MAR 25 1997

SANDIA REPORT

SAND97-0504 • UC-1300

Unlimited Release

Printed March 1997

Testing of the Sunstove Organization's Sunstove Solar Oven

T.A. Moss

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-94AL85000

Approved for public release; distribution is unlimited.

RECEIVED

MAR 28 1997

OSTI

MASTER

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation, a Lockheed Martin Company.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831

Prices available from (615) 576-8401, FTS 626-8401

Available to the public from
National Technical Information Service
US Department of Commerce
5285 Port Royal Rd
Springfield, VA 22161

NTIS price codes
Printed copy: A03
Microfiche copy: A01

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SAND97-0504
Unlimited Release
Printed March 1997

Distribution
Category UC-1300

Testing of the Sunstove Organization's Sunstove Solar Oven

T.A. Moss
Solar Thermal Technology Department
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-0703

Abstract

A Sunstove Organization's Sunstove was tested at Sandia's Solar Thermal Test Facility. It was instrumented with five type K thermocouples to determine warm-up rates when empty and when a pot containing two liters of water was placed inside. It reached inside air temperatures above 115°C (240°F). It heated two liters of water from room temperature to 80°C (175°F) in about two hours. Observations were made on the cooling and reheating rates during a cloud passage. The adverse effects of wind on the operation of the solar oven were also noted.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

SUNSTOVES™ MOLDED--SOUTH AFRICA & RECTANGULAR--MEXICO
VARIOUS MODELS INCLUDING ROUND and PANEL REFUGEE™ UNIT

The Solar Thermal Design Assistance Center (STDAC) at Sandia National Laboratories evaluated a Sunstove from the Sunstove Organization, at Sandia's Solar Thermal Test Facility in Albuquerque NM. It was designed for single family household cooking. It is targeting developing countries' alternative energy markets where conventional fuels are not available and wood is the primary fuel used for cooking.

Because of the wide variety and types of solar cookers being manufactured it is very difficult to come up with a number, such as a figure of merit, to indicate how each will operate under various weather conditions. The best way to determine how a solar oven will operate is to test it under real life conditions^{1,2}. These tests will not determine if a solar cooker is good or bad. It will, however, indicate the usefulness of the solar cooker for its intended usage.

The purpose of this test is to determine the basic operating characteristics of the Sunstove solar oven. For this report, only the basic tests of heat up rate, maximum temperature attained when empty, and the time to heat room temperature water to 80°C (175°F) were done. Further testing was too elaborate for the scope of this test. The solar oven is sized to cook about a two liter volume of food. Therefore, two liters was chosen as the volume of water to heat in the oven.

The Sunstove Organization's Sunstove solar cooker is a box type cooker. The difference between this cooker and other box type cookers is the reflectors are internal to the heated space rather than external (see fig. 2). Reflectors increase the solar collecting area, which enable the oven to obtain higher temperatures. The sides of the cooker are flared out to serve as internal reflectors and the bottom is blackened. It weighs about 8 lbs., has a molded polyethylene outer shell, fiberglass insulation, thin aluminum sheet interior (sides are reflective with the bottom blackened), and a 1.5 mm extruded acrylic sheet front that also serves as the door. The normal cooking temperatures of the oven allows the acrylic sheet to conform to the outline of the outer shell to create a seal. This solar oven sells for \$20 to \$25.

To measure the temperature inside the solar oven, five type K, 1/16" In600 sheathed, thermocouples were used. They were inserted through holes drilled into the side of the oven. This was done so the door, or window, seal would not be affected. Three of the thermocouples (front, middle, and back) measured the inside air temperature and two (side and middle) measured the water temperature. The front air thermocouple was centered on the front side and inserted one inch into the oven. The back air thermocouple was also centered on the back side inserted one inch into the inside of the oven. The middle air thermocouple was placed in the center of an imaginary line connecting the front and back air thermocouples. The thermocouples used to measure water

temperature went through feedthroughs in the side of the pan. This preserved the seal between the lid and pot, which reduced the amount of water vapor escaping and, therefore, condensing on the front window. One measured the water temperature close to the side of the pot and the other measured the water temperature at the center. When the water was not present, these two thermocouples measured the air temperature on either side of the middle air thermocouple perpendicular to the imaginary line connecting the front and back thermocouples. The temperatures inside the solar oven, outside air temperature, wind speed, wind direction, and direct normal insolation (DNI) were measured and stored by a computer data acquisition system every thirty seconds.

Initial testing characterized heat up rate, the highest temperature reached, the temperature profile, and how long the solar cooker can remain in one position before it needs to be turned back into the sun. Figure 1 shows the normal heat up rate for the oven. The Sunstove will stabilize in temperature in about 25 minutes. The peak temperature was about 120°C (248°F). The oven needed to be repositioned approximately every hour to maintain optimum temperatures. For the remainder of the testing period the oven was repositioned every 30 minutes.

Later tests determined the ability of the solar oven to heat up water. Figure 2 is a picture of one of these tests in progress. A black ceramic coated covered pot filled with two liters of water was used. The oven was preheated for about one hour before the pot filled with water was placed inside. The water and pot were at room temperature before being placed in the oven. Figure 3 shows the results from this test. It heated water to 80°C (175°F) in less than two hours depending on wind conditions, which will be explained later. The maximum water temperature reached was 92°C (198°F).

The temperature distribution inside the Sunstove is shown in figure 4. There is a large difference between the front air thermocouple and the other thermocouples. Because of the shape of the Sunstove, the front air thermocouple is placed about one inch from the window and its seal, and about one inch from the bottom of the oven. This thermocouple is closest to any heat leaks and farthest from the heat source than any of the other thermocouples. The other thermocouples were much farther from the window, its seal, and the bottom of the oven.

During testing it was noticed the outside walls of the Sunstove were warm to the touch. For the test on 8/24 standard household fiberglass insulation, 3.5" thick, was wrapped around the outside of the Sunstove. As shown in figure 3, the extra insulation had little effect on the maximum temperature attained during preheat and on heating the water. From this it can be concluded most of the

heat loss is from the large front window, or door. Adding more insulation to the sides would only marginally increase the inside temperature.

Wind always has an adverse effect on the performance of solar ovens. Figure 4 shows the inside air temperatures are depressed during high winds and increase during lower wind periods. The Sunstove never tipped over from the wind. A solar cooker with external reflectors is more prone to tipping over with high winds. The higher winds, however, would open the cover and let the hot air out. With the lowered inside air temperature it took longer to heat the water to 80°C (175°F) (see data on 5/31 in figure 3). To prevent the cover from opening during high winds it was taped down. Use of the tape may seem extreme, but under normal circumstances the cook would employ some means to hold the acrylic sheet down. What windspeed would start to lift the acrylic sheet was not noted since orientation between wind direction and oven is very important. Since the orientation of the oven tracks the sun throughout the day and very often the wind changes direction during the day, the orientation of the oven to the wind is always changing. It would be best to fix the door closed rather than determining what wind speed and orientation would be needed to lift the door.

Clouds also have an adverse effect on the performance of the solar oven. Figure 5 shows the effect of several cloud passages on the measured inside air temperatures. The figure shows the air temperatures inside the oven decrease rapidly during very cloudy periods but recover nicely when the sun returns. The water temperatures during this same period are shown in figure 3 for the Sunstove. These data show that during minor cloudy periods the water temperature is only slightly affected. This is to be expected, since water has a much greater heat capacity than air.

These tests show the Sunstove can obtain sufficient temperatures to slow cook about a two liter quantity of food. It can heat water above 80°C (175°F) in a reasonable period of time, usually less than two hours. This temperature is important because 80°C (175°F) and higher is required to sterilize water and its contents, such as food. The Sunstove is stable in high winds but the wind can lift up the cover. This problem is easily overcome and should not detract from the usefulness of the oven. The Sunstove, at 20-\$25, is more affordable than most solar ovens being manufactured for low income families in developing countries.

References

¹S.C. Mullick, T.C. Kandpal and A.K. Saxena, *Thermal Test Procedure for Box-Type Solar Cookers*, Solar Energy, Vol. 39, No.4, pp353-360, 1987

²European Committee for Solar Cooking Research (ECSCR), *Solar Cooker Test Procedure*, Version 2, November 1993

Intentionally Left Blank

Figure 1: Ave. air temperature vs. time showing heat-up rates without water. The average of all five thermocouples is shown. Note the break at 9:37. The window, or door, was opened to observe how fast the oven recovers when opened during cooking.

Figure 2: Photograph of the Sunstove heating two liters of water in a pan. This also shows the extra insulation that was added in an attempt to reduce heat losses.

Figure 3: Ave. water temperature vs. time heating two liters of water. Notice the effects of wind on the temperature on 5/31.

Figure 4: Air and water temperature distribution inside the oven during a typical test.

Figure 5: Temperature and wind speed vs. time. This shows the effect of wind on the inside temperatures of the solar oven.

Figure 6: Average air temperature and Direct Normal Insolation (DNI) vs. time showing the effect of clouds on the performance of the solar oven.

Intentionally Left Blank

Distribution:

A.S.E. Americas, Inc.
Steven T. Slavsky
4 Suburban Park Drive
Billerica, MA 01821-3980

AAA Solar Service and Supply, Inc.
Chuck Marken
2021 Zearing Avenue, NW
Albuquerque, NM 87104

Agua y Energia Electrica
Grupo - Fuentes Alternas
Sociedad Del Estado
Gabato 3713
1826 Remedios de Escalada
Buenos Aires, ARGENTINA

All Indian Pueblo Council
Tim Jeffrey Chavez
Pueblo Office of Environmental Protection
3939 San Pedro N.E., Suite B
Post Office Box 3256
Albuquerque, NM 87190

All Indian Pueblo Council
Mark Thompson
Pueblo Office of Environmental Protection
Post Office Box 3256
Albuquerque, NM 87190

Alliance to Save Energy
Malcolm Verdict
1725 K Street NW, Suite 509
Washington, DC 20006

American Solar Energy Society
Larry Sherwood
2400 Central Avenue, Suite G-1
Boulder, CO 80301

Arizona State University
Byard D. Wood, Ph.D., P.E.
College of Engineering & Applied Sciences
Tempe, AZ 87287-5806

Bright Ideas Cooperative
Peter Clay
3090 King Street
Berkeley, CA 94703

Burns-Milwaukee, Inc.
Thomas J. Burns
4010 West Douglas Avenue
Milwaukee, WI 53209 (5)

California Energy Commission
Promod Kulkarni
Energy Technology Development Div. R&D
Office
1516 9th Street
MS-43
Sacramento, CA 95814-5512

CDESON
Jorge Villaescusa Celaya
Reyes y Aguascalientes (Esq)
Col. San Benito
Hermosillo Sonora, 83190
SONORA

Centro Investigaciones Energeticas
J.M. Figarola
Medioambientales y Tecnologicas
Instituto de Energias Renovables
Avda. Complutense, 22
28040 Madrid,
SPAIN

CIEMAT - Madrid
Manuel Macias Miranda
Instituto de Energias Renovables
Avda. Complutense, 22
E-28040 Madrid
SPAIN

Citizens Conservation Corp.
Steve Morgan
530 Atlantic Avenue
Boston, MA 02210

Col. Universidad
Ing. Rafael Cabanillas
Enrique B. Michel #11
Hermosillo, SONORA,
MEXICO

Commonwealth of the Northern Mariana
Islands
Juan M. Babauta
2121 R Street, N.W.
Washington, DC 20008

Conservation and Renewable Energy
System
Ben Wolff
6918 N.E. Fourth Plain Blvd., Suite B
Vancouver, WA 98661

Consortium/Energy Efficiency
Lawrence Alexander
303 Congress Street, Suite 600
Boston, MA 02210

Council of Great Lakes Govs
Frederic Kuzel
35 E. Wacker, Suite 1850
Chicago, IL 60601

County of Hawaii
Steve Burns
Dept. of Research and Development
25 Aupuni Street
Hilo, HI 96720

County of Maui-Energy Division
Kalvin Kobayashi
250 S. High Street
Wailuku, HI 96793

Dept. of Business, Economic Dev. &
Tourism
Maurice H. Kaya
Energy Program Administrator
335 Merchant Street, Room 110
Honolulu, HI 96813

Direccion Sectorial de Energia
Apartado 126/2021
San Francisco, Guadalupe
San Jose, COSTA RICA

Diseno Solar y Arquitectura Bioclimatica
Everardo Hernandez
A-P 69-738
D.F. C.P. 04460,
MEXICO

Division of Energy and Intergovernmental
Affairs
Nathaniel Robinson
101 South Webster, 6th Floor
P.O. Box 7868
Madison, WI 53707

Ecotecture
Jasper O. Hardesty, AIA
803 Loma Linda SE
Albuquerque, NM 87108

ECOTOPE
David R. Baylon
Energy Efficient Solutions
2812 E. Madison
Seattle, WA 98112

Energy Foundation
Bill Keepin
75 Federal Street
San Francisco, CA 94107

Environmental Technology & Education
Center (ETEC)
Jon Nimitz, Ph.D.
3300 Mountain Road NE
Albuquerque, NM 87106-1920

Federal Conservation & Renewable Energy
Referral Service
P.O. Box 8900
Silver Spring, MD 20907

Florida Solar Energy Center
Library
300 State Road, Suite 401
Cape Canaveral, FL 32920-4099

Guam Energy Office
Jennifer Sgambelluri
P.O. Box 2950
Agana, 96910
GUAM

Hawaii Energy Extension Service
Andrea Beck
Dept. of Business & Economic Development
Hawaii Business Center
99 Aupuni Street #214
Hilo, HI 96720

Indo-American Credit Corporation Ltd.
Amit N. Shsh
Regd. Office: Iol House, Near Swati
Apartment, Opp. Central Bank Lane
Ambawaki Bazar
Ambawadi, Ahmedabad
(Guj.) -380 006, INDIA

Industrial Credit & Investment Corp. of
India, LTD.
P. H. Vaidya
169, Backbay Reclamation
Road No. 3
Bombay 400 020,
INDIA

Molokai Ranch
David Nakamura
Four Waterfront Plaza
Suite 400, Box 96
500 Ala Moana Boulevard
Honolulu, HI 96813

National Renewable Energy Laboratory
Russ Hewett
1617 Cole Blvd.
Branch 4710/122
Golden, CO 80401-3393

Nature Conservancy
Will Murray
1815 N. Lynn Street
Arlington, VA 22209

New & Renewable Energy Authority
Adel Tawfik Soliman, Ph.D.
P.O. Box 39 El-Souk El-Togary
Maadi 11693 Cairo,
EGYPT

New Mexico Home Builders Association
Jack Milarch
5931 Office Boulevard NE
Albuquerque, NM 87109

New Mexico State University
Steve Durand
Southwest Technology Development Inst.
Box 30001, Dept. 3 SOL
Las Cruces, NM 88003-0001

Office of Intergovernmental Affairs
Shirley R. Dykshoorn
State Capitol, 14th Floor
600 East Boulevard Avenue
Bismarck, ND 58505

Palau Energy Office
Gregorio Decherong
P.O. Box 100
Koror, 96940
REPUBLIC OF PALAU

Renewable Energy Training Institute
Jeffrey S. Ross
122 C St. NW, Suite 520
Washington, DC 20001

Solar Energy Industries Association
Scott Sklar
122 C Street., NW
4th Floor
Washington, DC 20001-2109

Solar Uno
Ellis Perez
Ave. Sarasota No. 54, Apto. 102
Santo Domingo,
DOMINICAN REPUBLIC

State of Hawaii
David A. Rezachek, Ph.D., P.E.
Dept. of Business and Economic
Development
335 Merchant Street, Room 110
Honolulu, HI 96813

The Solar Letter
Allan L. Frank
9124 Bradford Road
Silver Spring, MD 20901-4918

The World Bank
Ernesto N. Terrado
1818 H Street, N.W.
Washington, DC 20433

U.S. Department of Energy
Frank (Tex) Wilkins
Office of Industrial Technologies
Forrestal Building, MS EE-11, Room 5F-035
1000 Independence Avenue, SW
Washington, DC 20585

U.S./ECRE
Renewable Energy Training Institute
P.O. Box 10095
Arlington, VA 22210-9998

Union of Concerned Scientists
Donald Aitken
20100 Skyline Boulevard
Woodside, CA 94062

Winrock International
Chris Rovero
1611 N. Kent St.
Arlington, VA 22209

Richard Warham
3628 W. Pierce St.
Milwaukee, WI 53215 (30)

MS 0704 Elizabeth Richards, 6201 (10)
MS 0703 Timothy A. Moss, 6216 (40)
MS 9018 Central Technical Files, 8940-2
MS 0899 Technical Library, 4414 (5)
MS 0619 Review & Approval Desk, 12690
For DOE/OSTI