TOWARDS DEVELOPMENT OF TROPICAL SOLAR ARCHITECTURE: THE USE OF SOLAR CHIMNEY AS STACK INDUCED VENTILATION STRATEGY

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Abstract

The approaches in “*Renewable Energy*” are diversifying. We need to make shifts in our perceptions, our accepted models of thinking, making and doing, to “*Renewable Energy”* with our built environment in response to the tropical context. The climatic conditions of these regions are characterized by high air temperatures, high relative humidity’s and very low wind speeds, which make the environmental conditions uncomfortable. The use of solar chimneys in buildings is one way to increment natural ventilation and, as a consequence, to improve indoor air quality. In this context, this paper presents the first stage of full development on solar chimney as stack induced ventilation strategy. This research uses a cylindrical PVC pipe to a solar chimney in low cost residential building. The performance of the chimney was evaluated by predicting the temperatures along the pipe. The effects of air gap and solar radiation intensity on the performance of different chimneys were investigated. In order to verify the theoretical model, experiments were conducted on black and white pipe with each 13 feet heights. This black and white colored pipes were used to understand the effect of color on temperature difference along the pipes. The results indicated a temperature different of 5-6°C before top and bottom . This results encourage research to develop the solar chimney in tropical condition.

Key word : Solar Energy, Tropical Climate, Solar Chimney

A. Introduction

In terms of passive cooling, tropical climatic regions the most difficult problem to solve. The simplest and the most effective solution for active cooling is to introduce air conditioners. However, such equipment involves high initial and operational costs for installation, power and maintenance. Therefore air conditioners are unlikely to be applied widely, in particular, for residential building. Thus, a passive cooling system is more desirable. Although in Malaysia, passive cooling method is a popular cooling strategy adopted in residential building, researches (Pan, 1997; Tan, 1997; Jones, 1993; Zulkifli, 1991; Hui, 1998; Abdul Razak, 2004) have shown that its natural ventilation performance could not provide internal thermal comfort. Climate conscious design in the equatorial tropic assumes that air movement is one of the main cure fure thermal comfort ills.

According to Hui (1998), the indoor air velocity in low rise building 0.04m/s – 0.47 m/s (Hui, 1998). The reasons may be due to inappropriate design solutions for indoor air movement or low outdoor air velocity remains to be determined. However, recent data from the Malaysian Meteorogical Service Development showed that mean outdoor air velocity is between 1 m/s to 1.5 m/s. In theory, there are two natural ventilation mechanisms (ASHRAE, 1997). First is by wind pressure and the second is by temperature difference or stack effect. Both mechanisms have the same aim, which is to act as an aid to create air movement and consequently control the indoor air temperature (Sapian, 2004).

Natural ventilation may result from air penetration through a variety of unintentional openings in the building envelope, but it also occurs as a result of manual control of building's openings doors and windows. Air is driven in and out of the building as a result of pressure differences across the openings, which are due to the combined action of wind and buoyancy-driven forces. Today, natural ventilation is not only regarded as a simple measure to provide fresh air for the occupants, necessary to maintain acceptable air-quality levels, but also as an excellent energy-saving way to reduce the internal cooling load of housing located in the tropics. Depending on ambient conditions, natural ventilation may lead to indoor thermal comfort without mechanical cooling being required.

One of the more promising passive cooling methods for tropical climatic regions is the solar chimney (Satwiko, 1994). This method employs buoyancy driven ventilation to introduce physiological cooling. It utilizes solar radiation, which is abundant in these regions, to generate the buoyant flow. However, as currently applied, the induced air movement is insufficient to create physiological cooling. More studies are needed to improve the ventilation performance of this cooling method. The basic form of the solar chimney has long been known, and applied in vernacular architectural designs. In general, the induced air movement is not used directly to suck indoor air. Instead, it is used for ventilating the building (such as in the double skin building). A stack chimney is usually designed in combination with a wind tower in hot arid climatic regions. In many types of ventilated building, winds are considered to be more important than buoyancy. This is because wind induced ventilation flow is commonly stronger than stack induced flow, in particular, in low rise buildings. Stack induced ventilation (or buoyancy driven ventilation) is, so far, insufficient to create physiological cooling in warm humid climatic regions (tropical climate). Velocities associated with natural convection are relatively small, usually not more than 2 m/s (Mills, 1992). A milk house that was built in 1800s is a historical example of a stack chimney application in . This building has double walls which are combined into a shaft at their upper end. The south facing shaft wall was made from glass. The solar radiation that penetrates the glass heats the inner wall. Eventually, this inner wall heats the air which will rise and induce a flow of fresh air from the openings below (Watson, 1979). Two examples of stack chimney concepts is solar collector and stack height. The former shows one way to amplify stack effect by utilizing solar collectors and increasing the height of the hot air column (stack height). Critical parameters of this design are the stack height and cross sectional area of its inlet and outlet. A massive and high version of this type is needed to generate indoor air velocity as high as 1.0 to 2.0 m/s, which can be achieved easily in ordinary shallow buildings (with no obstruction at all). An attic that was designed to create a green house effect and eliminate the chimney. It heats a much greater volume of air compared to the previous design. Thus, in terms of air changes, it is likely to have a better performance (Baker, 1994). Another solar chimney design called *the Nigerian Solar* Roof. It was studied by Barozzi et. al., using physical and numerical (Computational Fluid Dynamics Codes) modeling and data from Ife, Nigeria. Two experimental findings were noticeable. Firstly, both physical and numerical experiments gave almost identical results. Thus, it showed the potential of CFD Codes to simulate air flow. Secondly, both types of modeling indicated the presence of buoyancy driven ventilation within the model. However, the air speed within the occupant's zone was too low to create physiological cooling. The term *Solar chimney* is used extensively in Barozzi's article as the *chimney* shape is quite obvious. On the other hand, in this thesis the term *Solar chimney* seems to be more suitable as the chimney takes the form of a roof (Barozzi, 1992).

Air movement created by the stack effect is usually too weak to achieve physiological cooling. It is less than the recommended air speed range for cooling of 0. 15 to 1. 5 m/s in tropical condition (Satwiko, 1994). It can be seen that two means are available for improving air movement: firstly, by increasing the air volume (stack height) and secondly, by increasing the air temperature difference. Meanwhile, the indoor air temperature has to be kept low. All the above designs involve stack effect. However, in terms of construction (complexity, technology, etc.) and material (cost, durability, availability, etc.) these designs are not suitable for wide application in low cost housing in tropical countries.

Studies of solar chimneys involve aerodynamic experiments on buoyancy problems which can be done using both physical modeling and computer modeling methods, the latter based on computational fluid dynamics (CFD). Both methods have advantages and disadvantages. Physical modeling is considered to give results that are easy to check. However, for an experiment which involves various model designs this method can become expensive and time consuming. The computer simulation method, on the other hand, allows easy modification of the design, more precise results in less time. Even though computer simulation has a high initial cost (for its hardware and software), the final cost might be lower than that of the physical experiment since changes in the model designs can be made easily.

The objective of this study is to present a experimental model to :

- understand the temperature different and distribution along the chimney
- understand the impact color in temperature distribution.

B. Basic Theory of Stack Effect

Stack effect pressures are generated by differences in air density with temperature, i.e. hot air rise and cold sinks. The air within a building during the wintertime acts like a bubble of hot air in a sea of cold air. In the summer time the situation is reserved, although air temperature differences area usually less.

The density of dry air, ρa, varies with temperature. The greater the height of a column of air, the greater the potential difference in pressure if that column is at a different temperature. The pressure difference generated by a column of air h meters high with temperature difference between indoor and outdoor air at standard temperature and pressure is approximately:

$$\Delta P = 3465 \cdot \Delta h \cdot \left(\frac{1}{T_o} - \frac{1}{T_i}\right) \text{ [Pa]}$$

where To and Ti are the outdoor and indoor temperature respectively, (in Kelvin = Celcius+273)

For example, if the air in a one meter high cylinder, open at the bottom and containing room temperature air (20°C) is taken into the outdoors at the temperature of -10°C, an outward pressure of the 1.34 Pa would act at the top (Figure 2). The pressure at the bottom must be zero since it is connected to the outdoors. The horizontal plane at which the pressure equals the outdoor pressure (i.e. the difference is zero) is called the Neutral Pressure Plane (NPP).

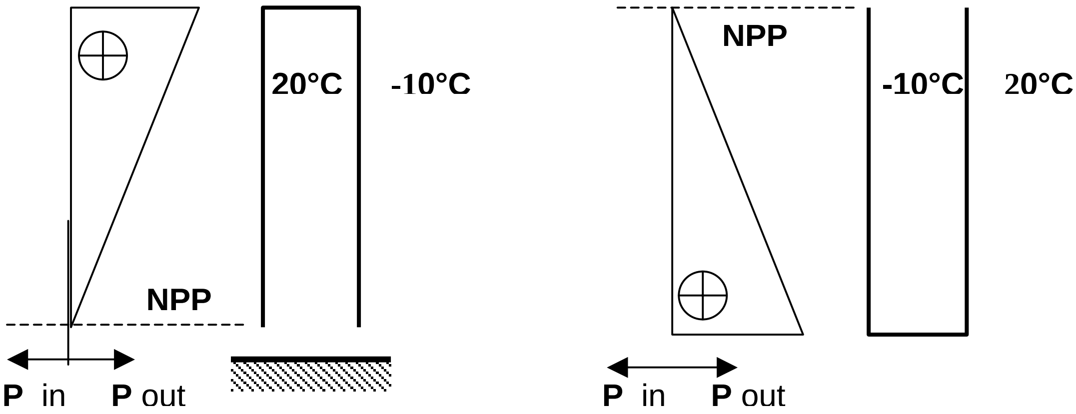


Figure 1. Pressure in open-ended cylinder due to bouyancy

If the cylinder remained outdoors, the air it contained would slowly cool down to the exterior temperature and no pressure difference would exist. If the cylinder were then inverted and brought back indoors, the pressure at the closed end of the cylinder would again be 1.34 Pa acting outward as the cold air fell downward relative to the indoor air.

In the above examples, no flow occurred because no flow path was provided. If an open ended cylinder containing room temperature air where used, any temperature difference between the cylinder and the surrounding air would cause flow, and the warm air would be immediately removed and replaced with cool outdoor air. However, if a heating coil were added to the cylinder to maintain the air temperature at 20°C, airflow in the bottom would be heated. This is analogous to a heated building. Friction would slow air flow and result in a constant pressure drop along the height of the cylinder. Note that the NPP would now be located at mid height and that air flow is involved (Figure 3). Obviously, the less air flowing through this cylinder the less heat energy required to maintain the interior of the cylinder at 20°C.

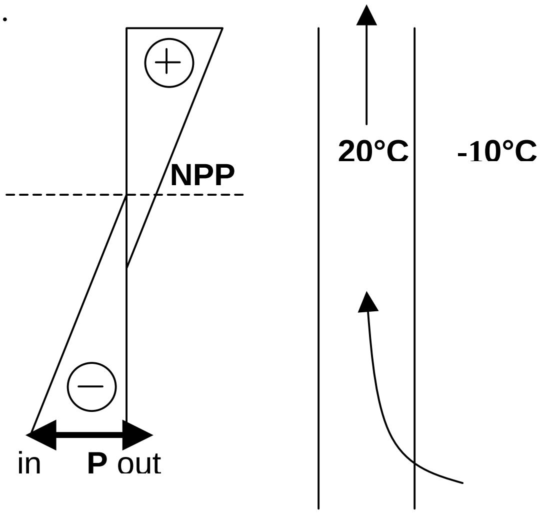
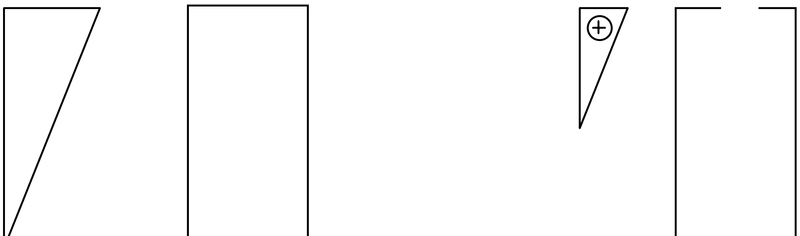
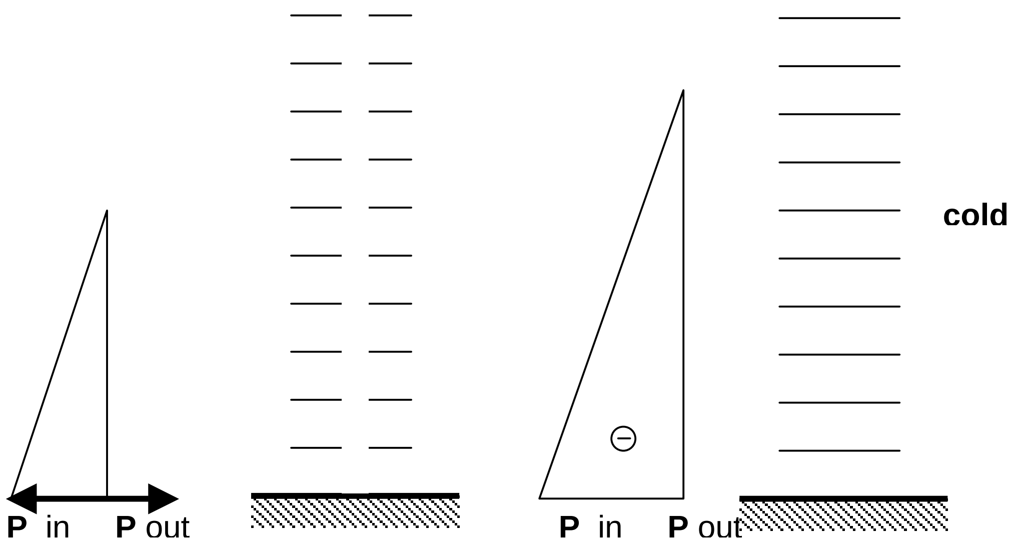


Figure 2. Flow through a heated cylinder or a building





Floors leakier than walls building acts like a perforated tube

Top leakier than bottom NPP rises

Figure 3. Stack effect in real building

In warm climate and during warm weather, stack effect reserves and air is often drawn in at the top and pushed out at the bottom. Infiltration of warm moist air in warm weather can cause as many problems as exfiltration of warm moist air in the winter (Straube 2001).

C. Research Design Solar Chimney Development

a. Stage of Research

The Solar Chimney project is initiated at Universiti Teknologi Malaysia in 2004 to investigate the opportunities to apply solar chimney to achieve indoor thermal comforts in tropical climatic conditions. The research work consists of

Stage One : A literature review is conducted to get a clear understanding of the state-of-the art knowledge in the field. This will enable to orientate our research work towards the areas which had not been covered in the past. This will include understanding the theoretical back ground, solar chimney design considerations and factors, user needs and response and finally typology of solar chimney used in building industry.

Stage Two. Development of actual scale solar chimney for initial experiments to understand the different parameters and their impact on stack ventilation. The experiment includes designing an alternative solar chimney in actual scale, analysis on the alternative design, finalizing the design and computes the construction drawings.

Stage Three: Studies of the impact of solar chimney on Indoor Climate using computer modeling and simulation.

Stage Four: Implementation of prototype full scale model in selected building type. Indoor Climate monitoring and data collection for further analysis.

Stage Five : Comparative Studies between computer model and physical model to get an effective results and evaluation base on the performance of the solar chimney design.

Stage Six: Suggestions and recommendations to improve the design of solar chimney and development of design guideline for solar chimney in hot humid climates.

This study completes stage two of the solar chimney project. The duration for this stage is two months and the measurements were taken for one month duration.

b. Experimental investigation in initial test model

Model test

The two experimental solar chimney are 13 ft high and 0.75 ft diameter cylindrical PVC vertical pipe, supported structurally by timber framework. A schematic illustration of the features of this design is shown in Figure 4. An opening at the top and bottom of the pipe which air to enter the channel. The resultant "greenhouse effect" is expected to keep chimney temperatures above ambient temperatures consistently. The models were black and white surface colors respectively. A different color surface was used to exaggerate the internal temperature difference along the solar chimney. It is not envisaged that selective surfaces would be employed in practice. The accurate monitoring of the outdoor air velocities and air velocity within the chimney is difficult. Therefore air temperature is used to evaluate the performance of the solar chimney.

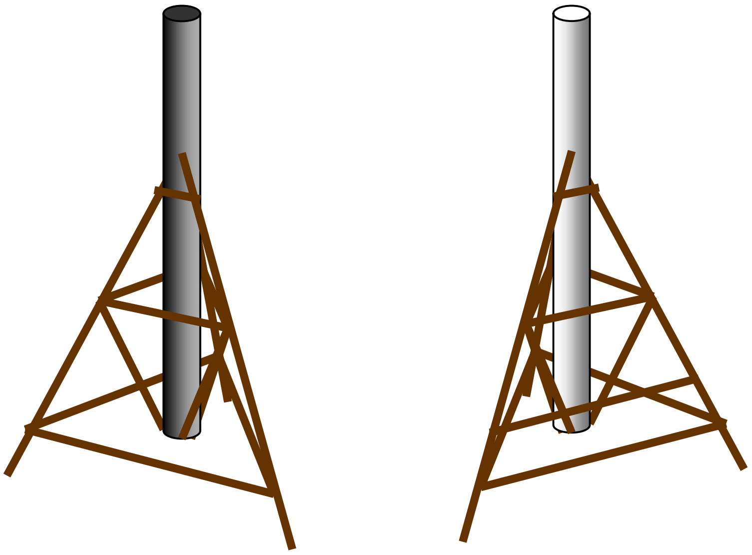


Figure 4. two initial test model : black pipe and white pipe

Measurement tool

The tool used to measure the temperature and humidity is the Dickson temperature and humidity data logger. Dickson data logger have dual channel sensors record and can store 2 months of humidity and temperature data with accurate and lightweight. Dickson data logger can store thousand of sample points and specifications represented in table 1.

Table 1. Specifications and system requirement Dickson data loggers

Humidity specifications	
Range	0-95% RH
Accuracy	+/- 2 % RH
Temperature Specifications	
Range	-40° to 176°F
Accuracy	+/- 1.8°F +/- 1°C
General Specifications (16.256 per channel	
Data Storage	32.512 sample points
Interval	10 sec to 24 hrs
Power (included)	Lithium Cell
Battery life	5 years
Dimension (LWH)	3.1” x 2.1” x 0.9”

Procedure

Duration set data logger in every 5 minutes from 10.00 Am to 18.00 PM. There are two kind measurement: first, measurement of different temperature for two color pipe (black and white pipe) and second, measurement of distribution temperature in black pipe. Data logger position for first measurement put in three point each one pipe and one point in outdoor. The point in each pipe on the bottom, middle, and top (figure 5). Data logger position for second measurement put in six point in black pipe and one point in outdoor (figure 6).

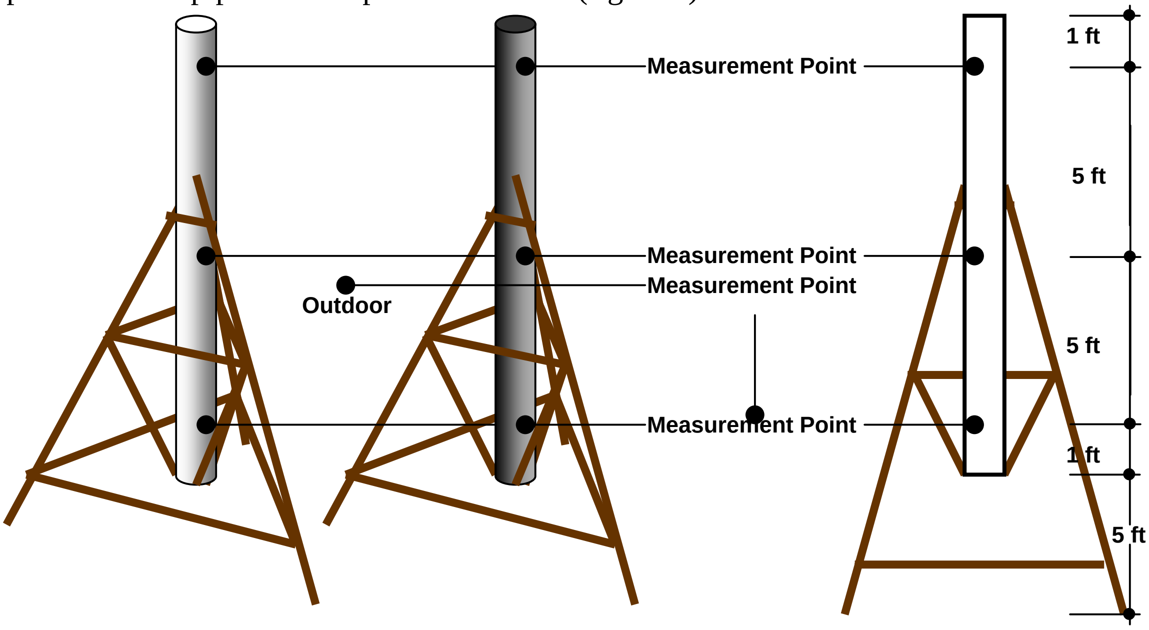


Figure 5. Data logger position to measurement different temperature in white pipe, black pipe and outdoor

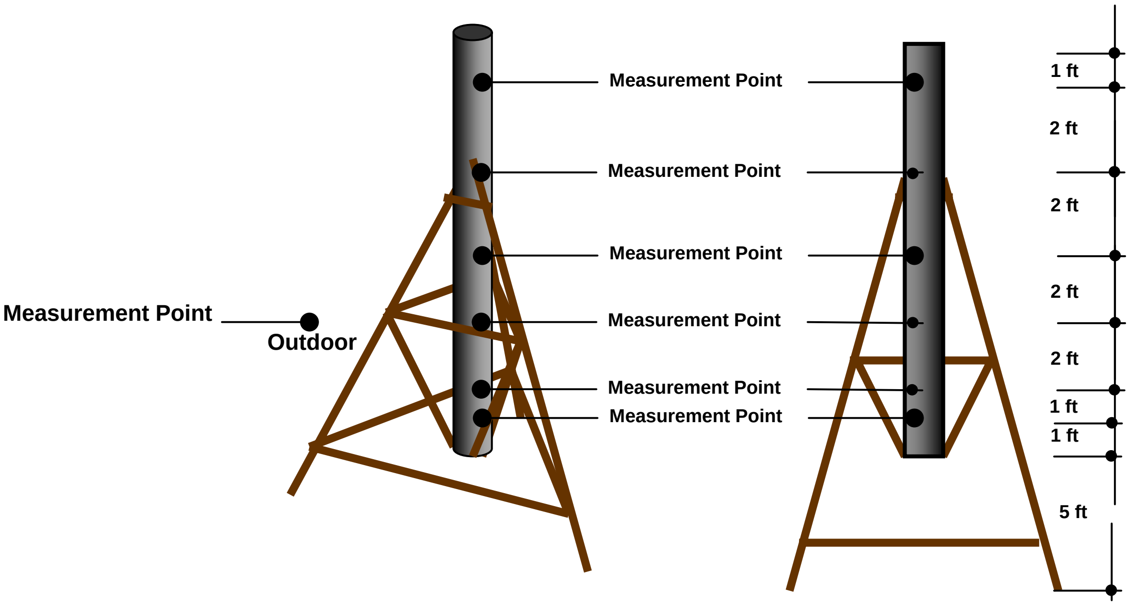


Figure 6. Data logger position to measurement distribution temperature in black pipe

c. Result and discussion for initial test model

Site Temperature and Humidity

A typical diurnal variation of the mean chimney air temperature against the outdoor temperature is illustrated in Figure 7. It can be observed that the chimney air temperatures were significantly above the outdoor in 10.00AM until 18.00 PM. Peak ambient temperature (outdoor temperature) of 30°-36°C, this condition base ventilation thermal comfort need 0.55 m/s air velocity (ASHRAE)

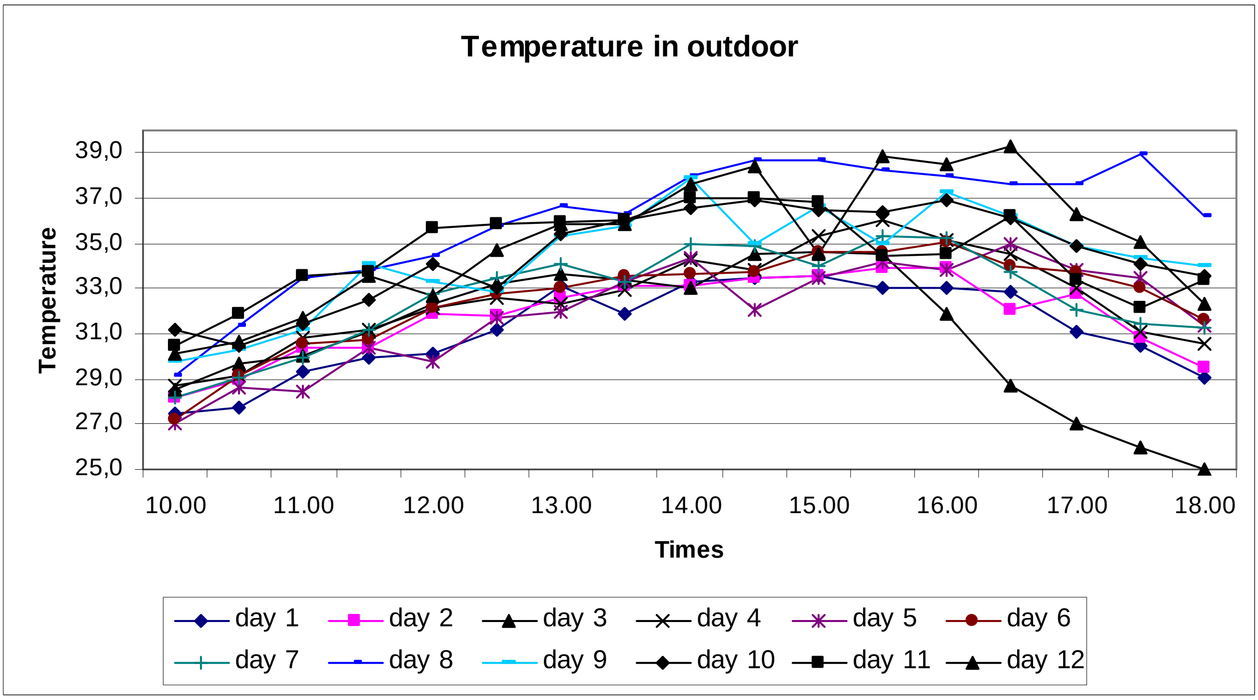
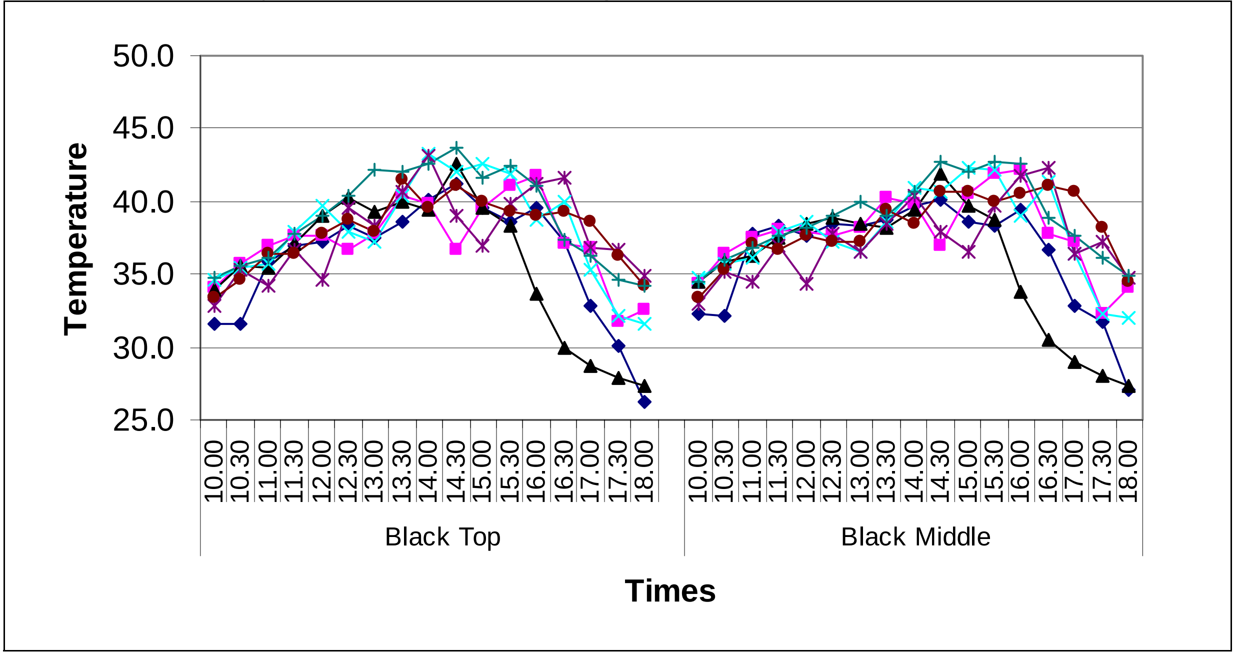


Figure 7. Temperature and humidity average in outdoor site

Temperature different

Preliminary investigations were conducted to determine the air temperature different at position of outdoor, bottom, middle and top in black and white pipe. Figure 8 showed that the heat absorbing PVC pipe temperature was highest in black pipe cases. The black pipe temperature was generally higher than the air temperature in white pipe. Air temperature in black pipe increasing start in 10.00AM and peak in 13.00 PM. Air temperature decrease but still high from 14.00 PM until 17.00 PM. The different temperature in black pipe for black top-black bottom 5°C and black top-outdoor 9°C. Effectiveness for time to large different temperature in 12.00PM until 16 PM for black top-outdoor. The measurement in day 3 showed the cloudly impact for decreasing different temperature. The heat absorbing black pipe exhibited a greater influence on the air temperature different for the narrower chimney. For the diameter chimney pipe, 0.75 ft, the air temperature distribution across the air gap depth was relatively flat in the central core region.



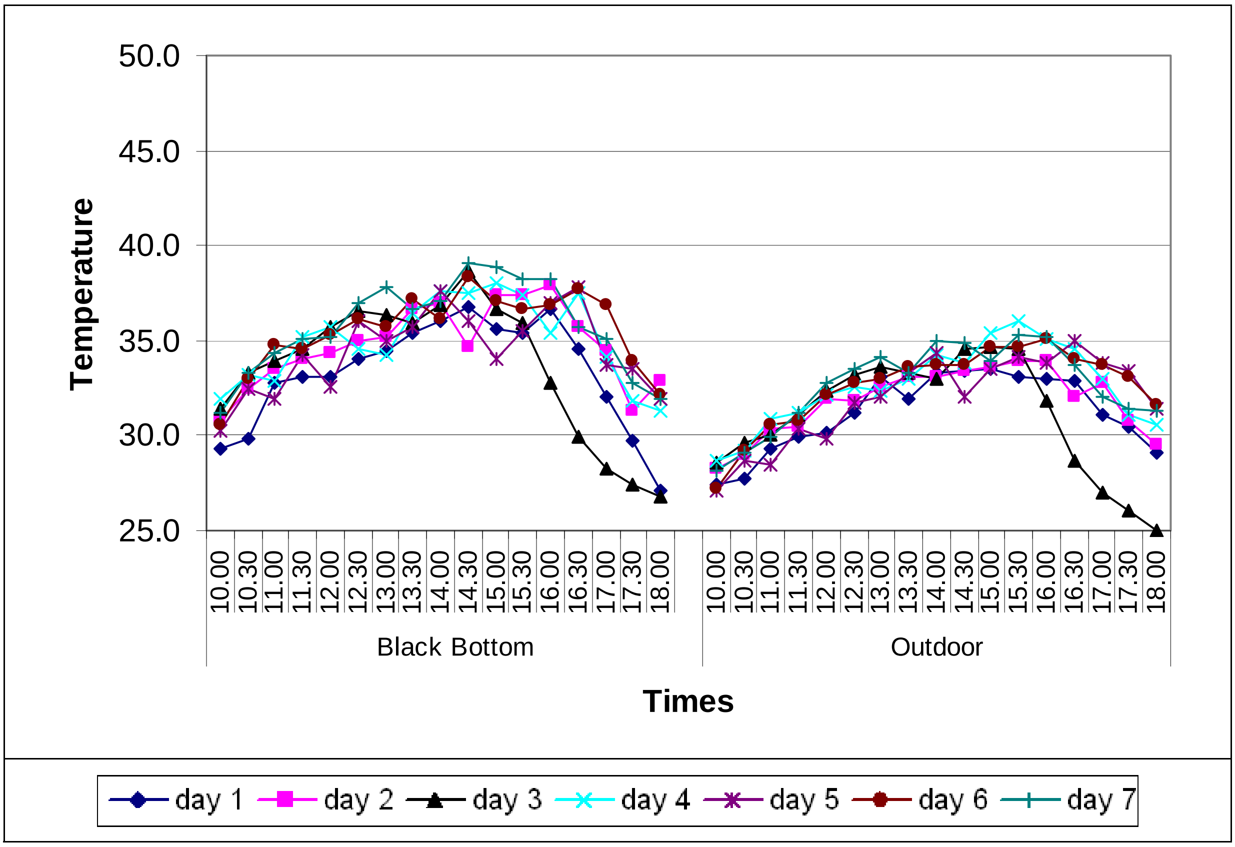
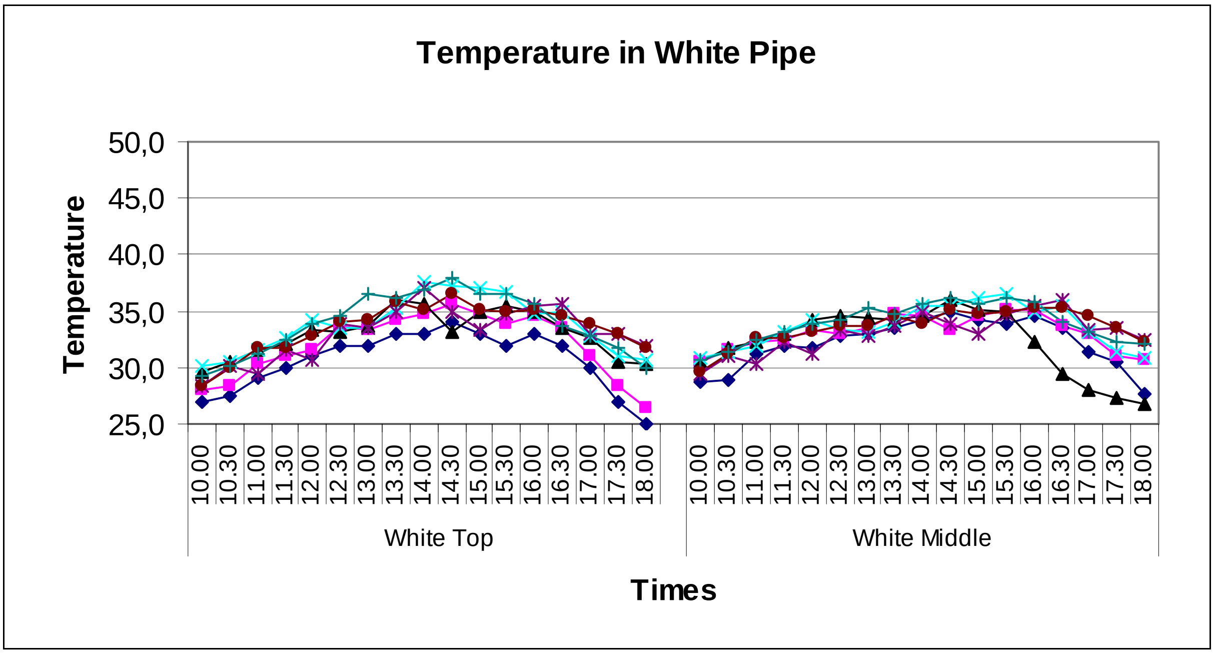


Figure 8. Temperature in black pipe

Figure 9 showed that the heat absorbing white PVC pipe. The white pipe temperature was generally lowest than the air temperature in black pipe but more high than outdoor. Air temperature in white pipe increasing start in 10.00AM until 16.00 PM. Air temperature in white top lowest than white bottom in 10.00 AM-13.00 PM and 16.00PM-18.00PM.



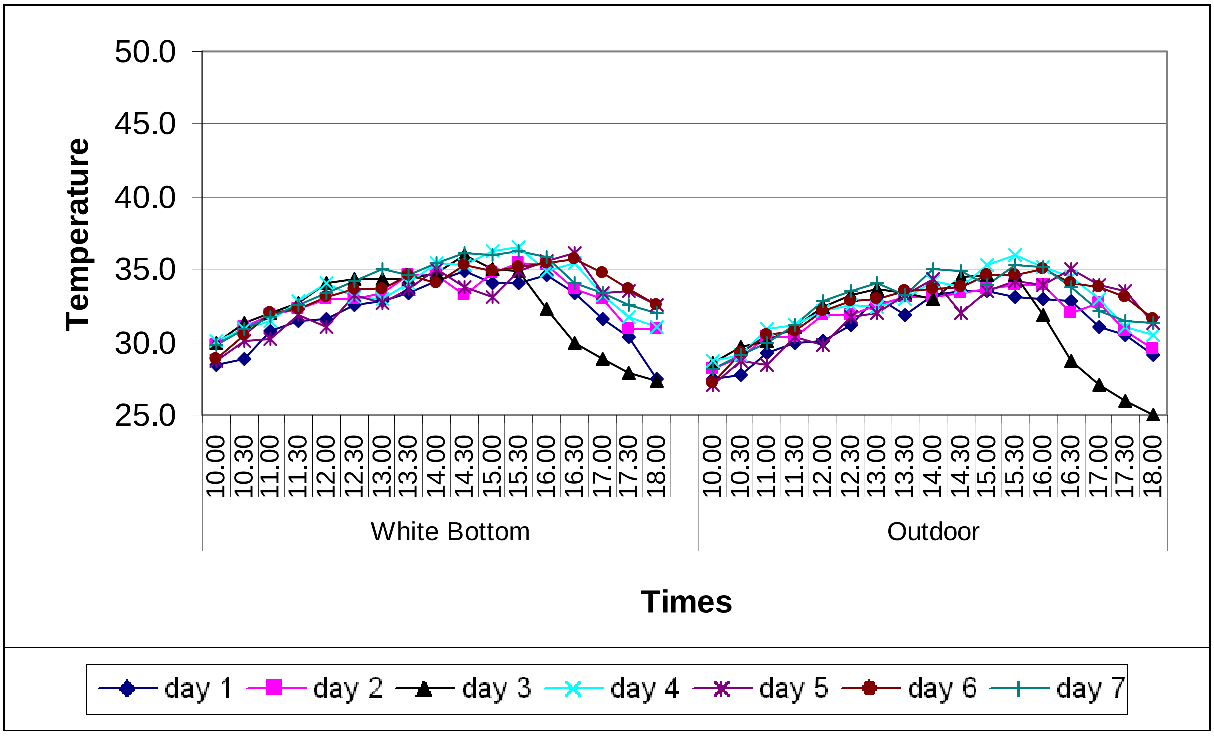
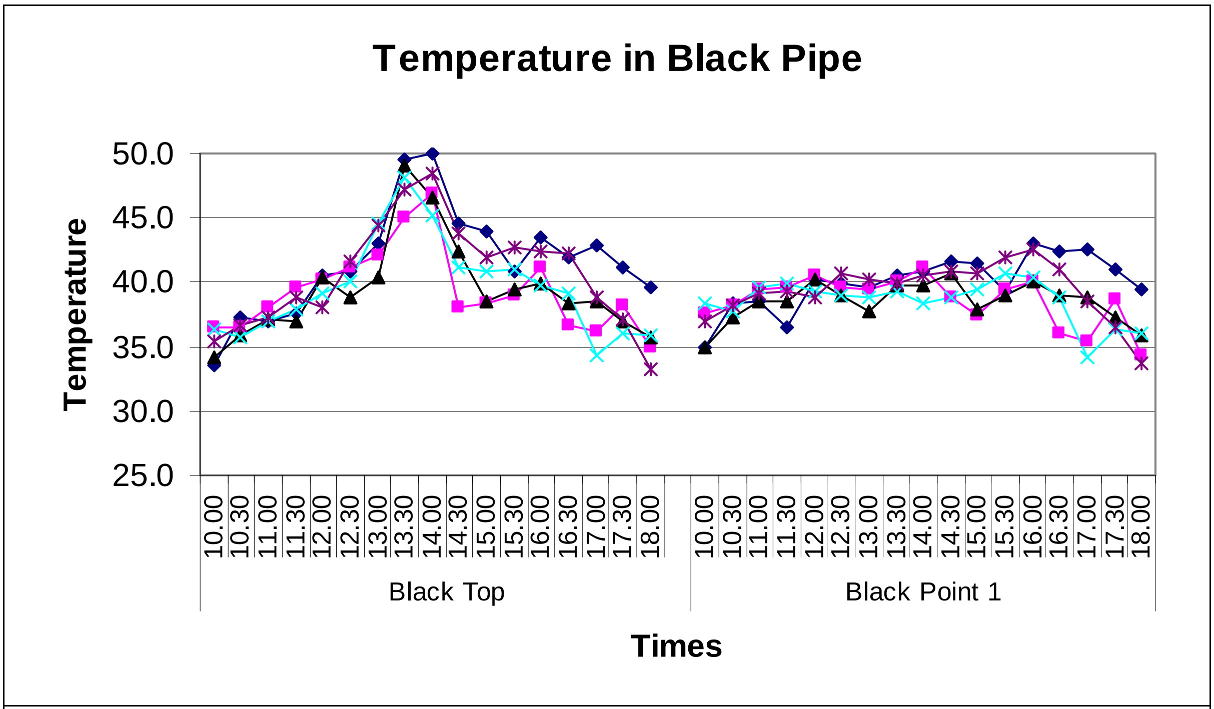


Figure 9. Temperature in White pipe

Generally, temperature different in black and white pipe is 5°C -10°C for compare in black top and white bottom. The effective time to this condition in 12.00PM-16.00PM. Half of black pipe potential to absorbs heat gain base no large different temperature for black top and black middle no

Temperature distribution

The temperature distribution in black pipe is illustrated in Figure 10. The point of black top pipe have highes temperature and lowest in point of black bottom. Temperature distribution depend on the time and area. The significant different temperature started in point 2 for 10.00 AM -13.00 PM. Posisition of point 2 in 4 feet from bottom or 1/3 high pipe.


Temperature in Black Pipe
Temperature
50.0
45.0
40.0
35.0
30.0
25.0
10.00
10.30
11.00
11.30
12.00
12.30
13.00
13.30
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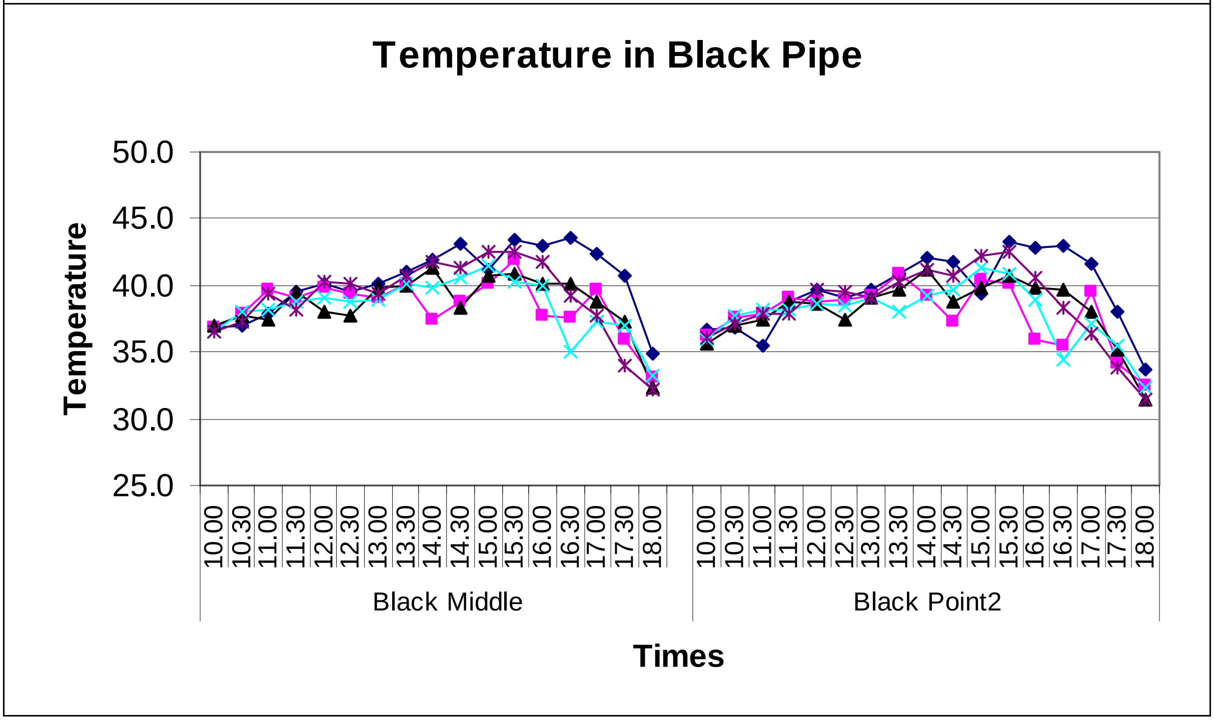
18.00
Black Top
Black Point 1
Times


Temperature in Black Pipe
Temperature
50.0
45.0
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13.00
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16.30
17.00
17.30
18.00
Black Middle
Black Point2
Times

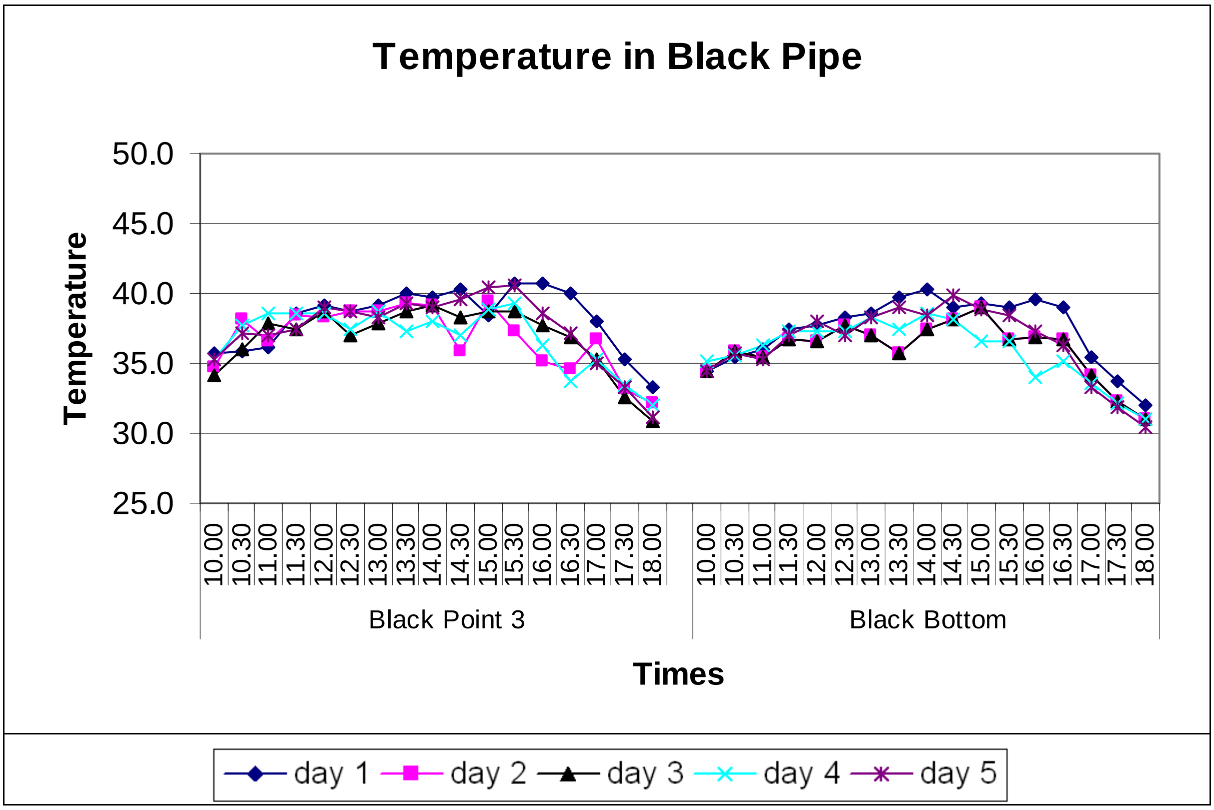

Figure 10. Temperature distribution in black pipe

D. Conclusion

The results obtained from the experimental solar chimney have illustrated that solar chimneys if designed properly can maintain chimney air temperatures consistently above the outdoor temperature which would enhance the desired buoyancy-induced air flow through the chimney. The desired performance was achieved with the solar "greenhouse" chimney studied. Better performance was obtained with a solar radiation absorbing surface within the chimney.

The study of the different color surface solar chimney has shown promising results. It is possible to create a maximum air flow of black pipe. The incorporation of a combined black and white color solar chimney to a pipe can be increase different temperature in the top and bottom. To obtain such an air flow rate the pipe should be extended the height and width pipe.

This air velocity could be increased by increasing the surface area of solar chimney. Finally, it is our opinion that natural ventilation seems to be feasible and viable and the opportunity to development solar chimney use low material for low cost residential building for renewable energy. This, of course, awaits a large scale testing in order to see how effective such a ventilation system would be in a real building.

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