperature of the storing material continues to increase over 33°C at 5 pm. Thus, the collection of solar energy is active due to a good insolation during the day which permits a thermal charge of the solar wall while the two fans are ventilating.

At the end of afternoon, the solar radiation decreases but the two fans are operating until 10 pm. This extended functioning of the fans corresponds to the extraction of the stored energy from the storage material. Its temperature decreases to 26°C due to mixed convection until the fans stop. Afterwards, the heat flux falls from 35 to 10 W/m^2 and the solar wall operates quietly during the evening.

When the temperature decreases under Th_{off}, the electronic controller shuts off the two fans at 10 pm. During the night, a long and low natural discharge of the solar wall continues. The inner heat flux is always positive, as shown by the dark blue curve on Fig. 7. The outer flux becomes negative at 9pm as shown by the green curve on Fig. 6 and a low quantity of the energy stored during the daylight is lost to the outer environment through the glazing.

Regarding the operation on the two following days, that is, July 1 and 2, the variation of the variables is almost the same. During the second day, that is, July 1, a lack of solar radiations occurred during the afternoon. The deficiency of solar collection induce a lower incoming heat flux into the material and a negative variation of the material temperature results. So the magnitude of the inner flux is lower and the fans are ventilating shorter duration.

The afternoon of the third day, that is, July 2, is characterized by a lower insolation because of a cloudy sky. The morning was very sunny with a good collection of solar energy and a good charge of the storing material.

V. CONCLUSION

In conclusion, it has been shown that better energy management can be realized by developing an active solar energy system which includes solar wall, electronic sensors, microcontroller and electric fans. Through the use of automatic controlled ventilation, different durations of thermal exchanges can be obtained. Fig. 9 illustrates these phenomena.

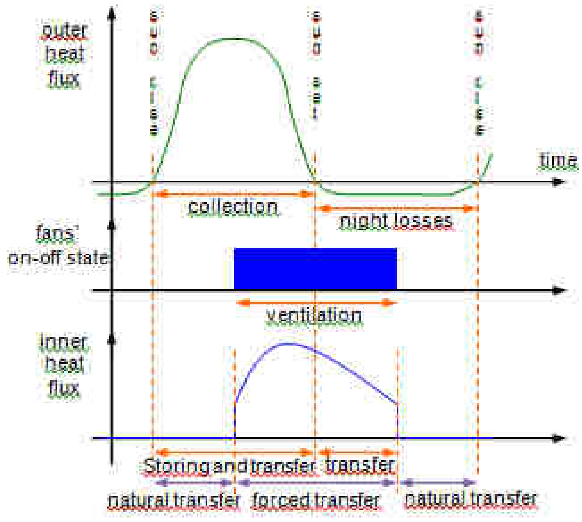

Fig 9. Different durations of thermal exchanges

Just after the sunrise and depending on the sun radiation level, the collection of solar energy starts through the outer glazing until the sunset. The storage material of the solar wall transfers and stores a quantity of energy until the afternoon. During the day, the temperature increase activates the fans and the forced ventilation extracts thermal energy through the inner surface of the charged mate4rial and injects warm air into the housing. This active transfer of energy continues until the night depending on the quantity of collected energy.

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