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FINAL REPORT

✓ A Roof-Mounted Solar-and-Wind-Powered Turbine

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A Roof-Mounted Solar-and-Wind-Powered Turbine

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Overview:

This project was an effort to convert solar energy into electricity by utilizing hot-air convection to turn a turbine. To be considered useful, such a mechanism must generate enough electricity at a cost low enough to be competitive with photovoltaics. The extraction of wind energy incidental to the solar experiment was anticipated.

The mechanism constructed generates an amount of electricity so small with respect to its cost that it cannot be considered competitive with photovoltaics.

Description of Mechanism:

An open-air collector of 256 square feet total area was constructed in four sections, each 16 ft. by 4 ft. The four sections were roof-mounted with a slope of 25.3 degrees facing directly south. Five-inch-diameter ductwork connected the highest points of the four collectors, providing a common outlet for the heated air. The collectors were arranged with space between them for walking, servicing, and avoiding obstructions. Photographs of the collectors under construction and mounted are found on page 5.

Three of the collectors are identical, having been constructed with lessons learned from the first. The first was constructed with a framework of two-by-fours, a solar window of Kalwall fiberglass-reinforced-plastic solar glazing, and a collector surface of Masonite, brush-painted flat black and insulated beneath with sheets of styrofoam. This collector weighed 173 pounds, requiring six persons to position it on the roof. The final three collectors were constructed with one-by-threes, Kalwall glazing, and Thermax (a styrofoam insulating board with foil facing) spray-painted flat black. Internal wooden spars were drilled to permit airflow while maintaining strength with light weight. These collectors weighed 44.5 pounds each and could be positioned by two persons.

The combined airflow of the collectors turns a turbine which drives a permanent-magnet DC generator. An outdoor battery box holding four 12-volt parallel-wired marine batteries was constructed in the expectation that the generator would charge the batteries. Twelve-volt outlets and light fixtures were wired to the batteries to permit discharging. Meters were installed for monitoring battery voltage and charge and discharge currents.

Performance of Mechanism:

A maximum steady-state collector output of 20 cubic feet per minute was measured early in the experiment. After a year of weathering, similar conditions produced an output of only 16.7 cfm. A three-page description of the method of measurement begins on page 6.

While the spray-painted foil surfaces of the lightweight collectors were initially blacker than the brush-painted Masonite surface of the heavy collector, the spray-painted surfaces greyed with exposure. Also, the lightweight collectors developed air leaks where waterproof glue used in the framing became plastic at temperatures approaching 200 degrees Fahrenheit. The heavier collector, while using glue as a sealer, could take more screws and nails during framing, so did not suffer from separations.

Although it was evident that the 20 cfm airflow would not generate a significant amount of electricity, a number of turbine configurations were bench-tested in order to determine exactly how much electricity could be generated. A fan was mounted in a five-inch-diameter canister and adjusted for a 20 cfm output. Experimental turbines were mounted in a mating canister. Details of the experiments are found on pages 10 and 11. The maximum electrical output was only 9.6 milliwatts.

Momentary electrical outputs several times that generated by a steady 20 cfm airflow are possible when the turbine is actually mounted on the collector and 20-or-30-mph wind gusts blowing from the south are channeled through the collector. Still, such outputs are less than 1/10th watt, at open-circuit voltages much too low to begin charging batteries. Also, the collectors make a noise like thunder when wind gusts through them, making the device aesthetically unattractive as a wind turbine.

Conclusions:

The small-scale use of hot-air convection to generate electricity is extremely inefficient, and does not hold promise as an alternative to photovoltaics. As planned, air expands when heated by incident solar energy captured by a black surface, and the consequent reduction in air density causes an updraft. But the airflow is insufficient for the extraction of a useful quantity of electricity. Most of the solar energy gathered by the collector escapes as heated air, and a machine to capture this energy would have to extract this heat and return cooled air.

Greater airflows could be achieved by heating the air to a higher temperature. However, at temperatures above 200 degrees Fahrenheit, noncombustible materials must be used. Wood will ignite spontaneously after prolonged exposure to temperatures of over 200 degrees.

Two collectors under construction, and four collectors mounted on the roof. Construction materials are one-by-threes, Thermax foil-coated insulating panels, flat black spray paint, and Kalwall solar glazing. The glazing must be added in the shade to prevent melting the Thermax, and the finished collector must be inclined when exposed to the sun. The collectors are fastened to the crown of the roof with angle irons and lag bolts, and to the guttering with cords. All four collector outputs are ducted to one common outlet port, where an airflow of 20 cfm at 200 degrees Fahrenheit may be measured at high noon on a calm, cloudless 80-degree day.

An Inexpensive Way To Measure Airflow

by Jerry W. Goerz, Lexington, Kentucky 10/28/82

This procedure was developed to measure airflow at the five-inch-diameter outlet port of a solar hot-air collector. It is an inexpensive alternative to using a flowmeter, and is useful for application where measurements do not need to be made continuously.

Materials required:

one large, lightweight plastic trash bag

one coffee can or other can large enough to fit over the outlet port

about six feet of duct tape

a piece of corrugated cardboard, styrofoam, or other gasket material large enough to fit over the outlet port

enough styrofoam "peanuts" to fill the trash bag

a rectangular box large enough to hold all the styrofoam "peanuts" which can fit into the trash bag

a stopwatch

Procedure:

Remove the ends of the can, leaving an open cylinder.

Tightly tape the opening of the bag around the can, forming a collar.

Fill the bag full of styrofoam "peanuts", but do not fill the can to which the bag is taped.

With the rectangular box empty, dump the "peanuts" into the box.

Smooth the "peanuts" out level in the box.

Measure the depth in inches of the "peanuts" in the box.

Measure the length and width of the box, in inches.

Multiply the length and width of the box. Multiply this product by the depth of the "peanuts". This gives you the volume of the bag in cubic inches. Divide this by 1,728 to find the volume in cubic feet.

Example: A 30-by-14-inch box filled to a depth of twelve inches has a "peanut" volume of 5,040 cubic inches or about 2.9 cubic feet.

Cut a hole in the gasket material, slightly smaller than the can opening.

Tap the gasket over the outlet port.

Grasping the closed end of the bag with one hand, encircle the bag with the fingers of your other hand and slide this other hand down the bag to the collar, expelling the air in the bag.

Now you are ready to measure airflow. It is best to have an accomplice to operate the stopwatch, although you might manage alone.

With one hand still constricting the opening to the bag, place the collar tightly over the gasket. Immediately release the opening to the bag, and simultaneously start the stopwatch. This may take some practice.

The bag will fill with air. When it is completely filled, there will be a sudden "whop" sound and the inflated bag will stiffen. Stop the stopwatch immediately.

Write down the elapsed time. Reset the stopwatch. Expel the air from the bag and repeat the filling procedure. Repeat several times.

Calculate the average time required to fill the bag. This is done by summing the individual times and dividing this sum by the number of trials.

Example: The filling times recorded for ten trials are:
9.48, 8.83, 8.28, 8.64, 8.99, 8.41, 7.86, 9.67, 8.84, and 9.02 seconds. This is an average of 8.8 seconds.

Calculate the airflow in cubic feet per minute. This is done by multiplying the bag volume (in cubic feet) by 60 (seconds per minute) and dividing by the average filling time (in seconds).

Example: If an average of 8.8 seconds is required to fill a 2.9 cubic foot bag, the airflow is
 $2.9 * 60 / 8.8 = 19.8$ cubic feet per minute.

This completes the measurement of airflow. However, you may wish to know the airspeed (velocity) of the air at the outlet port. To calculate this, first calculate the cross-sectional area of the outlet port, in square inches.

To calculate the area of a circular port, find the radius by dividing the diameter in half. Then multiply the radius by itself, then multiply this product by 3.1416.

Example: A five-inch-diameter opening has a cross-sectional area of
 $2.5 * 2.5 * 3.1416 = 19.6$ square inches.

To find the area of a rectangular port, simply multiply the length of the opening by the width.

Now, divide the cross-sectional area in square inches by 144 to convert to square feet. Divide the airflow by this number to find the airspeed in feet per minute. Divide this airspeed by 60 to find the airspeed in feet per second.

Example: An airflow of 19.8 cubic feet per minute exits a port with a cross-sectional area of 19.6 square inches. The cross-sectional area in square feet is
 $19.6 / 144 = 0.136$ square feet.
The airspeed in feet per minute is
 $19.8 / 0.136 = 145.6$ feet per minute.
The airspeed in feet per second is
 $145.6 / 60 = 2.43$ feet per second.

Airflow Data

Definition of Terms:

Tamb: ambient temperature, in degrees Fahrenheit

Told: outlet temperature, in degrees Fahrenheit,
of older, heavier collector

Tnew: outlet temperature, in degrees Fahrenheit,
of newer, lightweight collector

Lshadow: length of shadow of a 12-inch rod mounted
perpendicular to the collector surface

Angle: angle of incidence of solar energy on collector

Avg: average time in seconds to fill a 2.9 cubic foot bag
with outlet air

Note: refer to note number for detailed trials

cfm: cubic feet per minute airflow

Comparison, single vs. combined collector outputs, August 1981:
(exact date not recorded)

	Time	Tamb	Tnew	Lshadow	Angle	Avg	Note	cfm
single new:	12:40	84	180	3.00	72	10.6	1	16.4
single new:	1:22	84	180	2.25	79	11.7	2	14.9
all four:	1:56	84	180	2.75	77	9.2	3	18.9

Typical measurements, four outputs combined:

Date	Time	Tamb	Told	Tnew	Lshadow	Angle	Avg	Note	cfm
9/12/81	12:00	78	169	169	5.50	66.4	9.8	4	17.7
9/12/81	1:04	78	184	180	2.00	80.5	8.8	5	19.8
9/12/81	1:35	78	186	184	1.25	84.0	9.4	6	18.5
9/05/82	1:10	82	180	165	2.75	77.1	10.5	7	16.6
9/05/82	1:40	82	182	167	2.25	79.4	11.3	8	15.4
9/05/82	2:00	82	182	167	2.25	79.4	10.5	9	16.5

Note 1:

$(11.7+11.05+10.12+11.21+10.27+11.4+10.78+10.46+9.4+9.62)/10=10.6$

Note 2:

$(13.27+9.35+10.81+9.81+13.20+13.43+11.78+12.35+11.88+11.72)/10=11.7$

Note 3:

$(10.66+9.81+10.94+9.68+9.46+8.03+7.36+9.06+8.71+8.44)/10=9.2$

Note 4:

$(11.08+7.54+8.02+11.17+8.46+11.07+9.48+11.95+9.88+9.32)/10=9.8$

Note 5:

$(9.48+8.83+8.28+8.64+8.99+8.41+7.86+9.67+8.84+9.02)/10=8.8$

Note 6:

$(9.67+9.60+9.81+8.66+9.27+10.46+8.63+9.58+8.89+9.69)/10=9.4$

Note 7:

$(10.84+13.13+10.24+8.99+9.07)/5=10.5$

Note 8:

$(13.49+10.05+10.95+11.46+10.39)/5=11.3$

Note 9:

$(10.08+12.50+9.61+10.92+9.48)/5=10.5$

Clockwise from upper left: batteries, battery housing, turbine experiment components, indoor 12-volt lighting with metering. The solar cell array, not part of the grant project, can be purchased off-the-shelf for \$150, and provides up to 25 watts to charge the batteries. Compare it to the hot-air collectors pictured on page 5, which produce only 9.6 milliwatts!

Turbine Experiment Data

Housing diameter: 5 inches

Turbine blade diameter: 4.5 inches

Generator: ETCO VC239 permanent-magnet carbon-brush DC motor, coil resistance of 8 ohms

Blades: made by radial cuts in a 4.5-inch diameter metal disc

Definition of Blade Angle:

Terms:

Voc: open-circuit voltage, in volts

Isc: short-circuit current, in milliamperes

Vloaded: voltage across a 10-ohm load, in volts

P: power into a 10-ohm load = $(V_{loaded}^2)/10$, in milliwatts

Turbine	Blades	Angle	Voc	Isc	Vloaded	P
No. 1	8	30	0.44	23.0	----	----
No. 2	8	15	0.48	25.0	0.28	7.84
No. 3	16	30	0.49	24.5	----	----
No. 4	16	15	0.50	24.0	0.31	9.60
No. 5	8+16	15	----	----	0.24	5.76