EARTH/AIR HEAT EXCHANGE COOLING TUBES: AN EMPIRICAL STUDY

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ABSTRACT

This paper describes an experiment intended to discover if blowing air through buried PVC tubes can effectively assist in cooling buildings by using the relatively stable thermal mass of subterranean soil to cool the air. Three different lengths of earth/air heat exchange cooling tubes at a 10 ft. (3.05 m) depth in semi-arid Lubbock, Texas,are compared. Initially a 100 ft. (30.48 m) and a 200 ft. (60.96 m) tube were constructed and monitored. Later the two tubes were connected making it possible to compare their performances to that of a linked 300 ft. (91.44 m) tube.

1. INTRODUCTION

In most of the inhabited world the underground soil temperature is cooler than ambient air during the summer cooling season. Many strategies have been found to utilize this cool soil to add comfort to buildings. Earth/air cooling is achieved by either "direct" cooling, burying or partly burying a building in the ground or by "indirect" cooling, circulating a fluid, usually air, through the underground and into a building. Both of these approaches have reportedly resulted in varying degrees of success.

Recently there has been a renewed interest in these "passive" cooling strategies and many buildings have been constructed utilizing earth contact cooling. Burying or partly burying a building is usually very costly and severely limits design and material choices, therefore indirect cooling research is suggested. Economic considerations further suggest the need to discover the shortest and least costly cooling tube that will be effective for a specific site.

2. EXPERIMENTAL APPARATUS

In 1985 a 12 in. (30 cm) diameter PVC tube 100 ft. long and a similar tube 200 ft. long were buried with their centerlines 10 ft. below grade in an open farm field. The tubes are non-corrugated, 80 psi strength and are water tight. Vertical stacks of the same material are attached at each end; one for incoming air and the other for exhaust air. To minimize the effect of earth temperature above 10 ft., the stacks are insulated with 2 in. of rigid polystyrene. All four vertical stacks are outfitted with a shallow sump depression at their bases in case water should accumulate. Very little has. To drive the air, blower boxes with 1/3 horsepower motors are mounted at the intake stacks and wind powered roof turbines are mounted at the exit exhausts. Exhaust air, which could be discharged to a building, is discharged directly to the environment for this experiment. Installation techniques and methods were uniform.

The tubes are arranged in two squares. Each corner is made of two 45° PVC elbows. The arrangement of the tubes is intended to facilitate a) combining the tubes to create the 300 ft. linked tube, b) providing a closed loop possibility, and c) reducing the area to approximate the layout of a backyard installation.

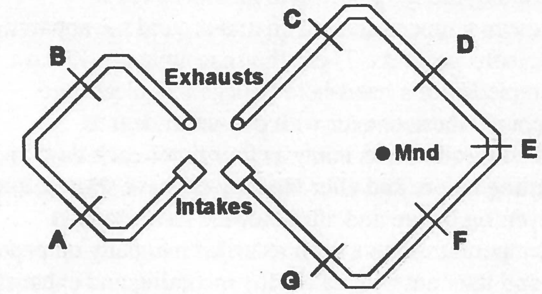

Fig. 1. Plan view of 100 ft. and 200 ft. tube configuration.

In 1991 the 100 ft. tube and the 200 ft. tube were joined using a 12 in. diameter above ground metal duct. The exterior of the linkage was insulated with 2 in. of foil-faced rigid polyurethane and a 16 in. (40 cm) highly reflective, metal duct. To insure that this linked tube simulated the performance of an underground 300 ft. tube a study was conducted to determine if air temperatures changed while passing through the linkage. It was found that air temperatures at each end of the connection were almost identical. Air temperatures varied only ± ½° over the sequence of up the stack, across the connection, and down the other stack even when the ambient air was up to 20° F hotter.

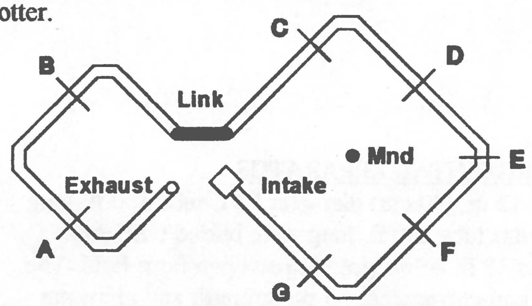

Fig. 2. Plan view of 300 ft. tube configuration.

2.1 Operating Schedule

Unlike the pragmatic homeowner application where the apparatus would likely be operated only when needed, in this experiment ambient air is blown through each tube on a uniform schedule, from nine a.m. to six p.m. throughout the year. This is done to allow comparisons of both of the tubes for winter pre-heating as well as summer cooling.

3. MONITORING PROCEDURES

Dickson battery powered 7-day circular chart recorders graph temperatures of the air at both ambient air intake and cooled air exhaust locations 24 hours a day. For this report, "exhaust temperatures" are air temperatures at the exhaust stacks measured 10 ft. below grade and "ambient air" temperatures are NOAA (National Oceanic and Atmospheric Administration) data for Lubbock, Texas. Type K thermocouple sensors planted at a number of stations along the tubes facilitate measurement of subterranean temperatures in, on and around the apparatus as the seasons progress. These thermocouple arrays have been sampled with a hand-held Omega 871 electronic thermocouple thermometer with one-tenth degree Fahrenheit resolution as many as four times each day: in the morning before and after the blowers have started, and in the evening before and after blowers have stopped. These temperatures have been recorded manually on paper charts, and later entered, as are the incoming and exhaust air temperatures, on computer spreadsheets.

As shown in Fig. 1 and Fig. 2, at the 200 ft. tube thermocouples are located at 33 ft. (station G), 66 ft. (station F), 100 ft. (station E), 133 ft. (station D), and 166 ft. (station C) from the intake stack; at the 100 ft. tube at 33 ft. (station A) and 66 ft. (station B) from the intake stack. Each array consists of thermocouples above the tubes at 3, 6, 8, 9 ft. below grade ; below the tubes at 11, 12, 14 ft. below grade; beside the tubes at 1 ft. (Hz 1), 2 ft. (Hz 2), 4 ft. (Hz 4) measured horizontally from the center of the tubes. Thermocouples are also positioned on the exterior surface (Outside), interior surface (Inside), and center of the tubes (Tube). A soil temperature background site (Mnd) consists of thermocouples at 3, 6, 8, 10, 11, 12, and 14 ft. below grade.

All thermometers are checked periodically for accuracy using a scientific mercury thermometer. As thermocouple readings are at risk of being adversely affected by nearby television and radio transmitters, special efforts are made to shield the electronic thermometer.

Some charts have missing data. These are the result of human error or instrumentation failure. The most common failures are broken solid conductor thermocouple wires. Occasionally data appears to contain anomalies or incorrectly recorded temperatures. This report includes these infrequent discrepancies. In no case are recorded temperatures altered. All temperatures in this report, including NOAA ambient, are sampled at three hour intervals starting at midnight. The graphs connect these points with straight lines and do not show variations between points. It does accurately capture the blower start time, 9 a.m., and stop time, 6 p.m.

Monthly average air temperatures were collected from NOAA data for the years of the study. (Fig. 6) Temperatures were usually close to the monthly means (based on the last 40 years) especially for summer months. However with 16 days over 100° F (37.7 C), June of 1990 was unusually hot. The mean of 84.4° F was 6.8° F (3.8 C) degrees hotter than the 40 year June mean.

4. ANALYSIS METHODS

This is a report of some of our most significant findings. Comparisons are made; contrasts are shown. Critical temperatures are graphed and analyzed. NOAA air temperatures and tube exhaust temperatures are compared for different times of day and season for each tube length. Temperatures in, on and around the tubes are graphed. Soil temperatures at stations near the tubes for different depths are shown.

4.1 Performances of three tube lengths compared

The performances for different lengths of tubes are compared for a mid-summer period during two years (Fig. 3) when ambient highs reached the 90s. Note that when the blowers start, 9 a. m., the exhaust air temperatures are nearly the same for all tube lengths. By the time the blowers are turned off, 6 p.m., the 100 ft. exhaust temperatures are nearly 80° F; the 200 ft. exhaust, about 75° F. Despite nine hours of use on hot days, the resulting 300 ft. exhaust air temperatures remain in the low seventies.

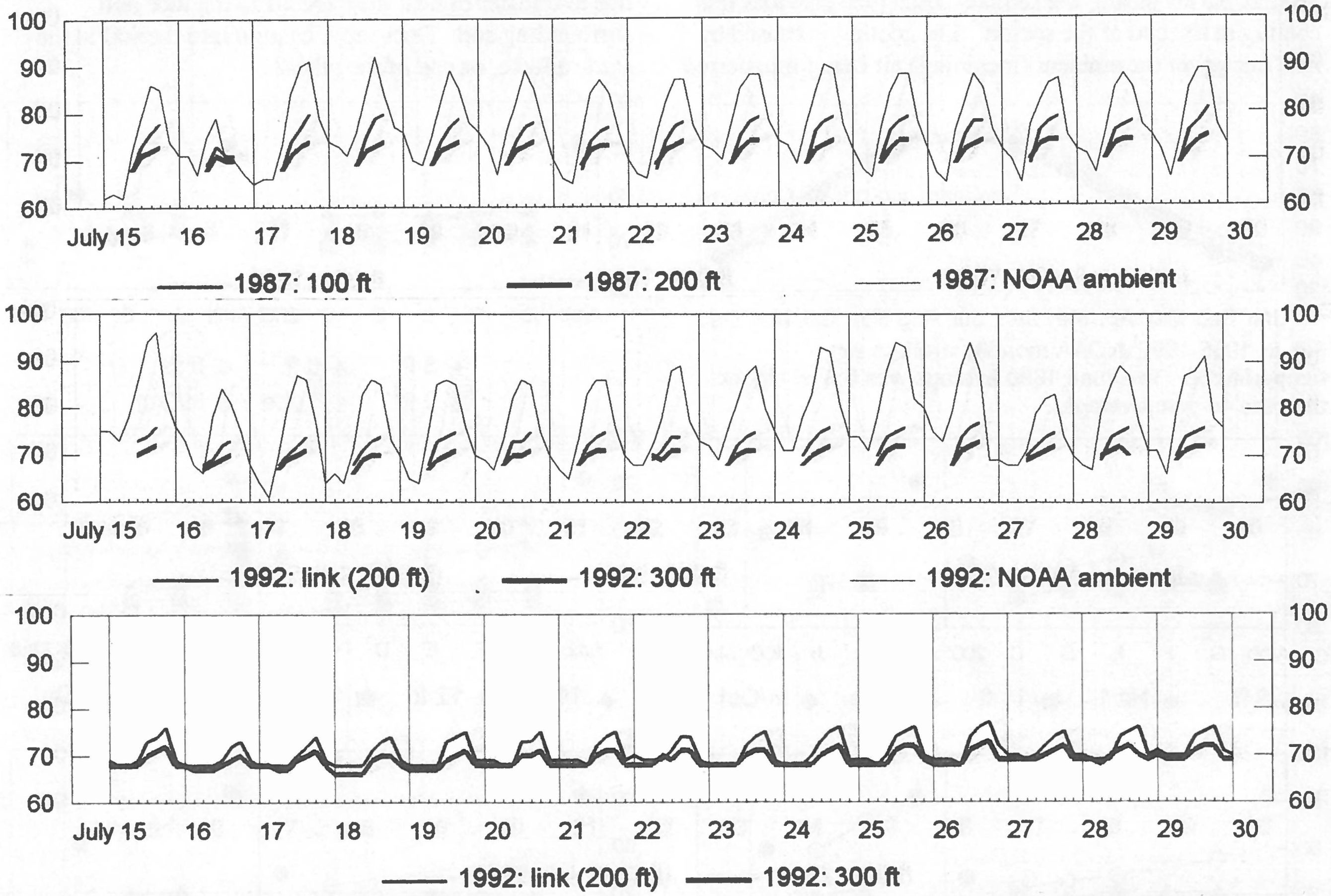

Fig. 3. July 15-30: Air temperatures at 100 ft., 200 ft., link ,and 300 ft. tube exhausts . The top graph shows 1987 100 ft. and 200 ft. exhaust temperatures during blower operation (9 a.m.- 6 p.m.) with NOAA ambient air temperatures. The middle shows 1992 200 ft. link and 300 ft. exhaust temperatures during blower operation with NOAA temperatures. The bottom graph shows the same 1992 exhaust temperatures displayed continuously.

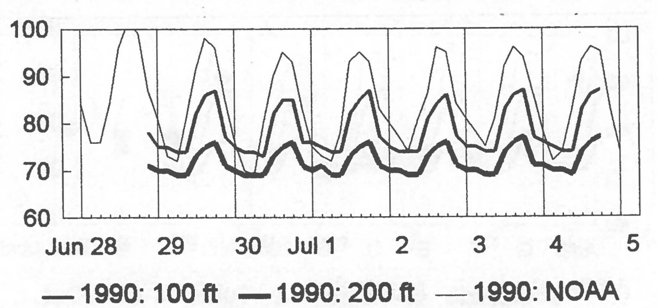

Fig. 4. June 28- July 5, 1990: After the record heat of June. Air temperatures at 100 ft. tube and 200 ft. tube exhausts reported continuously with NOAA ambient air temperatures.

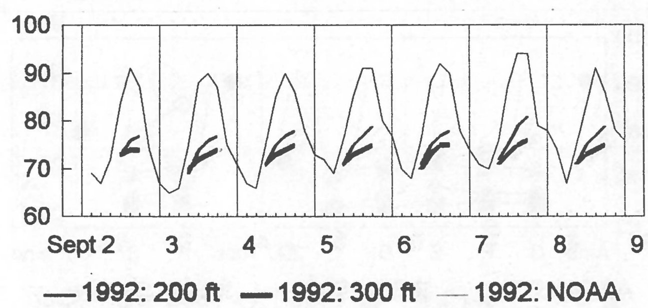

Fig. 5. September 2-9, 1992: Late in the cooling season. Air temperatures at link (200 ft.) and 300 ft. tube exhaust during blower operation (9 a.m.- 6 p.m.) with NOAA ambient air temperatures.

4.2 Temperatures of tube and soil

Exhaust air temperatures are influenced by a number of different factors: a) the temperature of the incoming ambient air, b) the temperatures of the PVC tubes and c) the temperature of the surrounding soil. The graphs show the temperatures in, on, and around the tubes at blower start and stop time for a typical day in July. Because the ground warms during the summer, each tube provides less cooling at the end of the season. The cooling is caused by heat energy in the ambient (incoming) air being transferred to the subterranean soil. Heat is transferred in all directions out from the tubes. In the early cooling season the soil near the tubes is cooler than the soil at other sites in Lubbock at the 10 ft. depth because cold air has been blown through the tubes in winter. By the end of the season the soil temperature around the tubes has become quite warm due to transfer of heat from the air to the tube and surrounding soil. Does more heat go into the soil at the start, middle, or end of the tubes?

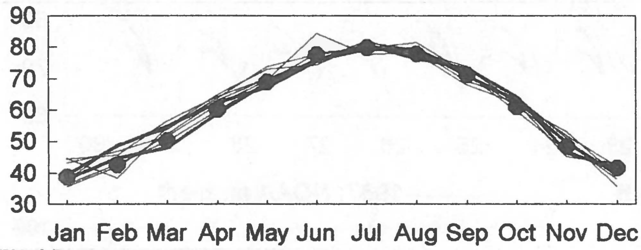

Fig. 6. 1985-1992: NOAA monthly average air temperatures. The June 1990 average was 6.8° F higher than the 40 year average.

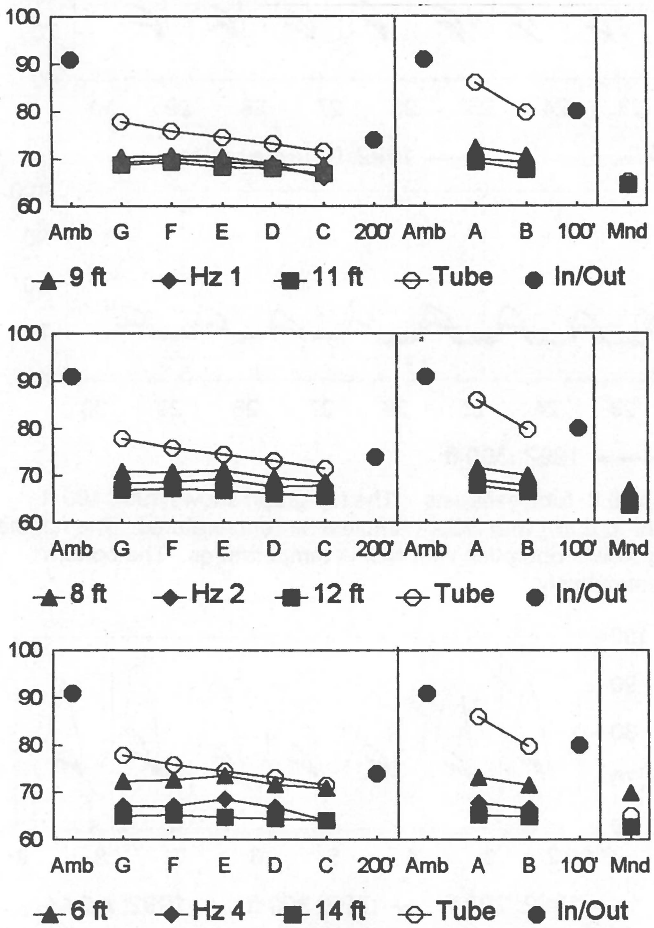

Fig. 7. July 17, 1987, 6 p.m.: Temperatures of 200 ft. tube and 100 ft. tube. The top graph shows temperatures 1 ft. from the center of the tube; middle, 2 ft. from the center of the tube; bottom, 4 ft. from the center of the tube.

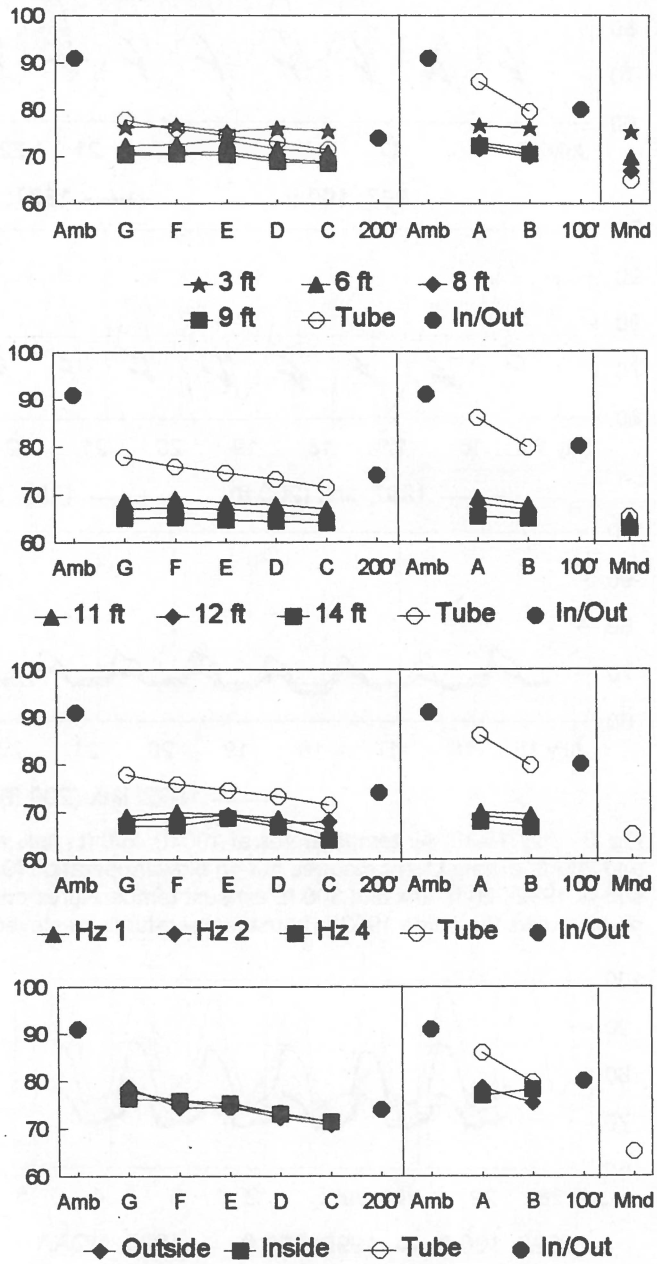

Fig. 8. July 17, 1987, 6 p.m.: Temperatures of 200 ft. tube and 100 ft. tube. The top graph shows temperatures above the tube; next, below the tube; next, beside the tube; bottom, surfaces of the tube.

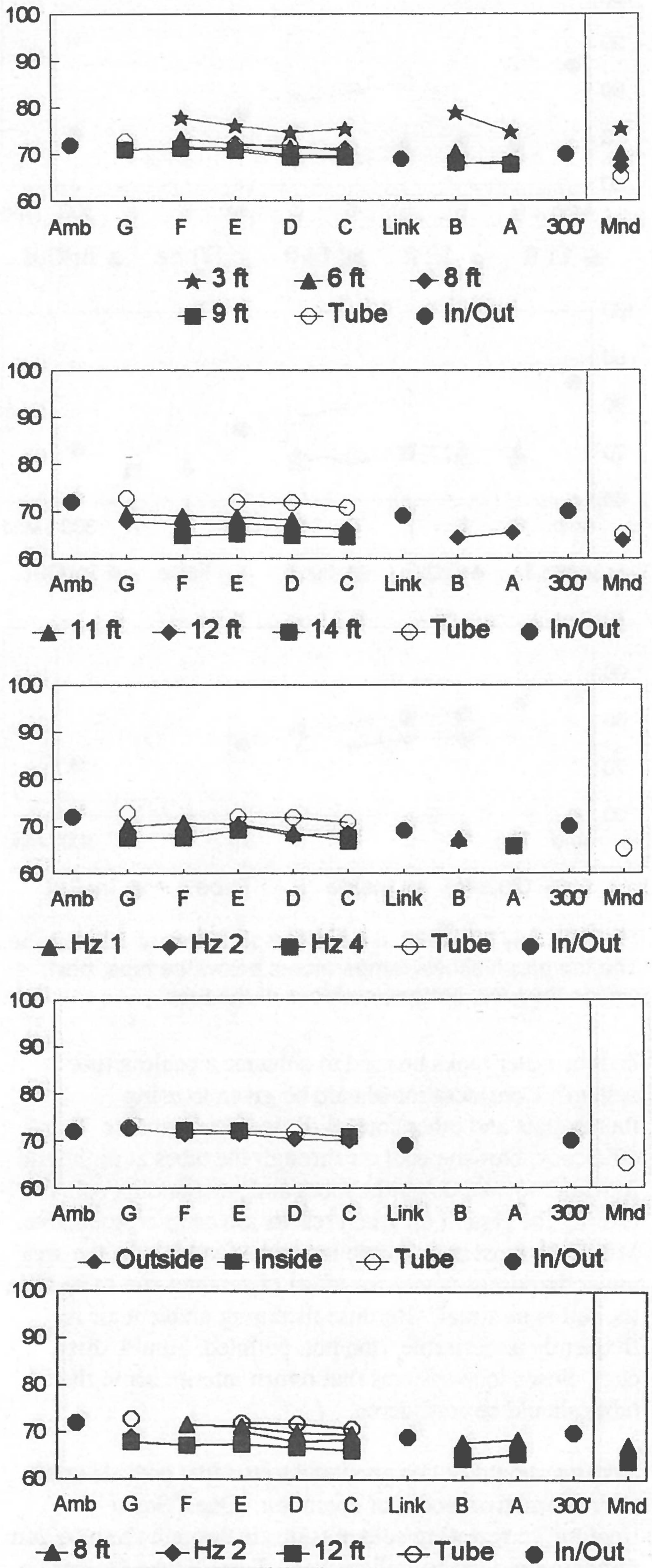

Fig. 9. July 22, 1992, 9 a.m.: Temperatures of 300 ft. tube. The top graph shows temperatures above the tube; next, below the tube; next, beside the tube; next, surfaces of the tube; bottom, 2 ft. from the center of the tube.

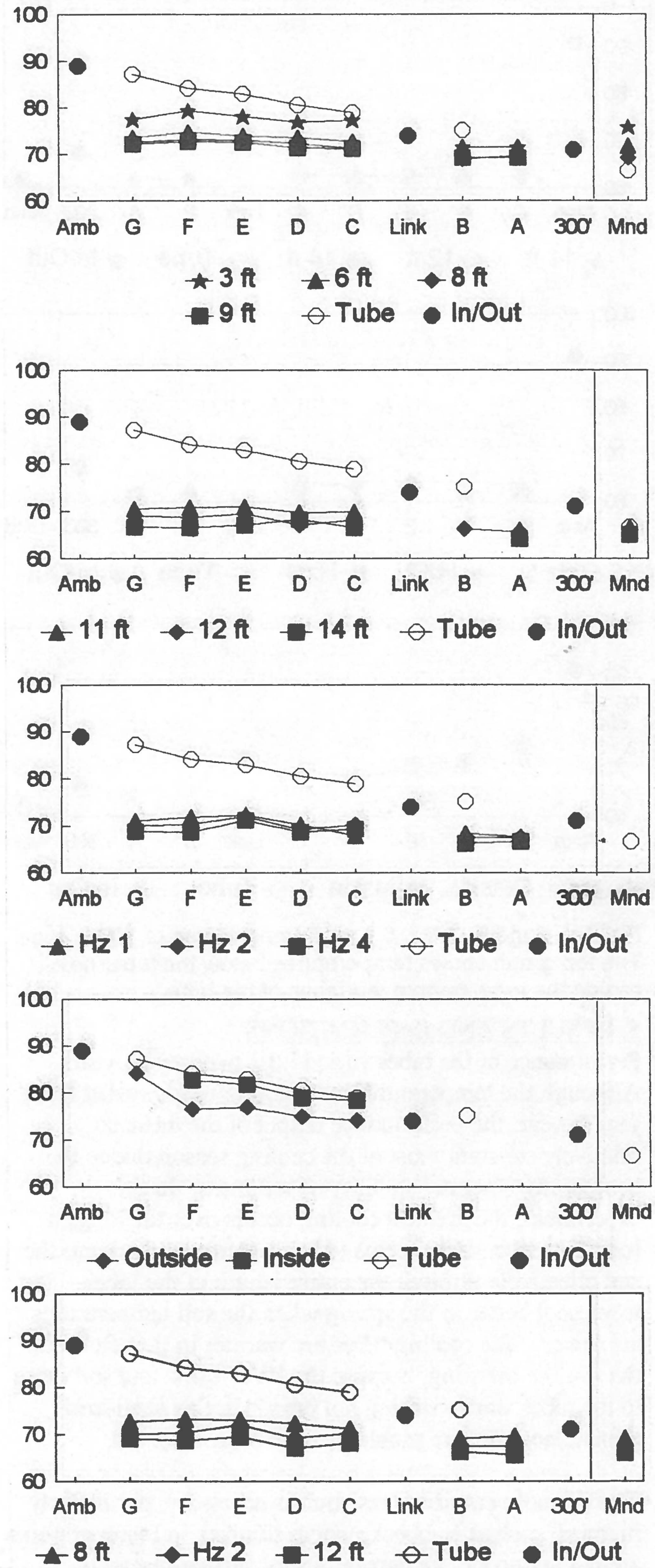

Fig. 10. July 22 1992, 6 p.m.:Temperatures of 300 ft. tube. The top graph shows temperatures above the tube; next, below the tube; next, beside the tube; next, surfaces of the tube; bottom, 2 ft. from the center of the tube.

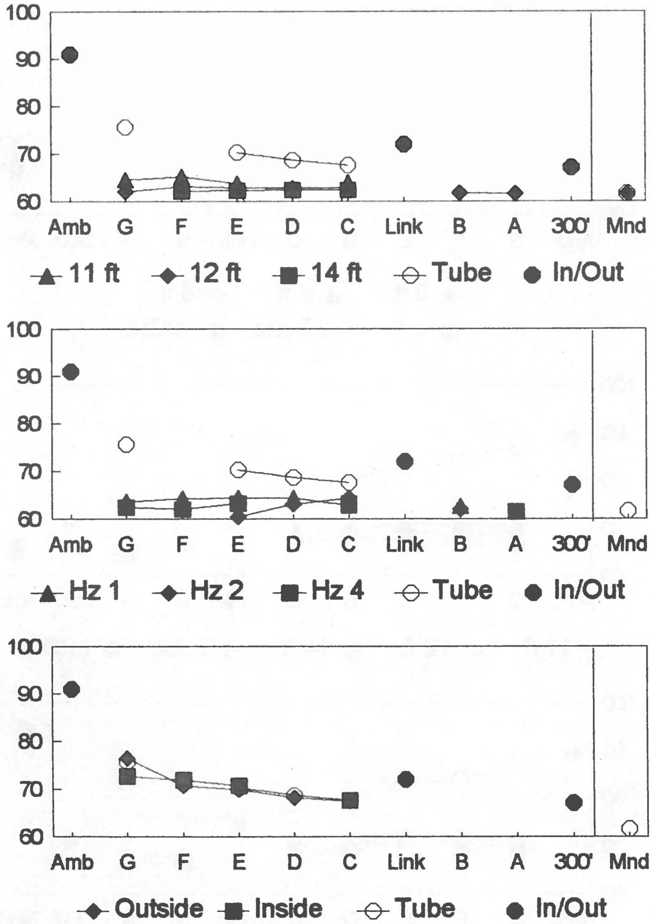

Fig. 11. June 5, 1992, 6 p.m: Temperatures of 300 ft. tube. The top graph shows temperatures below the tube; next, beside the tube; bottom, surfaces of the tube.

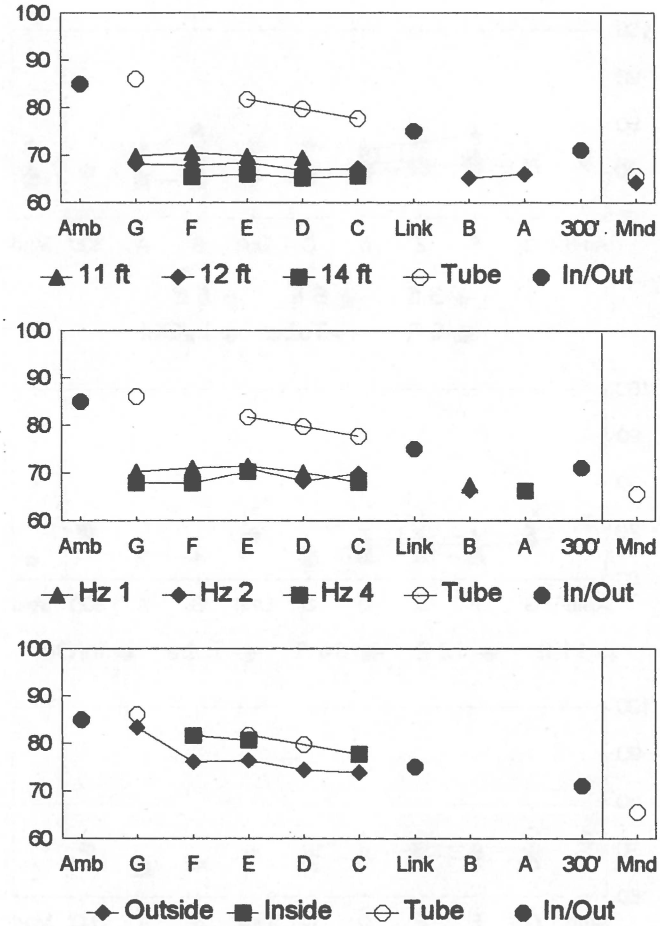

Fig. 12. July 20, 1992, 6 p.m: Temperatures of 300 ft. tube. The top graph shows temperatures below the tube; next, beside the tube; bottom, surfaces of the tube.

5. RESULTS AND IMPLICATIONS

Performance of the tubes varied little over recent years. Although the temperatures and cooling needs varied from year to year, the performance output of the tubes is relatively constant most of the cooling season due to the comparative thermal stability of soil mass. In this experiment, the greatest cooling occurs over the longest length of tube. Heat seems to have been absorbed into the soil effectively through the entire length of the tubes. The tubes cool better in the spring when the soil temperatures are lower. The cooling tubes are warmer in the afternoon than in the morning, because the PVC tubes and soil close to the tubes warms during hot days. In this semi-arid climate,no moisture problems have been observed.

Clearly more empirical research is necessary, particularly in areas, such as Lubbock, where summer soil temperatures are not very cool. Opportunities for further research include: comparing the performance of different tube materials, lengths, diameters, cross-sections, depths, layouts and flow rates. Might the thermal mass of rock beds or water tanks be used to enhance a cooling tube system? Consideration should be given to using thermostats and other control devices to maximize efficiency, blowing cool air through the tubes at night and in winter to cool down the tubes and surrounding soil and turning the system off when results are counterproductive. Might the most appropriate locations for tubes be the area under buildings where the effect of summer sun in heating the soil is minimal? Because incoming ambient air is frequently undesirable, (too hot, polluted, humid, dirty, etc.), closed loop systems that return interior air to the tubes should be considered.

Systems should be designed and tested that provide users with alternative modes of operation: One, "Super Cooling," circulating cold outside air through the tube and discharging it to the environment, Two, "Make-Up Air," circulating outside air through the tube and into a space, and Three, "Recirculation," recirculating interior air through the tube and into a space in a closed loop.

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Main entry under title:

Passive '94: including and continuing the proceedings of the National Passive Solar Conference; v. 19

1. Solar energy - Passive System - Congresses.

   I. National Passive Solar Conferences (19th: 1994)
   II. Series XIX. Title: Passive ninety-four

ISBN 0-89553-209-3

Proceedings of:

THE 19th NATIONAL PASSIVE SOLAR CONFERENCE

San Jose, California
June 25-30, 1994

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S.M. Burley
M.E. Arden
R. Campbell-Howe
B. Wilkins-Crowder

VOLUME 19

American Solar Energy Society
2400 Central Avenue
Boulder, CO 80301

Printed on recycled paper

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19th National Passive Solar Conference

Conference Proceedings
San Jose, California
June 27-30, 1994

Solar 94

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