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EXPERIMENTAL STUDY ON COMBINED WINDOW / SOLAR COLLECTOR FOR PASSIVE THERMAL COMFORT AND WATER HEATING

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A3 – Energy Sources
Use of Solar Energy

Abstract. *Thermal comfort and water heating in buildings are two services which consume a lot of electric energy. Windows are essential esthetic elements in a building permitting natural illumination and visual contact with the external ambient. They are responsible for the big thermal load and degradation of the room interior due to UV radiation. Hot water is equally energy consuming service necessary for domestic and commercial sanitary activities. To reduce energy consumption and emissions while keeping passive thermal comfort and supply of hot water for general use, a novel window that combines the function as a window and also as a solar collector for hot water is proposed. This window can also be used as skylight element for natural internal illumination. The window is composed of double glass separated by a gap where water is allowed to flow under a head. A radiation reflecting film is fixed on inner surface of the second glass sheet. The combined window/solar collector was tested under real open air conditions at different angles of inclinations ranging from nearly 0° to 90°. The results indicate a thermal efficiency varying from 45% to 67% and hot water volume of 47(L) at final temperature of 57 ^{o}C for collector area of 0.5358(m^2).Also it was found that, at small inclination angles the collector performance was also good confirming its suitability as an element for skylight.*

Keywords: *Thermal comfort, solar collector, passive comfort, combined window/solar collector, free hot water*

1. Introduction

Energy is one of the fundamental and essential requirements of living beings. Since the conventional energy resources are fast depleting and their cost is increasing, it is a prime concern of human being to save energy. Most of the power is obtained by the use of fossil fuels, (like coal, oil, gas etc.) which are not environmental friendly and emit an excessive amount of carbon dioxide and other pollutants that in turn cause global warming and greenhouse effects. The main solution to this problem is to effectively make use of the renewable energy sources available around us. Renewable energy is commonly defined as energy obtained from replenished natural resources such as solar energy, wind energy, tidal energy and wave's energy etc. Solar energy is one of the best and cleanest energy resources. The use of solar energy is not only beneficial to protect the natural environment of our world, also easily attainable, most economic and effective as compared to other energy resources.

Recently, integration of renewable energy system with architectural design has drawn the focus of researchers to make the building structure thermally efficient. *(Directive 2010/31/EU, 2010).*Precisely, windows are the major element responsible for building energy inefficiencies, due to the thermal loss or gain. Recent estimates depict that windows contribute 35% to 40% to the total building energy costs (*U.S. Department of Energy (Ed.), 2009).* The transmission index of a clear glass is about 90% which indicates that almost all the solar radiations can pass through it, which in turn are converted to heat when absorbed by internal ambient and are responsible for degradation of the room interior. Yet windows are obviously a necessary element of architecture, and architectural trends seem to show increasing usage of glass in building facades, which increases the problem further. Modern fenestration systems have been developed to improve building efficiency, cost adequacy and thermal comfort (Corgnati *et al*. 2007) because windows, without any doubt, are essential feature of an architectural design. The use of solar thermal collectors placed in certain parts of the building envelope has been suggested in order to resolve this concern (Hestnes, 1999).

In order to fulfil the increasing sustainability and conservation demands, window technology is going under rapid evolution. In recent years, a number of innovations in design and material have given new perspectives to window glazing. Literature review shows that considerable efforts had been invested in research and develpment of window technology.Some glass window concepts have been investigated by using alternative filling materials such as silica aerogel by (Einarsrud *et al*. 1993),use of phase change materials(PCM) by (Ismail and Henríquez, 2002). Arasteh *et al*., (2008) have proposed the use of thin plastic films as non-structural center panes in order to improve efficiency yet maintaining overall window width, mass, and visual transmittance. Etzion and Erell (2000) described a novel ventilated reversible glazing system to minimize the transmission of radiant energy through windows. Their glazing system was designed in such a way that it was capable to overcome flare and radiation damage to interior furnishings, yet causing no energy-efficiency reduction compare to a conventional window. Ismail and Salinas (2006) formulated simplified models for spectral radiation modeling by examining gases with strong infrared radiation absorption characteristics.

Ismail *et al*. (2008) compared the thermal efficiency of glass windows filled with absorbing gas with windows filled with phase change material (PCM). Fluid flow through the gap between the glass sheets of a double panel window can enhance the thermal efficiency of windows. Experimental work on ventilated windows has been reported by (Onur *et al*. 1996).
Chow *et al*. (2010) formulated a solar window for cooling-demand climate. Their paper describes an innovative concept of water-flow window and highlights the potential fields of application. The results indicate that this new design is able to supply hot water, as well as reduce air-conditioning load and increase thermal and visual comfort. Clarke *et al*. (2011). Tested a prototype of the water-flow glazing system, with a reflective coating at the inner pane. Their results show that the year-round space cooling load for a range of feed water flow rates can be reduced from 22% to 35%.Chow and Chunying (2013) presented a liquid-filled solar glazing design for water-flow. A water-flow window had been constructed at the front wall of an environmentally controlled test cell to keep track of its performance under full-scale operational building-like conditions. A comparative study was done in which different glazing types were used.

This paper proposes a novel combined window /solar collector for passive thermal comfort and water heating as a particular type of Transparent Solar Thermal Collector that has two glass sheets making up a chamber through which water can flow in a controlled way. The static head of the water circuit allows stream of water to flow within the gap between the two glass sheets. A radiation reflective film is provided at the inner glass sheet. This combined window/solar collector absorbs a part of the incident solar radiation, which is then utilized to heat up the water flowing through the gap between two glass sheets. The energy flow-paths related to such a glazing system are shown in Figure.1.

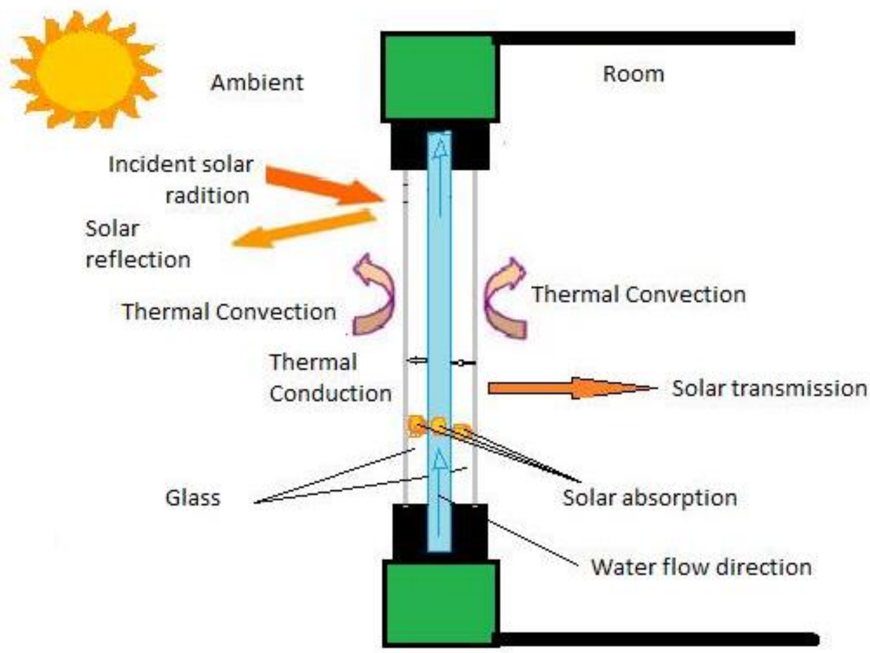

Figure 1. Energy flow-paths within water-flow glazing system

2. Experimental set-up

The double glass window of area 0.5358(m^2) with radiation reflective coating at inner pane has been tested experimentally at different angles. By measuring the water flow rate, inlet and outlet temperatures of the flow circuit across the glazed area, the useful heat gain of the system is determined. A radiation meter was installed parallel to the window/solar collector to record the incident solar radiations. The sensor signals (including thermocouples) were sent to a data logger and downloaded periodically for performance analysis. In this way, the system efficiency which is the ratio of useful heat gain to the water to the incident solar radiation on the glazing surface was evaluated.
The experimental set up for testing combined window/solar water heating collector is shown schematically in Figure.2 (a, b). It consists of a window/solar collector, water feeding tank, storage tank and a water circulating pump. The combined window solar collector is made up of two glass sheets of total dimensions of 0.94(m)x0.57(m) and effective area of 0.5358 (m^2). The glass sheets are bound together with spacing of 5(mm) between them, their perimeter is sealed and the combined sheets are allocated within a metal frame hinged at its top side to two columns attached to a movable base for easy transport. The circulating water is fed at the bottom header from the water feed tank under static head and discharged at the top header to the storage tank. To ensure uniform water distribution in the spacing between sheets a fine

screen is placed along both headers. The water circulating pump sucks water from the storage tank and supplies it to the top feed tank.

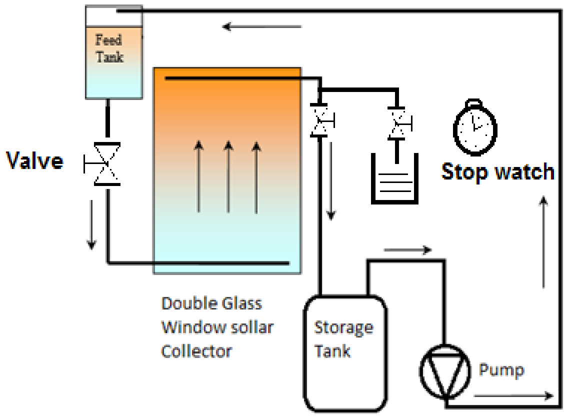

Figure 2(a). Schematic diagram of double glass window /Solar collector as a water heating device.

Figure 2(b). Experimental setup.

In order to evaluate the thermal performance of the collector, measurements of the temperature distribution along and over the front glass internal surface area were taken by calibrated thermocouples of the T type. The external surface area and the external surface temperature of the back glass sheet were also measured. Temperatures were also measured along the water flow direction between the glass sheets and at entry and exit of the combined window/solar collector.
The feed tank allows water to flow through the combined window/solar collector under gravity action. Its mass flow rate is measured by directing the water flow at the exit of combined window/solar collector to the mass measuring section as indicated in Figure.2 (a). After collecting a certain mass in a certain time the water is reverted back to the water circulation circuit. The wind velocity, the ambient temperature were also measured. The solar radiation is measured by an instrument placed at the same inclination of the combined glass sheets.
The detailed technical specifications of the collector, the thermal storage and measuring devices are listed in the Table-1.

Table 1 Technical specification of the components and instruments

Design parameters and devices	Specifications
Tilt angles	0°,5°,10°,20°,35°,45°,55°,65°,75°,90°
Uncovered area of collector	0.5358 m^2(0.94×0.57)
Support	Aluminum
4 Thermocouples	T-Type
Radiation meter	Solar power meter MES-100
Field logger	Novus V 1.4
Storage tank	47(Liters)
Feed tank	11(Liters)

2.1. Test procedure

The procedure used in a typical test of the combined window/solar collector usually started by fixing the combined window/collector to the required inclination relative to the horizontal position and the radiation measuring instrument parallel to the surface of the window/collector. The valves fitted to the storage tank and the water feed tank are set to the operation position. All thermocouples are connected to the data acquisition system and the initial temperatures are registered. The pump is switched on and the reading of the radiation measuring instrument is registered. Water flow rate is measured after every 15 minutes and an average is considered as representative of one full day of testing. The tests usually continued for 5 hours daily. Wind velocity and ambient temperature were measured each hour. It is important to mention that the measurements were used to calculate the hourly average parameters by taking the hourly average of the measured parameters and the results are presented on an hourly basis as will be seen later.
This test procedure repeated for the following day after setting the combined window/solar collector to the new inclination each day. The inclination angles are presented in Table 1. It is important to mention that the inclination is varied since the window consequently the solar collector can take any angular position except 0^o to the horizontal. In this position the glass sheets were damaged due to vapor formation and blockage due to stagnant conditions in the collector.

Uncertainty analysis of experimental measurements were performed for the mass flow rate, heat gain and temperature indicated by the thermocouple. The uncertainty found is presented in Table 2

Table 2 presents the accuracy of various measuring devices used in the experiment

Parameters	Accuracy
Temperature difference (Thermocouple)	±0.505 (°C)
Heat gain (Q)	±6.15 to 11.06 (W)
Mass flow rate	±2.94e^{-4} to 3.47e^{-4} (kg/s)
Solar power meter	±0.38 W/m^2
Tilt angle	±1°

2.2. Theoretical Analysis

In order to determine the efficiency parameters of solar thermal collectors, following equations were used.

T_{in} *Inlet temperature (°C)*
T_{out} *Outlet temperature (°C)*
ΔT T_{out}-T_{in}
η *Efficiency*
I_o *Incident radiation (W/m^2)*
A *Area of glass window (m^2)*
$\dot{m}$ *Mass flow rate (kg/s)*
C_p *Specific heat of Water (Room Temp.)(J/kg.k)*
Q_{out} *Energy out (W)*
Q_{in} *Energy in (W)*

In order to determine the efficiency of solar thermal collectors, two different procedures can be used: the steady state test and the quasi dynamic test method. During the steady state test, all boundary conditions such as incident solar irradiation, ambient temperature and inlet temperature of collector shall be maintained constant. In This technique, the basic idea is to expose the collector to solar radiation and measure the inlet and outlet temperatures of the working fluid flowing through it with a known flow rate. The heat rate gained by the fluid is then given by. (Duffie & Beckman, 2006)

$$Q_{out} = \dot{m} c_p \Delta T \qquad (1)$$

The source of heat in a solar collector is solar energy and the input power is usually the incidence radiations, Io, received on the surface of the collector, absorbed and then transferred to the working fluid.

$$Q_{in} = I_o A \qquad (2)$$

By dividing the net energy output by the input energy, an overall efficiency can be defined. Such efficiency is considered as instantaneous efficiency because it is a function of instantaneous operating conditions such as the ambient temperature, the wind speed, etc.

$$\eta = \frac{Q_{out}}{Q_{in}} \qquad (3)$$

3. RESULTS AND DISCUSSION

The experiments were conducted over a period of three months, from November to January, on a parking area located at Unicamp University Campinas. The experiments were conducted from 10.00 am to 03.00 pm.
The collector was tested at 0°,5°,15°,20°,35°,45°,55°,65°,75°,90° angles at constant mass flow rate. All readings were taken periodically for performance analysis. After every 30 minutes the solar radiations values were measured by solar radiation meter.
Figure.3 (a,b) shows the variation of solar radiations and outlet temperature (T_{out}) respectively at an angle of 90^o to the horizontal (when the window is in vertical position) during the experimentation hours. The outlet temperature was up to 40°C for the volume of 47L of water during 5 hours.

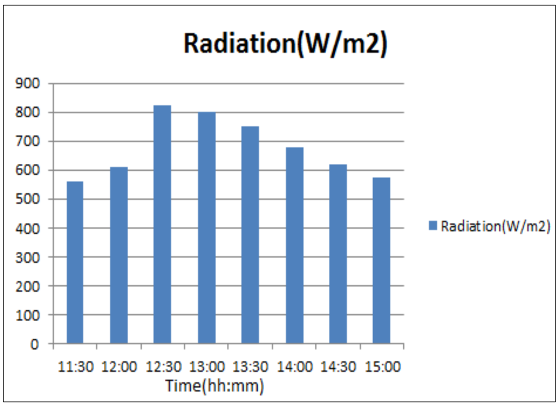

Figure 3(a). Variation of solar radiations during experimentation hours at 90°.

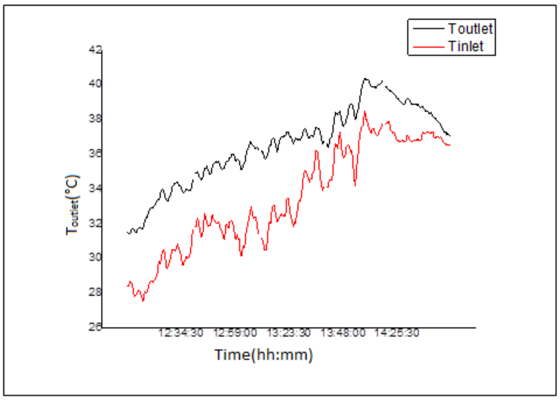

Figure 3(b). Variation of hot water outlet temperature during experimentation hours at 90°.

Figure 4(a,b). Shows the variation of inlet temperature (T_{in}) and outlet temperature (T_{out}) w.r.t time at an angle of 0^o.It can be seen that at some points the inlet temperature is higher or equal to outlet temperature to due to vapor formation. It shows that window/collector can be used at any angular position except 0^o to the horizontal.

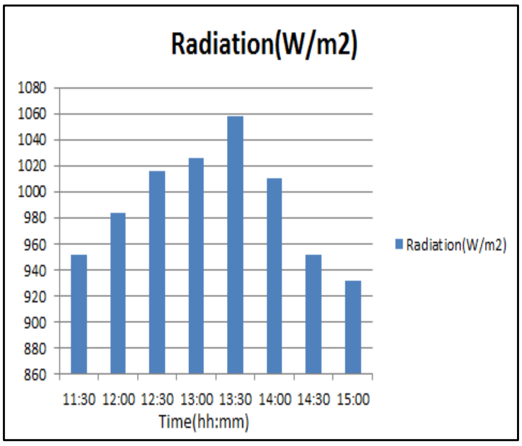

Figure 4(a). Variation of solar radiation during experimentation hours at 0°.

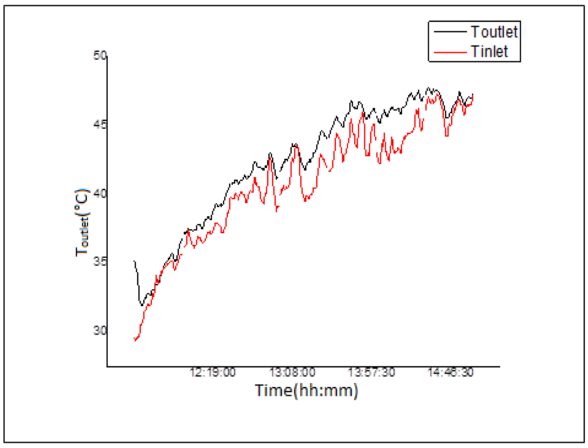

Figure 4(b). Variation of hot water outlet temperatures during experimentation hours at 0°.

Figure 5. Shows the average variation of inlet and outlet temperatures during experimentation hours with respect to angle. The maximum average outlet temperature recorded was 323 (k) at an angle of 45° degree. The average temperature difference (T_{out}-T_{in}) was about 7($^{\circ}$C) at an angle of 90^o (which corresponds to the case of normal window position).

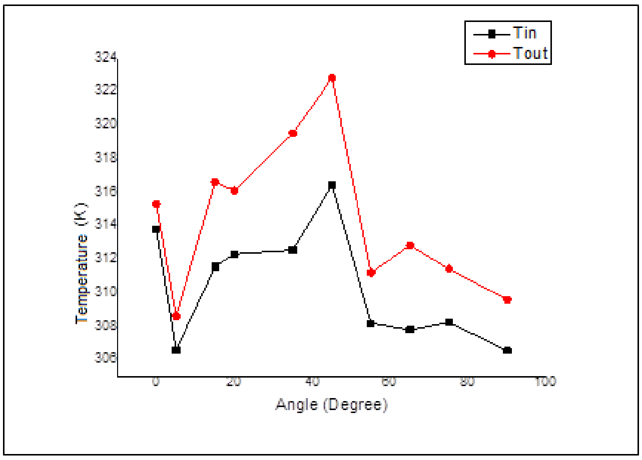

Figure 5. Variation of temperature at different angles

Figure 6(a, b). Show the variation of Q_{in} , Q_{out} and thermal efficiency w.r.t. angle. The efficiency of collector was higher between 45° angle to 65° angle. The thermal efficiency at angle of 90° (when the window is in vertical position) was 43%. Therefore, this novel window is an interesting alternative to conventional windows in order to reduce solar gains, to protect the interiors of building, to reach significant heating, ventilation and air conditioning (HVAC) energy savings, and to take advantage of solar energy for commercial and domestic water heating.

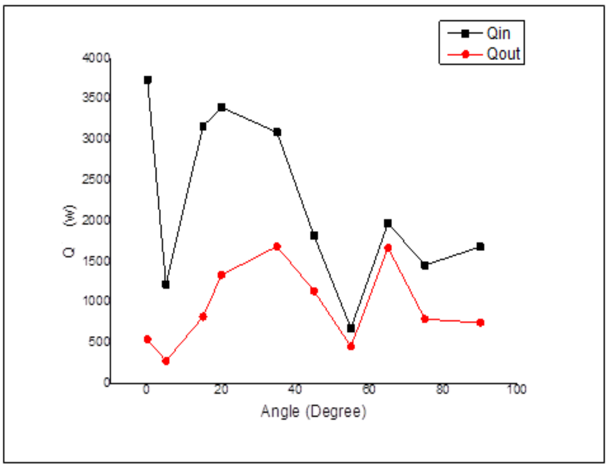

Figure 6(a). Variation of heat gain at different angles

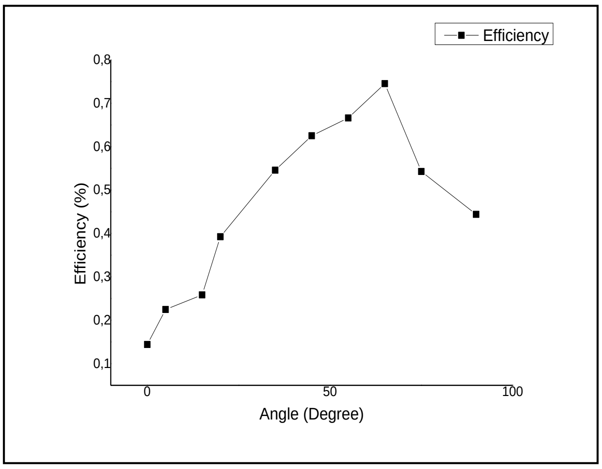

Figure 6(b). Variation of thermal efficiency at different angles

4. Conclusions

Field tests of the combined double glass window/ solar collector proved that the concept is feasible and can be used in domestic and commercial buildings for thermal comfort, architecturally more appealing and hot water generation. The presence of the reflective film seems to increase the heat gain while keeping the back side of the collector facing the room at relatively low temperature. The field tests showed variation of thermal efficiency of 45% to 67% at final temperature of 57(°C) during five working hours with collector area of 0.5358(m^2).

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