# Numerical and Experimental Evaluation of an Enhanced Transparent Insulation System on a Glass-Plate Cavity

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***Abstract.*** *Flat plate solar collectors for use in domestic hot water systems have their efficiency highly compromised by the heat losses on top. This region has the insulation com- plicated as it depends on high transparency levels to let solar radiation reach the absorber surface of the collector. Heat losses by this surface typically represent 60% more than global ones. Several alternatives have been analyzed to attempt to work around this issue highlighting the use of transparent insulation materials or double glazing. However, these techniques have not shown feasibility to allow their commer- cial application. This work evaluates the use of an insulation system that has little effect on collectors transparency and it consists of using hurdles in the region between the absorber plate and the glass cover. Experimental tests were performed to evaluate the thermal convection in this region with heating at the bottom provided by using electric heaters with electronic temperature control. A two-dimensional numerical solution using isothermal surface was also obtained using Openfoam software. The numerical results show the existence of an optimal insulation condition which varies according to operating conditions of collector. The results obtained for sloped cavi- ties at various angles are presented and discussed but still greater detail is presented for a 30 ◦ slope with horizontal. The results show that if these systems are properly designed they can significantly improve the efficiency of glazed solar collectors.*

***Keywords****: Solar energy, Transparent Insulation Material (TIM), CFD Simulation using OpenFoam*

## 1. INTRODUCTION

Analyzing the energy demand in the world consumption matrix it is verified a significant increase in per capita consumption of contemporary society. Although technological advances have been able to meet this demand, the major trouble is that the main world energy source is not a sustainable resource. As concerns to solar energy, it is an important alternative source and sustainable for long term. Many ways to take advantage of solar radiation were developed, but the use in Solar Domestic Hot Water Systems (SDHWS) is yet the most widely used alternative. These systems are usually composed by solar flat plate collectors which, although widely studied, still have relatively low efficiency. The main reason for the low efficiency is the heat losses from the top surface of the collector. Thermal insulation in this region is very complex, because their inclusion implies less transparency of the system and, consequently, also decreases the energy absorption of collector, as reported by Hollands (1965).

Several studies have been made to find what Transparent Insulation Materials (TIM) are able to meet these conditions. A classification for various possible uses of transparent insulation schemes is Wong et al. (2007) and Kaushika and Sumathy (2003). In these studies, the systems are divided into four groups, according to their constructive aspects. Others also show gains in thermal efficiency by using these systems, such as Marcus (1983) and Hollands and Iynkaran (1993). In these work, the reduction in heat losses in some conditions by using honeycomb thermal insulations is estimated.

Hollands and Lynjatan (1985), in their turn, introduced a gap between the plate and the transparent insulating material. In this case, it was found a significant decrease in convective heat transfer coefficient for the flat solar collector. Results for thermal efficiency in collectors show gains up to 40%, as presented by Kaushika and Sharma (1994).

Abou-Ziyan and Richards (1997) and Ghoneim (2005) investigated some possible combinations. Results have shown that the use of a single one air space, underneath the trans- parent insulation material, is the most effective scheme.

The thermal effectiveness of Transparent Insulation Materials (TIM) depends basically on reducing the thermal losses on collector top. However, this value is also dependent on the collector operation and on environment temperatures. Working with these parameters, Rommel and Wagner (1992) analyzed the increase of collector thermal efficiency at high operating temperatures in a range from 90◦C to 150◦C. Complementing this study, Wong et al. (2007) also evaluated the improved efficiency during colder periods.

Other aspects that may present problems in using Transparent Insulation Materials(TIM) were highlighted by Simon (1976) and Rommel and Wagner (1992). The main issues high- lighted were imperfections in manufacturing, degeneration in high working temperatures, high cost and lack of important information on the subject. Considering the importance from transparency for insulation material, Hollands et al. (1978) and Kaushika and Priya (1991) evaluated the optical behavior in a wide range for solar radiation incidence angles.

Analytical and numerical models for studying the behavior of transparent insulation materials were also developed. For example, analytical solutions using predefined physical parameters can be found in works from Platzer (1992) and Hollands and Iynkaran (1993). These models are based on estimating the film coefficient and can evaluates the heat flow inside the cavities.

Kaushika et al. (1994) and Kessentini et al. (2012) included the dynamic effects in the numerical model presented. Hollands and Iynkaran (1993) in their turn, used polynomial approximations to predict air flow thermal behavior. Kumar and Kaushika (2005) used the models to evaluate the effects in changes of collector inclination angles. In this study it was verified that horizontal systems have more intense flow instabilities than the inclined ones. So, the collector slope helps to stabilize the flow and, consequently, the transparent insulation system workability.

Another option that has been used recently is the replacement of air inside cavity by other gases or aerogels. Vestlund et al. (2009) and Dowson et al. (2012) show that one can achieve a significant reduction in heat losses with this technique. The major problems reported in this case are collector airtightness needs and implementation costs.

Although many efforts have been directed towards studies of Transparent Insulation Material (TIM), the materials previously developed present an inadequate cost-benefit ratio for their commercial application. Structured materials with transparent systems tend to have a higher cost. Hence, only significant improvements in performance could make them economically feasible. Simple structured insulation systems, such as the case of transverse hurdles, tend to have lower costs.

Based on this situation, this study conducted an experimental evaluation of hurdles influence at perpendicular to natural flow within the plate-glass space. Experimental tests were performed on a prototype with dimensions close to commercial collectors. The prototype structure was built using wood and a removable upper glass plate, as to allow the placement of hurdles. As a heat source, resistance wires are used in the lower side of a thin aluminum plate. Fig. 1 shows the device scheme. Different slopes are also analyzed due to possible differences in local latitude. The prototype has dimensions of 1000x500 millimeter.

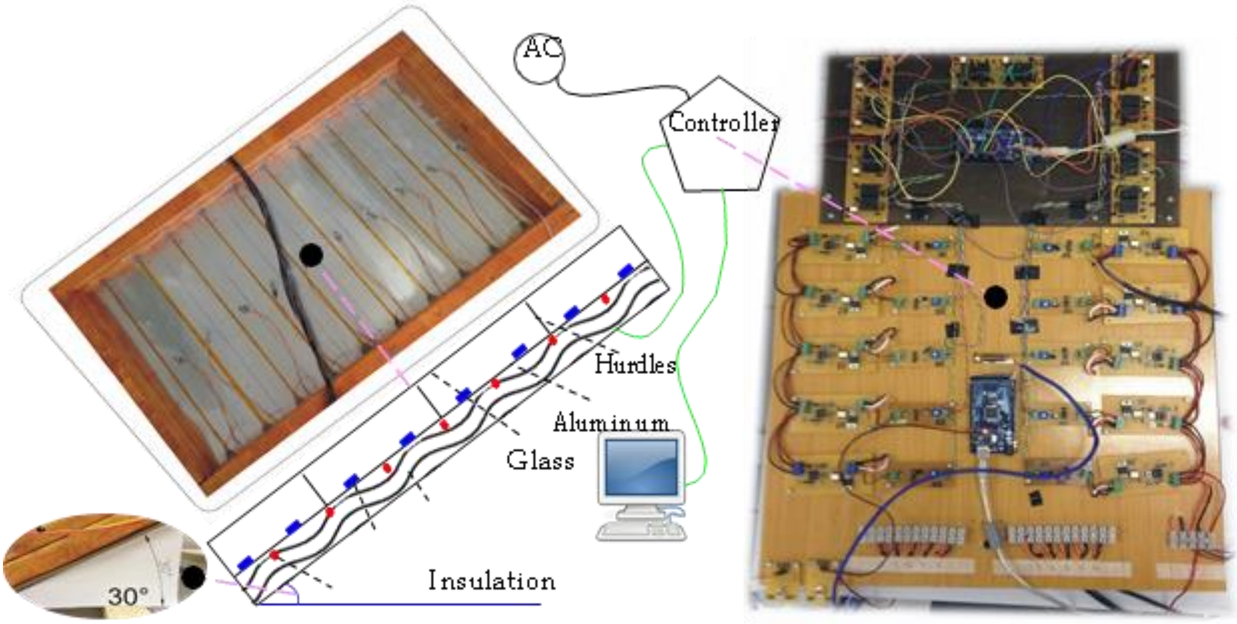


Figure 1. Scheme for experimental test device.

## 2. MATERIAL

The thermal conditions and heat losses from solar collectors were simulated for different conditions. Tests were made on a hot box with 40 mm distance from a thin hot aluminum plate to glass cover. The heat flux was provided by 10 electrical resistances attached at the bottom of aluminum plate, equally spaced by 100 millimeters each. The aluminum plate has small thickness and high thermal conductivity allowing temperature uniformity on its surface. A temperature sensor was attached to every mid-space between consecutive resistances. Tests were performed with the same reference temperature specified in all sections. The number of cavities was tested from one to five and for different inclination angles of 0◦, 30◦, 45◦ and 60◦.

Fig. 2 highlights the positioning of temperature sensors secured in the glass. The calculated average of these sensors to be considered as the temperature of the glass surface.

Figure 2. Position of glass temperature sensors.

In Fig. 3 it can be seen barriers within the prototype, these barriers serve to lock the internal convective flow.


Figure 3. Position of the barrier.

The apparatus was built using 22 mm thickness wood on the lateral sides, a 4 mm thick transparent glass at the top and a 0.1 mm thick aluminum plate at the bottom. At the bottom of the aluminum plate a 5 cm layer of glass wool insulation was added. A 3 mm thick wood is used as hurdle for separating the cavities. Hot glue was applied at the bottom for better packing. The number of hurdles is different and determine the number of cavities on the test. Fig. 4 shows details from box assembly and the electric circuits present on the controller board.

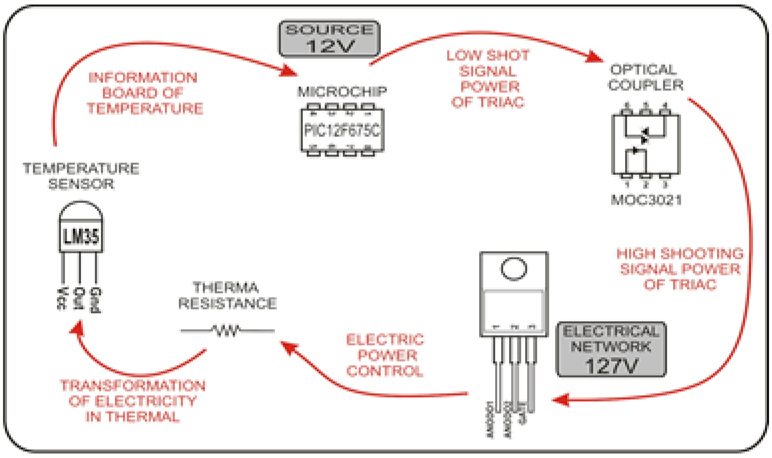


Figure 4. Schematic diagram of the electronic control.

One independent controller was mounted for adjusting the power for each resistance. A PIC (Programmable Interface Controller) was used for the power adjust based on the temperatures reading. The LM35 (sensor thermal resistance) low cost temperature sensors, based on thermoresistance effect, are used for temperature measurements. The temperature signal was transmitted simultaneously to the controller and to an Arduino board for registering. Using this electric scheme with a dimmer controlled by the PIC device, one can establish a constant temperature condition on the aluminum plate. Temperature is set for each of the ten PIC independently. The glass cover has also four LM35 on its external surface for temperature measurements during testing procedures.

The dimmer board was controlled by a variable on PIC code defining the cut-time based on AC frequency. A zero-cross detector alternate current sensor was built for computing the time of cut. Total time is based on 60 Hz grid frequency used in Brazil and, so the maximum limit time is 8.33 ms. For each resistance section on the plate a greater time of cut implies less power on this section. For better control on each device, voltage converters were used for lowering the grid voltage. A TRIAC device was used for triggering AC wave. Despite only one zero-cross detector was needed for the system, the triggering circuit works independently and one was needed for each resistance. This electronic device can control the supply voltage to electric resistances by measuring the plate temperature. It can increase or decrease the electric power if the temperature is lower or greater than the setup value.

Another independent circuit was used for power measurements using resistances arrangement for voltage measurements. The voltage circuit was the same for all circuits and it is calibrated for the measurements using an external multimeter. On preliminary tests a problem was detected when all circuits are in simultaneous operation. To solve this problem, another control board was built using relays for connecting only one measurement circuit at any time. This auxiliary circuit as the voltage meter were both made by using one Arduino board.

Fig. 5 shows an overview of the experiment, containing all equipment used.

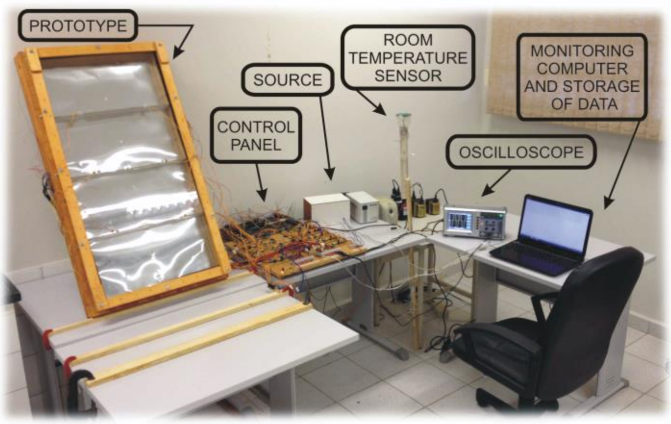


Figure 5. General view experiment.

## 3 RESULTS AND DISCUSSIONS

Since this study aims to develop alternatives for the implementation of transparent insulation systems, its main objective is to evaluate the effect of the reduction in heat transfer rate when increasing the number of cavities. The limiting condition indicates that a very large increase in the number of cavities turns spacing very small. In this case, the convective motion would be nulled approaching to the conduction case what is the ideal condition for transparent insulation systems. However, the use of a very large number of hurdles can affect the transparency of collector surface and, therefore, its thermal efficiency. Thus, the appropriate condition for this case would be a reduction in heat transfer with a small number of cavities. So, tests will be performed for cases from one to five cavities.

All tests were performed in Bauru (SP), Brazil with 22◦ south latitude. Tab. 1. shows experimental results for this case with hot plate inclined on 30◦ relative to the horizontal plane.

The experimental results for this case show some stability in heat transfer rate when increasing the number of cavities. However, one can see a small reduction in heat transfer rate when changing from one to two cavities. From this number, there is astability in this value. However, it is worth highlighting that, to enable the experiment it was necessary to use a finite spacing between consecutive resistors. As it is known, the effect of the convection is intense near the edges and the relative position of resistance in the cavity is a factor that could affect the results. Furthermore, the statistical uncertainty presented by measures could result in more significant changes in their magnitude order. In this situation, the best alternative would be the evaluation in dissipation on each cavity using a resistance distribution uniform only in this region.

Table 1. Results from hot box inclined on 30◦ to the horizontal plane.

| Number of Cavities | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $\bar{T}$ - aluminum plate (◦C) | 101.0 ±0.10 | 101.2 ±0.11 | 101.1 ±0.10 | 101.2 ±0.10 | 101.1 ±0.09 |
| $\bar{T}$ - glass cover (◦C) | 42.70 ±0.06 | 36.20 ±0.02 | 34.78 ±0.02 | 35.54 ±0.03 | 35.38 ±0.01 |
| $\bar{T}$ - Environment (◦C) | 25.64 ±0.29 | 26.78 ±0.21 | 26.07 ±0.26 | 26.61 ±0.32 | 26.02 ±0.24 |
| Heat Power (W) | 84.62 ±5.74 | 88.04 ±5.18 | 91.01 ±5.75 | 89.90 ±5.27 | 90.38 ±5.83 |
| h - Experimental(W/m2/K) | 2.66 ±0.18 | 2.48 ±0.15 | 2.52 ±0.16 | 2.51 ±0.15 | 2.52 ±0.16 |

Fig. 6 presents other experimental results for several inclinations previously highlighted. The results show a similar trend in presenting a reduction of heat transfer rate in a determined condition and thereafter return to growth situation. However, this optimal insulation point tends to present itself in different positions for each different physical situation.

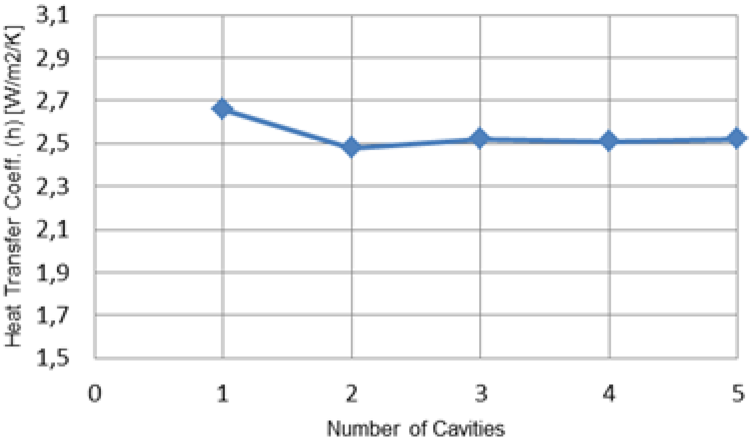


Figure 6. Heat transfer coefficient h for inclination of 30◦ with horizontal and different number of cavities.

These results indicate that the use of transparent insulation systems optimized by this way will have a significant dependence on the operating conditions.

Besides the slope, this optimum condition is influenced also by the collector operating temperature, environmental temperature and others. Additional numerical studies, analyzing the behavior of convection in different conditions, contribute a lot in this regard.

## 4. CONCLUSIONS

This paper presents a experimental and empirical analysis of the use of hurdles in confined air spaces as a way of reducing the rates of heat transfer between their upper and lower surfaces. The study showed that for every physical situation there is a number of cavities when an important reduction in heat transfer rate is observed. This reduction is associated with a phenomenon of recirculations formation, which causes a reduction in the heat transfer coefficient, mainly on its extremities. This change in flow pattern can be exploited to reduce heat losses from solar collectors without affecting their transparency significantly.

In developing this study, it was obtained experimental and empirical results that show good agreement to each other.

The empirical solution has the limitations of Hollands' expression and cannot be used in the evaluation of some conditions. In cases where it can be applied, the results were close to those obtained by other techniques. Further studies aiming the use in solar collectors with non-uniform temperature conditions are required, but the tendency is that this technique will be successfully applied on the design of high efficiency solar collectors.

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