EARTH/AIR HEAT EXCHANGE COOLING TUBES

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ABSTRACT

This paper describes two projects. In the first project, soil temperatures at irrigated and non-irrigated sites, with depths to 30 feet, have been measured in Lubbock, Texas since 1983. Soil temperatures under a heated and cooled commercial building have been monitored since 1985. The effect of micro-climate on soil temperature at various depths and the effect of yearly climate variations will be illustrated.

The second project involves the performance of two earth/air heat exchange "cooling tubes" installed in Lubbock and monitored since 1985. A one-hundred foot long, twelve-inch diameter PVC plastic pipe buried ten feet below grade has been compared to a similar two-hundred foot long pipe. Fresh air was forced through each and the exhaust air was discharged to the environment. Cooling (and heating) performance studies comparing intake air temperature and exhaust air temperature will be displayed.

1. INTRODUCTION

In the early 1980's Associate Professor of Architecture, Melvin H. Johnson, and the author began to explore strategies of using the thermal mass of soil to assist in the heating, and particularly the cooling, of buildings. Three basic approaches have been used and currently are being used successfully. One approach uses existing caves or constructs habitable spaces underground. Another brings the mass of the earth up to the surface with heavy berms or adobe construction. The third approach utilizes a heat exchanger to transfer heat from a building to the surrounding earth. The researchers chose to explore this third approach more thoroughly. Investigating this third method, however, first required a better understanding of soil temperatures.

2. OPERATION

2.1 Soil Temperature

Soil temperatures at various depths have been studied since the 16th century, but the researchers felt most data was of questionable accuracy and utility. Popular myths of soil temperatures abound, but these appear to be based on even less reliable sources. The researchers decided testing was necessary and appropriate apparatus was set up in Lubbock, Texas.

Soil temperatures at various sites and depths have been measured since 1983. The installation procedures, apparatus and monitoring have been identical at all sites. A 2-1/2 inch hole was dug with a manual auger at each site. A bundle of 24-gauge, type-K thermocouple, teflon-coated wires of various lengths was carefully lowered to the correct depths in the hole. The soil removed from the hole was slowly poured down the hole. A removable cap fabricated from a four-inch PVC sewer clean-out was installed at grade to protect the wires and thermocouple plugs. No settlement of the soil has been observed at any site.

The monitoring procedure consisted of removing the cap and individually attaching each thermocouple plug to an Omega 871 electronic thermocouple thermometer with one-tenth degree Fahrenheit resolution. Most sites had thermocouples at 3-foot, 6-foot, 8-foot, and 10-foot depths. One site also had 12-foot, 18-foot, 24-foot, and 30-foot depths. The temperatures were recorded on log sheets and later entered into a Lotus-1-2-3 spreadsheet.

Ambient air temperatures were recorded at the time of monitoring, but all ambient temperatures referred to in this section of the paper are from the Local Climatological Data, Monthly Summary, published by the National Oceanic and Atmospheric Administration (NOAA). Their data are gathered at the airport, located eight miles from the thermocouple sites. NOAA defines the daily mean as the average of the daily high and daily low temperatures. This set of numbers is plotted for each year. Some graphs show the 5-year mean of these daily numbers based on 1983-1988. Some graphs also show the smoother curve of NOAA's 30-year mean.

The thermocouple readings were graphed directly from the Lotus-1-2-3 spreadsheets, without manipulation, except for the graphs that show means. When the temperatures were not recorded, because of school vacation for instance, the cell was left blank. An average of once per

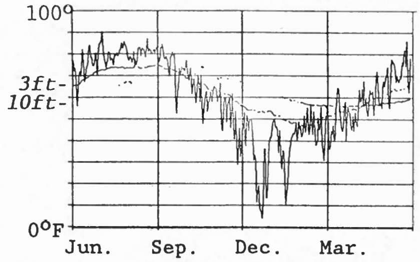
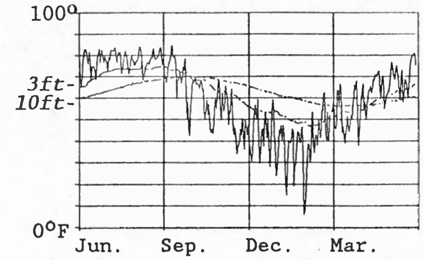


Fig. 1. **Architecture Bldg. 1983-1984;** *3 ft. depth, 10 ft. depth, ambient daily mean*



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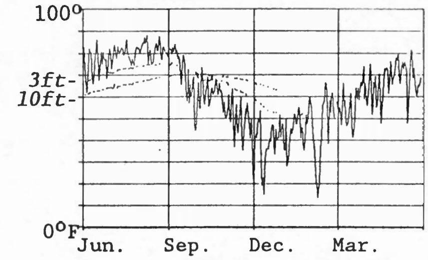

Fig. 3. **Architecture Bldg. 1985-1986;** *3 ft. depth, 10 ft. depth, ambient daily mean*

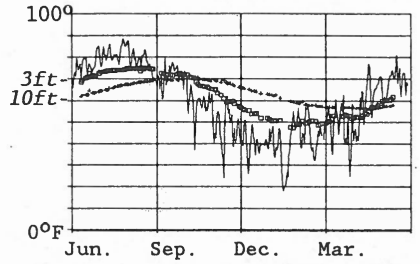

Fig. 4. **Architecture Bldg. 1986-1987;** *3 ft. depth, 10 ft. depth, ambient daily mean*

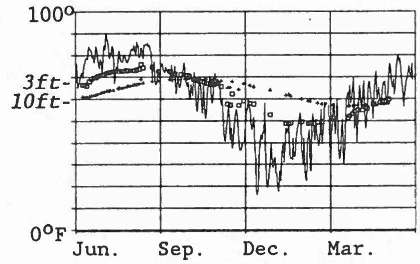

Fig. 5. **Architecture Bldg. 1987-1988;** *3 ft. depth, 10 ft. depth, ambient daily mean*

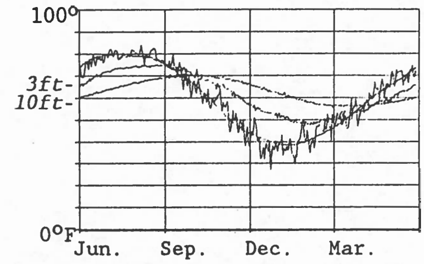

Fig. 6. **Architecture Bldg. 1983-1988 Means;** *3 ft. depth, 10 ft. depth, ambient daily mean, ambient daily 30-year mean*

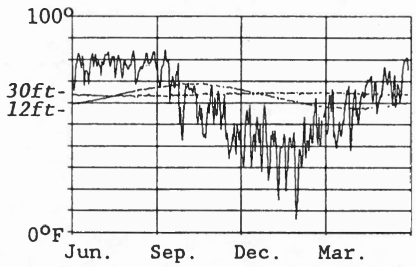

Fig. 7. **Architecture Bldg. 1984-1985;** *12 ft. depth, 30 ft. depth ambient daily mean*

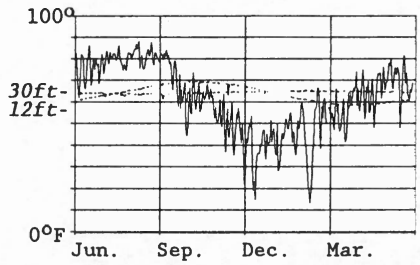

Fig. 8. **Architecture Bldg. 1985-1986;** *12 ft. depth, 30 ft. depth ambient daily mean*

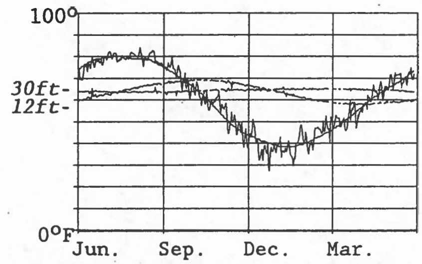

Fig. 9. **Architecture Bldg. 1983-1988 Means;** *12 ft. depth, 30 ft. depth, ambient daily mean, ambient daily 30-year mean*

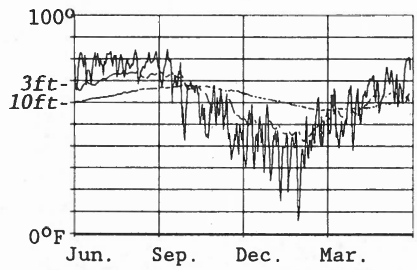

Fig. 10. **Art Bldg. 1984-1985;** *3 ft. depth, 10 ft. depth, ambient daily mean*

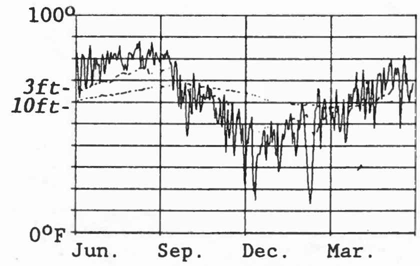

Fig. 11. **Art Bldg. 1985-1986;** *3 ft. depth, 10 ft. depth, ambient daily mean*

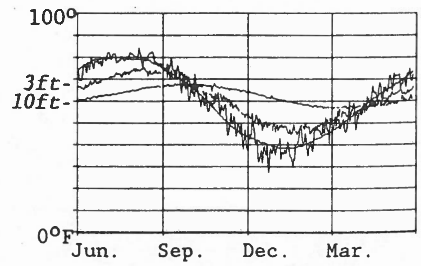

Fig. 12. **Art Bldg. 1983-1988 Means;** *3 ft. depth, 10 ft. depth, ambient daily mean, ambient daily 30-year mean*

graph an obvious major error, perhaps transposing a number, was erased. The software ignores missing data. Several small anomalies remain visible on most graphs as sudden one-day variations. Apparently these are some sort of measurement or logging errors. When readings were taken every day, or nearly every day, the graphs were plotted in the line-mode and single, isolated readings do not show. Several graphs were plotted in the symbol-mode to show isolated readings taken at less frequent intervals.

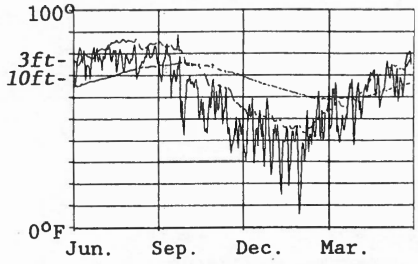

Fig. 13. **Parking Lot 1984-1985;** *3 ft. depth, 10 ft. depth, ambient daily mean*

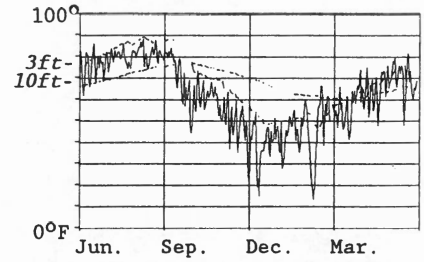

Fig. 14. **Parking Lot 1985-1986;** *3 ft. depth, 10 ft. depth, ambient daily mean*

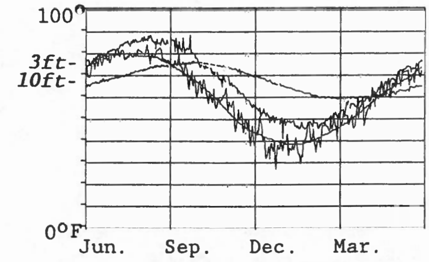

Fig. 15. **Parking Lot 1983-1988 Means;** *3 ft. depth, 10 ft. depth, ambient daily mean, ambient daily 30-year mean*

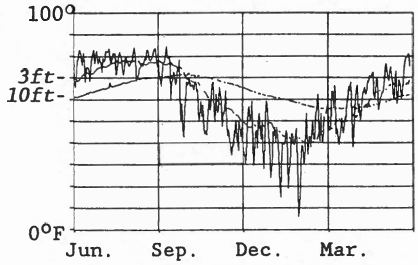

Fig. 16. **Wells Hall 1984-1985;** *3 ft. depth, 10 ft. depth, ambient daily mean*

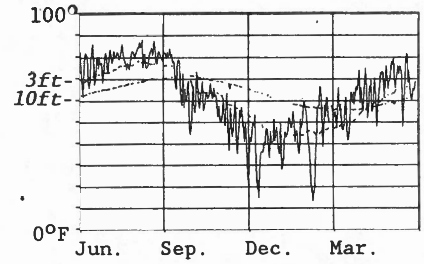

Fig. 17. **Wells Hall 1985-1986;** *3 ft. depth, 10 ft. depth, ambient daily mean*

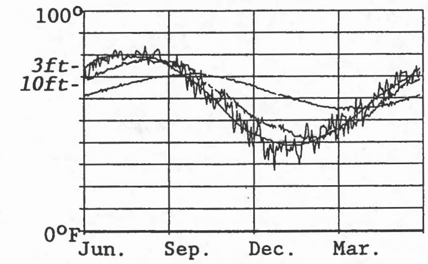

Fig. 18. **Wells hall 1983-1988 Means;** *3 ft. depth, 10 ft. depth, ambient daily mean, ambient daily 30-year mean*

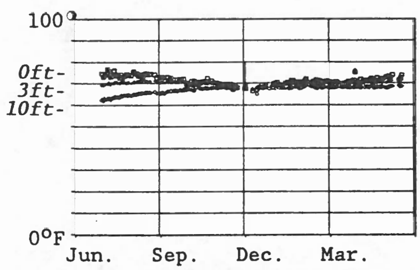

Fig. 19. **Toy Store 1985-1986;** *0 ft. depth, 3 ft. depth, 10 ft. depth*

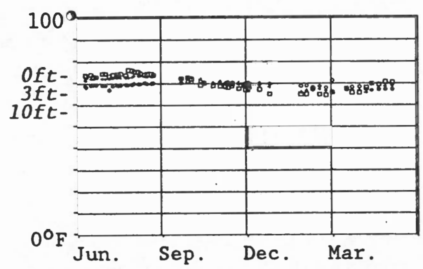

Fig. 20. **Toy Store 1986-1987;** *0 ft. depth, 3 ft. depth, 10 ft. depth*

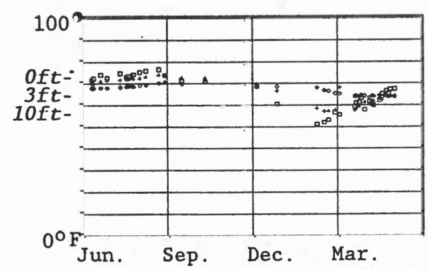

Fig. 21. **Toy Store 1987-1988;** *0 ft. depth, 3 ft. depth, 10 ft. depth*

All sites are on the Texas Tech University campus except the Toy Store which is located nearby. The Architecture Building site, Figures 1-9, was in full sun with an irrigated lawn. The Art Building site, Figures 10-12, was in partial sun under a tree canopy, bare earth, and not irrigated. The Parking Lot site was in a non-irrigated island at the edge of an asphalt parking lot and appears in Figures 13-15. The Wells Hall site was 14 feet north of a three story dormitory building (Figures 16-18). Summer sun reached the site but it was in full shade during the winter with an irrigated lawn. The Toy Store, Figures 19-21, was under a retail space in the Crossroads strip shopping center. Before the concrete floor slab was poured, thermocouples were installed using a procedure identical to that used at the other sites. However, to allow monitoring, the thermocouple wires ran 30 feet north under the slab to an exterior wall. Figures 22-25 show comparisons of the Architecture Building, Art Building, Parking Lot, and Wells Hall sites.

2.2 Tubes

The performance of two earth/air heat exchange "cooling tubes" have been monitored since 1985. A one-hundred-foot long tube has been compared to a similar two-hundred-foot long tube. Both are located at the same site and built at the same time. The installation procedure, construction materials, operating schedule and monitoring have been identical. Figure 26 shows the layout, varying only in length, of each tube. A ten-foot, six-inch deep trench was dug by a contractor. The tube was constructed of a 12-inch diameter, non-corrugated, 80 psi PVC irrigation pipe. Corners were built from two 45° PVC elbows.

The vertical intake and exhaust stacks were also 12-inch diameter PVC tubes with PVC tees used to attach the stacks to the horizontal tube and create a shallow sump below the stack. The stacks were insulated with 2 inches of rigid foam to minimize the effects of the earth temperature above the ten-foot depth.

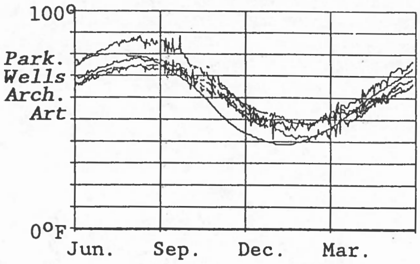

Fig. 22. **Three Feet: Various Sites 1983-1988 Means;** *Architecture Bldg., Art Bldg., Parking Lot, Wells Hall; ambient daily 30-year mean*

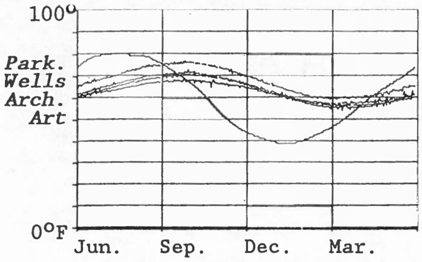

Fig. 23. **Ten Feet: Various Sites 1983-1988 Means;** *Architecture Bldg., Art Bldg., Parking Lot, Wells Hall; ambient daily 30-year mean*

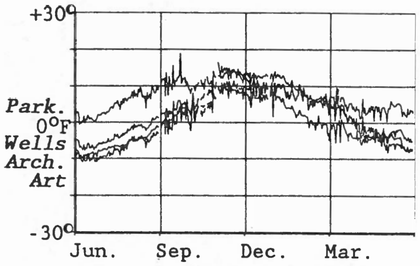

Fig. 24. **Three-foot Deviation 1983-1988 Means:** *Architecture Bldg., Art Bldg., Parking Lot, Wells Hall; deviation of 3 ft. depth soil temperature from ambient daily 30-year mean*

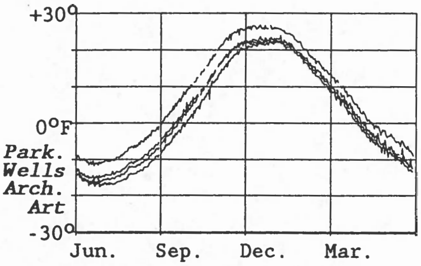

Fig. 25. **Ten-foot Deviation 1983-1988 Means:** *Architecture Bldg., Art Bldg., Parking Lot, Wells Hall; deviation of 10 ft. depth soil temperature from ambient daily 30-year mean*

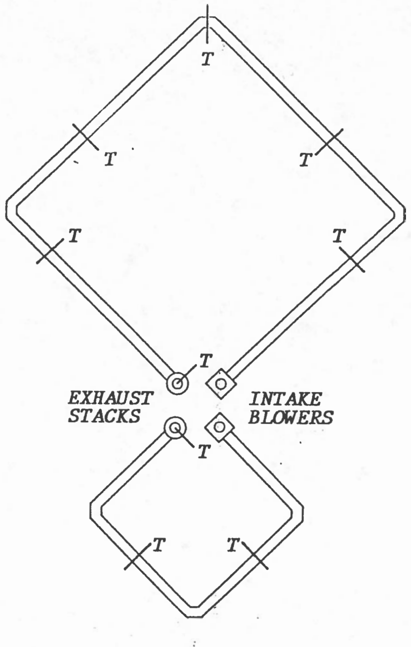

Fig. 26. **Tubes, Layout Diagram;** *100-foot long tube, 200-foot long tube*

Type-K thermocouple arrays were installed at the "T" locations indicated in Figure 26. The arrays were located 33 feet and 66 feet along the run of the tube from the intake stack on the 100-foot long tube and 33 feet, 66 feet, 100 feet, 133 feet and 166 feet from the intake stack on the 200-foot long tube.

The tube site was about 200 feet from the base of the University TV and radio broadcast antennae. Radio frequency interference was a problem with some types of thermocouple thermometers and long thermocouple wire runs. Battery-powered, 7-day chart recorders were placed in the exhaust stacks and near an intake stack for continuous recording and as a verification of thermocouple readings.

The intake at each tube consisted of an evaporative cooler box with the water pump and pads removed. A squirrel-cage blower powered by a one-third horsepower electric motor forced ambient air through each tube. Each exhaust stack was capped by an unpowered, 12-inch attic turbine. Simple timers turned the blowers on at 9 a.m. and off at 6 p.m. daily, year-round.

Extensive monitoring of all the thermocouples at the tube site was performed but space and time limitations do not permit a thorough examination of that data in this paper.

3. CONCLUSIONS

3.1 Soil Temperatures

Figures 1-9 show data from the Architecture Building site and NOAA. Note the ambient daily mean during the colder winter of 1983-1984 compared to 1985-1986. Both the three-foot and ten-foot depths plot nearly the same each year. Figure 6 shows a mean composite of the previous graphs. This averaging smooths the lines and covers missing cases. The three-foot depth has a range of about 27° while the ten-foot depth varies only about 14°. The deeper the temperature reading, the smaller the variation. Also note the peaks and valleys, maximums and minimums, are later in the year for the three-foot depth compared to the ambient temperature. The ten-foot depth peaks even later. The deeper the temperature reading, the greater the time lag.

Figures 7-9 show data from the 12- and 30-foot depths at the same site. Note the flatter curves and increased time lag. It is impossible to see at this scale, but the 30-foot temperatures show about a 2° range and a five-month lag.

The other sites, Figures 10-18, show similar responses. Figure 22 places the five-year means of the four sites on one graph. At the three-foot depth, the Parking Lot is hotter year-round but the other sites differ only slightly from each other. In Figure 23, the ten-foot depth, the same is true. Summer warming is slightly less for the Art Building site perhaps due to the tree canopy. Figures 24 and 25 show the same data as the two previous graphs but on a different vertical scale and plot the deviations of the soil temperatures from the ambient daily 30-year mean. At the ten-foot depth, the soil is about 20^{o} warmer than the air during December and about 15^{o} cooler during June.

Figures 19-21 show data from a set of thermocouples under a retail space in a strip shopping center. Figure 19 shows the temperatures stabilizing after construction and the tenant, Toys Plus, opened for business. The store went out of business in January 1988 and the space was vacated. Although the readings unfortunately were taken infrequently during this time period, the graph clearly shows cooler temperatures, particularly directly under the slab when the mechanical system was shut off.

3.2 Tubes

Figures 27-29 show the chart recorder records for the week of June 22-29, 1987. Figure 27 shows the ambient air temperature on a 0 -100 F scale recorded just outside the 200-foot tube blower box. Figure 28 shows the air temperature on a 45 -90 F scale at the base of the exhaust stack in the 100-foot tube and Figure 29 shows the air temperature on a 45 -90 F scale at the base of the exhaust stack in the 200-foot tube. For both tubes the exhaust air temperature began to rise when the blowers were switched on at 9 a.m. The exhaust temperature continued to rise until 6 p.m. when the blowers were switched off and the temperatures dropped sharply. In the late afternoon with the ambient temperature about 100 F, the 100-foot tube cooled the air to about 80 and the 200-foot cooled the air to about 73 .

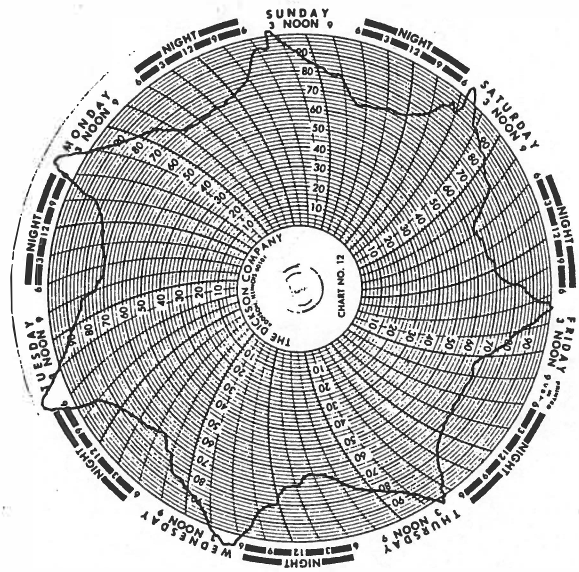

Fig. 27. Tubes, June 22-29, 1987; *ambient*

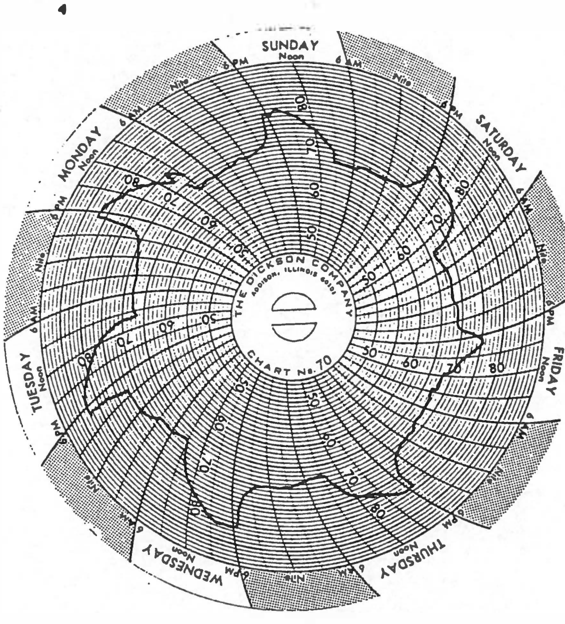

Fig. 28. Tubes, June 22-29, 1987; *100-foot long tube exhaust*

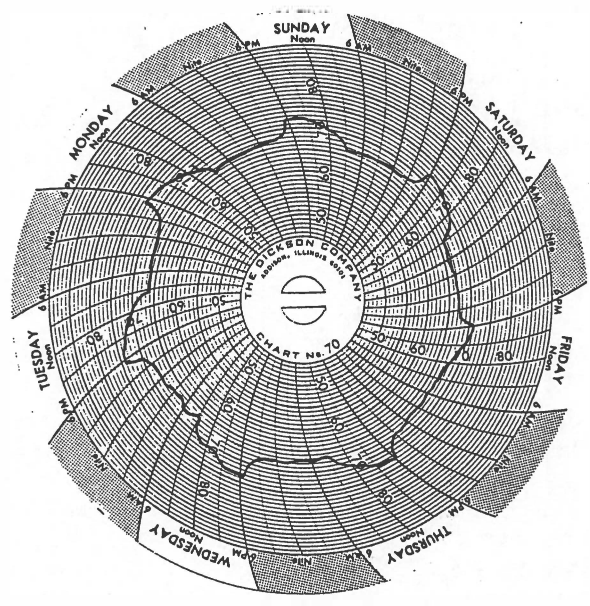

Fig. 29. Tubes, June 22-29, 1987; *200-foot long tube exhaust*

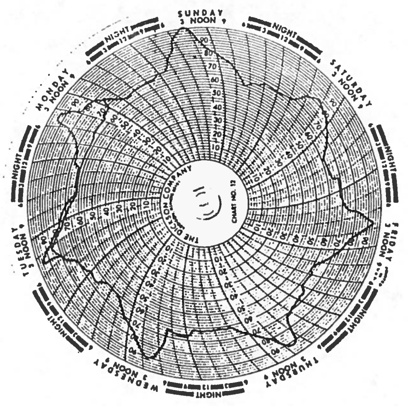

Fig. 30. **Tubes, September 7-15, 1987**; *ambient*

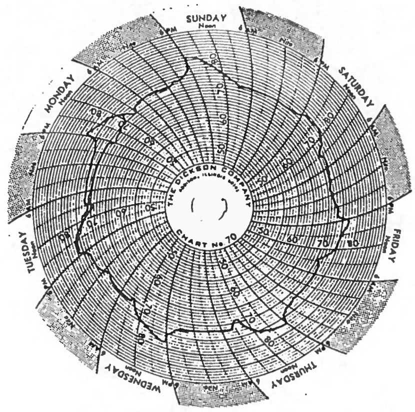

Fig. 31. **Tubes, September 7-15, 1987**; *100-foot long tube exhaust*

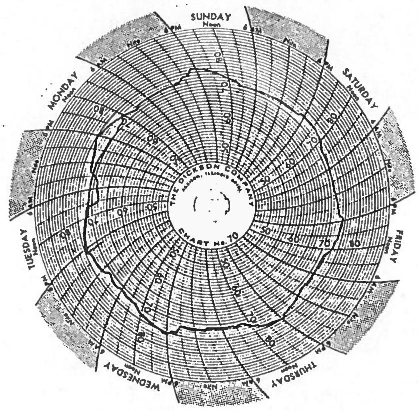

Fig. 32. **Tubes, September 7-15, 1987**; *200-foot long tube exhaust*

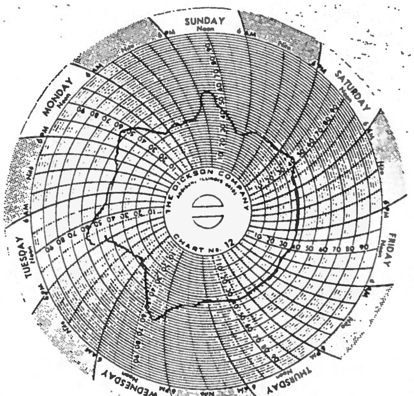

Fig. 33. **Tubes, February 17-24, 1987**; *ambient*

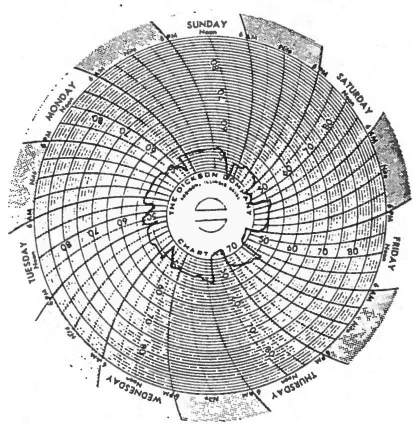

Fig. 34. **Tubes, February 17-24, 1987**; *100-foot long tube exhaust*

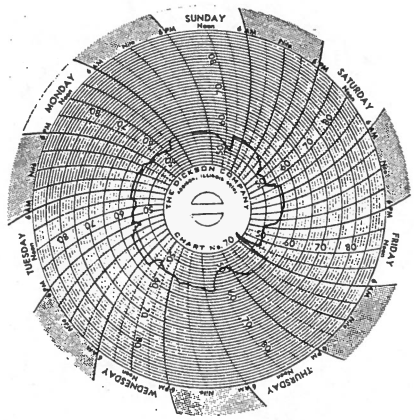

Fig. 35. **Tubes, February 17-24, 1987**; *200-foot long tube exhaust*

A late summer week, September 7-15, 1987 is shown in Figures 30-32. The double trace is from the charts being left on the recorders for eight days. February 17-24, 1987 is shown by Figures 33-35.

The soil temperature sites and tubes are continuing to be monitored. Additional annual weather conditions, additional data and particularly additional analysis, will improve the findings. Some questions have been answered by these studies but many others have been raised. What would be an optimum depth for tubes? What would be an optimum length? What control mechanism? Finally, are the tubes a cost-effective method of cooling and/or heating? The author believes buried earth/air heat exchange tubes can have a significant impact on building heating and cooling strategies but much additional research must be conducted in order to answer these questions.

4. ACKNOWLEDGMENTS

Thanks to Mel Johnson, my research partner, from the beginning of this project, Chip Higgins, graduate student, for preparing all the graphs, and many other students for taking temperatures especially on frosty mornings and blistering afternoons.

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