LOW COST SOLAR CHIMNEY PERFORMANCE-IMPROVING ENHANCEMENT

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ABSTRACT

Solar chimneys are potentially important components in energy-providing systems. These are passive solar systems which transduce solar irradiance to airflow. The airflow, in turn, can be transformed into electricity. While the ability of the solar chimney to create airflow has been examined in a number of different studies, little attention has been focused on improving the performance of the solar collector. In principle, increasing the thermal lift of the chimney would improve the chimney's overall airflow production and extend the upper limit of energy production.

We examine an improvement to the solar collector design for the simple solar chimney capable of being implemented with a set of additional low-cost panels used to direct airflow. The box-type solar collector is replaced with a solar collector that increases the overall path length of the airflow through the collector. The airflow in the solar chimney increases despite the increased path length. We demonstrate a progressive increase in thermal lift and a concomitant increase in wind speed. The overall energy in the wind flow increases by 55.0% and the temperature gradient in the chimney increases by 18.2% as compared to the wind energy and thermal gradient in a box type solar chimney.

KEYWORDS: solar chimney, airflow control, solar collector, thermal gradient

1 INTRODUCTION

Solar chimneys [Schlaich, Schiel; Schlaich Bergermann and Partner] are renewable energy devices specifically designed to transmute solar irradiance to usable wind energy. In the presence of solar energy, the air within the solar chimney is warmed and becomes buoyant in comparison to the air surrounding the solar chimney. This buoyancy enables the generation of internal wind as the buoyant air rises in the chimney, escaping through the top, and causing more, cooler air to enter from the bottom. The internal wind is most typically used to drive wind turbines that generate electrical power or to enable cooling and enhance ventilation [Ai, et al.]. However, pressure drops have to be taken into account with the inclusion of a turbine [Koonsrisuk, Chitsomboon]. More recently, solar chimneys have been used to enable atmospheric energy use as an energy source [Kazadi, et al.].

Solar chimneys are driven by the buoyancy generated as a result of the higher temperature of the air in the chimney. Generally speaking, the higher the temperature of the air, the greater the buoyancy of the air in the chimney. As a result, it is interesting to consider methods of increasing the temperature of the air leaving the solar collector. This topic was taken up briefly by Denis Bonnelle in his doctorate thesis [Bonnelle] but there has heretofore been no careful and consistent work done on this topic to determine whether an optimal solar collector design exists.

We have done preliminary work that has shown that both thermal lift and induced wind speed can be enhanced through a careful design of the pathway air takes through a box collector without increasing any other aspect of the solar chimney. In this proof of concept study, we empirically investigate the improvement of a micro-chimney (ten feet tall and two square feet of solar collector). We demonstrate that the airflow pathway alone may be used to enhance both the solar chimney's thermal lift and its induced airflow. We also demonstrate that the pathway has an optimal path length at which the thermal lift and induced wind are maximized.

The paper is laid out as follows. Section 2 describes the design of our solar chimney. Section 3 provides details of our experimental procedures and data. Section 4 offers a discussion of the data and relevant theoretical considerations. Section 5 concludes.

2 OUR SOLAR CHIMNEY

Figure 2.1 provides a diagram and a picture of our solar chimney. The solar chimney consists of two major parts. One part is a solar collector and comprises a wooden box with a clear acrylic top panel. The second part is the chimney that is attached to the solar collector.

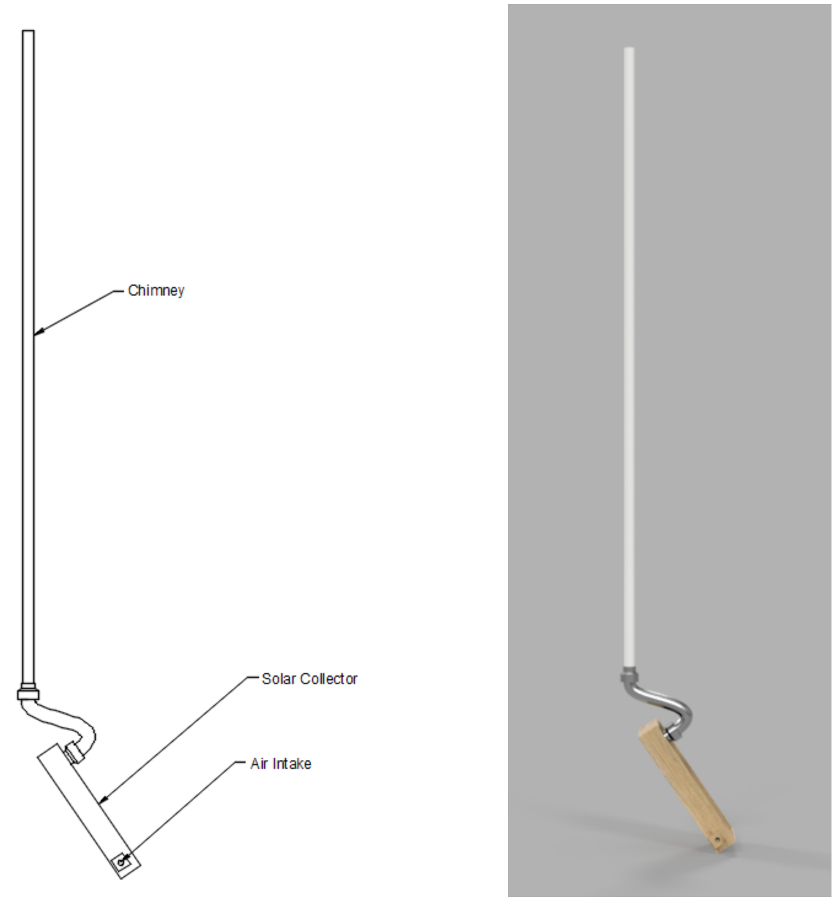

Figure 2.1: A basic solar chimney. The solar collector comprises a box with a clear top. Light entering the chimney as the solar collector heats the air and generates an up-flow through the chimney. Additional air is drawn in through the intake and the cycle continues.

Our solar chimney is designed similarly to a sloped solar chimney, in that the solar collector is built at an angle, at 55° from the horizontal. The chimney is also placed at the edge of the solar collector [Dhahri, Omri]. The box has dimensions (12, 24, 2.5) inches on each side. The interior of the box is painted black. The bottom of the box is made from 11/32” thick plywood while the sides are made from 1.5” thick white wood posts. Panels 3/4" thick and 8 7/8" long that are placed within the box are made of furring strips. A 1/8" acrylic panel is placed on the top of the box; light enters the box through this panel.

A 1" hole is placed as an air intake on the bottom left side of the box. A 2" hole in the acrylic panel is used to connect the box, using a 3" diameter conduit, to a 2" diameter vertical acrylic tube 10' in length. The entire solar chimney is contained within our test facility to avoid environmental variation with the exception of an unavoidable daily thermal variation in our facility. Our facility is not climate-controlled.

As the solar chimney is located within a closed facility, we illuminate it with a light panel constructed using twenty-four 72W light bulbs placed evenly over a 1' by 2' panel. This panel provides an average of 300 W/m^2. A map of the solar collector illumination is provided in Figure 2.2.

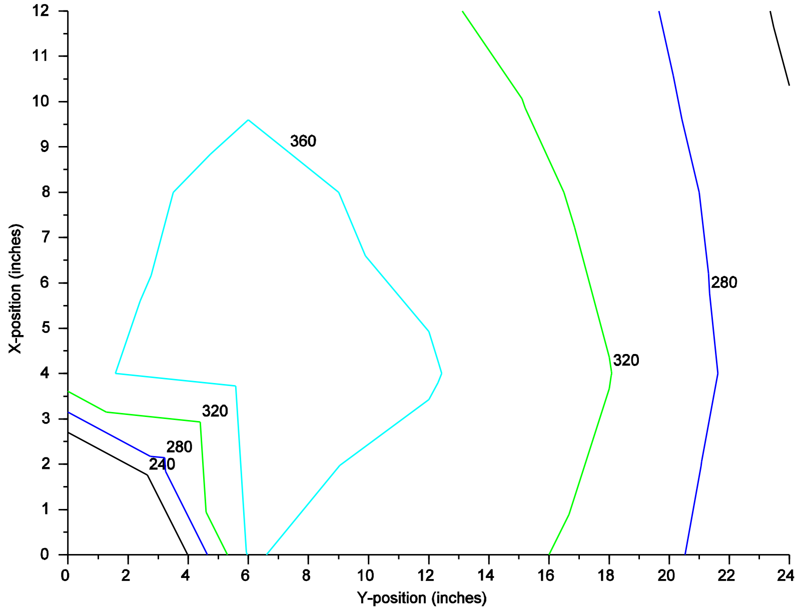

Figure 2.2: The solar irradiance our solar collector was exposed to.

The light is arranged so as to simulate a perpendicular illumination by sunlight.

Operating a solar chimney requires only that the solar collector is exposed to light. Upon exposure to light, the air within the solar collector heats up and becomes relatively buoyant. As a result, given an outlet, this buoyant air rises. The outlet in a solar chimney is the chimney part, and the buoyant air rises through it, exerting an upward pressure that creates an internal vacuum and draws in more air from the inlet to the solar collector.

As indicated in Figure 2.3, our solar collector has been altered to control the airflow in the system. This naturally increases the path length. Air flowing in at the input hole must pass through a maze built into the box, passing over a potentially very long overall path before reaching the chimney. It is expected that this configuration will increase the thermal energy transfer to the air along the pathway, yielding a column of air in the chimney of increased buoyancy. There is a directly proportional relationship between buoyancy and the gradient between the mean air density in the chimney and the ambient air density. This air density gradient can be related to the thermal gradient [Ekechukwu, Norton].

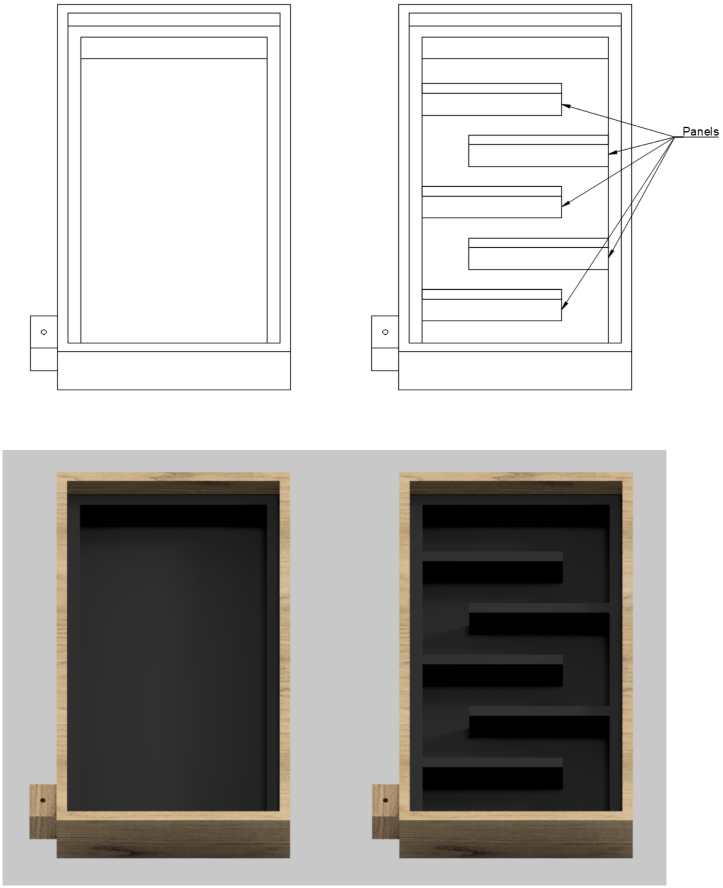

Figure 2.3: The solar collector is designed to redirect airflow through an increased path length than might be used in a box-type solar collector. By varying the number of panels equally spaced throughout the solar collector with apertures alternating from one side of the solar collector to the other, the airflow's pathway through the solar collector can be enhanced.

3 EXPERIMENTAL PROCEDURE AND RESULT

We examine the performance of the solar chimney by measuring the airflow through the chimney and the thermal gradient of the air passing through the solar collector. Figure 3.1 illustrates the measurement points diagrammatically. The speed of the wind passing through the solar chimney is measured at the wind inlet to the solar collector. It is indicated by the point A in Figure 3.1. We use a Amprobe TMA-20HW hot wire anemometer to measure the wind speed at this point.

The temperature is measured at two points, indicated in Figure 3.1 as points A and B. These are measured with two Omega HSTH-44034-40 stationary thermistors. The incoming air passes over the thermistor at point A and, after it is heated in the solar collector, it is measured in the base of the chimney at point B.

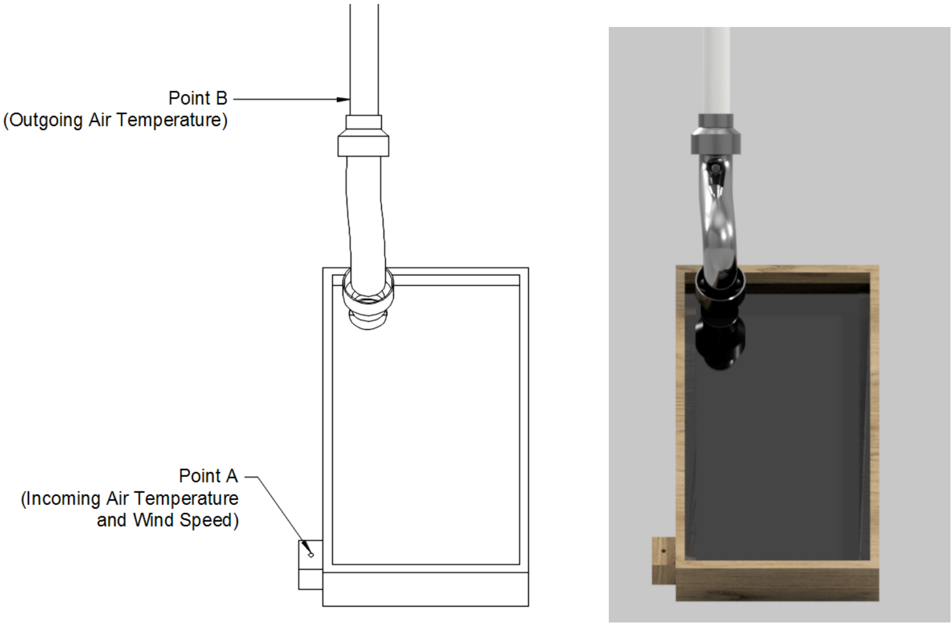

Figure 3.1: This diagram illustrates the data measurement points of the solar chimney in this study. At point A, both the wind speed and incoming air temperature are measured. At point B, the outgoing air temperature is measured.

The difference between these two temperature measurements is reported, eliminating the effect of the daily temperature variation within our test facility.

Figure 3.2 presents the variation of the wind speed at the solar chimney entrance point as a function of the estimated path length within the solar collector. The wind speed is optimized with five panels extending the path length and exhibits a 15.73% increase in velocity as compared to the speed exhibited when no panels are used.

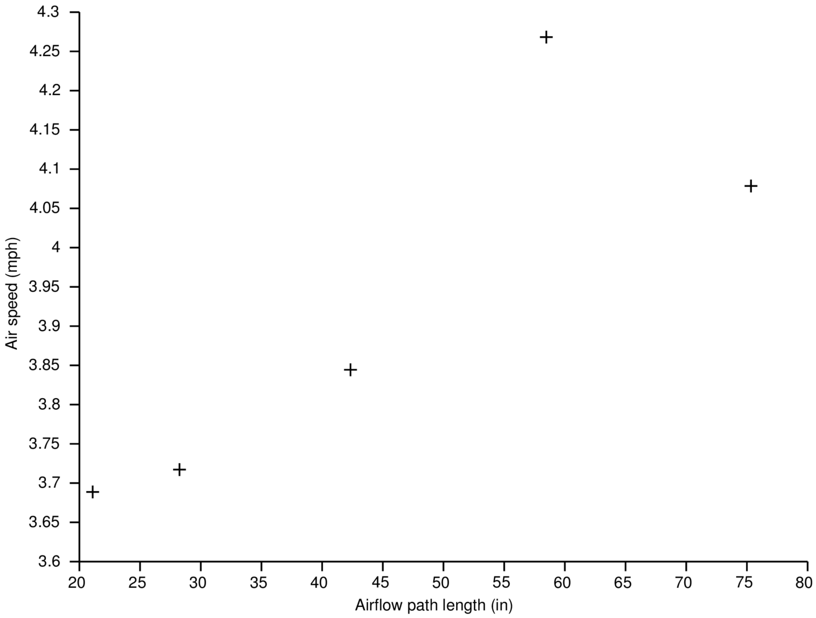

Figure 3.2: This graph gives the effect of the variation of the path length of airflow through the solar collector on the wind speed in the solar chimney. The data illustrates an optimal path length which generates a maximal internal air flow.

Figure 3.3 shows the variation of the thermal gradient in the solar chimney as a function of the estimated path length within the solar collector. As with the speed, there is a strong variation of the temperature gradient as the length increases. The temperature gradient increases 18.2% over the empty box temperature gradient. Unlike the wind speed, however, the thermal variation has no peak; it continues increasing as the path length increases.

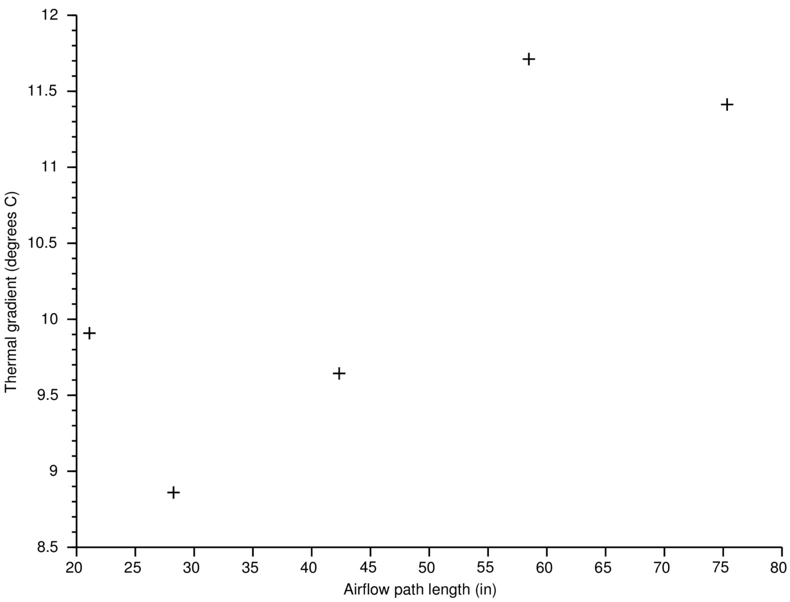

Figure 3.3: This gives the effect of the variation of the path length of airflow through the solar collector on the thermal gradient between the incoming and outgoing air in the solar collector. As one might expect, increasing the airflow pathway length generally increases the thermal gradient within the solar collector.

4 ANALYSIS AND DISCUSSION

It is clear from the data presented in Section 3 that the development of a proper elongated pathway for airflow in the solar collector is an important part of solar collector design. Using a simple box-type solar collector yields airflows that are significantly slower than that which can be achieved using an increased path solar collector.

The effect is somewhat counter-intuitive. If the path length of the solar collector increases, its effective pressure drop also increases. As a result, all other things being equal, the difference in performance from this effect alone should go in the opposite direction. Yet, the concomitant increase in thermal gradient negates the effect of increasing path length up to a point. The point at which the increased path length becomes a greater factor in the overall speed than the thermal gradient increase is the point at which the effect is maximized.

As solar chimneys are receiving increased attention and application, it will be important to investigate simple and inexpensive ways of generating increased airflow. This improves the overall performance of the solar chimney without significantly increasing the cost of the installation. While the improvement in our system was significant, it will be interesting to see how the improvements in performance in larger systems compare to these. It will also be interesting to see how changing the various system design parameters (height, size of collector, wall height, cavity width, inlet size, etc.) will alter the performance improvement [Gontikaki, et al.]. Finally, it will be interesting to see how integration of these systems with entrochemical systems enables acquisition of environmental energy exceeding that possible with solar thermal panels at a smaller installation size than otherwise possible.

5 CONCLUSIONS AND FUTURE WORK

In this paper we have presented a simple empirical study of the effect of increased solar collector path length on the solar chimney's airflow and thermal gradient performance. We have demonstrated that increasing the path length in the solar collector of a solar chimney has the effect of increasing the overall wind speed and thermal gradient in the solar chimney. We have measured an increase of 15.72% in wind speed, resulting in a 55% increase in wind energy along with and an increase of 18.2% in thermal gradient above baseline with a clear optimal path length. If the collector roof reflectance, collector roof emissivity, ground surface absorptivity, and ground surface emissivity are taken into account, there may be an even greater increase in the thermal gradient [Pretorius].

We are interested in developing an algorithm than enables path optimization of the solar chimney given any solar collector configuration. Future work on this will include simulation studies that can validate our current work and generate optimal path configurations for solar collectors of varied sizes and geometries.

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