MICRO-GEOTHERMAL DEVICES FOR LOW-ENERGY AIR CONDITIONING IN DESERT CLIMATES

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INTRODUCTION

In the developing world, particularly in hot, desert climates, there is a great need to provide effective, low-cost cooling methods for residences and small commercial buildings. In many situations, the building heat load is very high, and conventional technologies are prohibitively expensive. Low-cost conditioning through evaporative cooling may reduce temperature levels, particularly in dry climates, but the corresponding increase in humidity creates an uncomfortable environment. On the other hand, less effective and less costly cooling means may be capable of reducing temperatures so that residences and buildings can be tolerably occupied during the hottest portions of the day. This article describes the application of an inexpensive micro-geothermal air-cooling device. The effect of this cooling method is assessed and the energy savings evaluated.

During March, 2005, a faculty-led student research team from the University of St. Thomas (St. Paul, MN) traveled to Mali, Africa to implement the cooling modality described in the foregoing. The research trip lasted ten days; five days involved on-sight testing and concept evaluation. Mali, located at the westernmost edge of the Sahara desert, is one of the poorest nations in the world. Its location and development status makes it a prime candidate for implementation of inexpensive cooling solution that, if successful, can be expanded to include other nations in the region and around the world.

The research project focused on cooling of Community Learning and Information Centers (CLICs) which are small, single-room buildings which house 5-10 personal computers. A photograph of a typical CLIC is presented in Figure 1. Computers outfitted with internet capability are used by local residents to access websites and CD-ROM information related to health, education, economics, growth, and democracy. Continuous operation of computers and other heat-generating devices and heat dissipated by inhabitants pose additional thermal problems. First, the energy dissipated by the equipment and people must be accommodated by the cooling solution. Second, the sensitivity of the electronics to dust requires that doors and windows to the structure remain closed, especially during the hottest and driest months of the year. This period usually lasts from six to seven months and coincided with the current research project.

Figure 1. A typical building used in geothermal cooling experiment

In the absence of natural ventilation through doors and windows, cooling means such as traditional compressor-based air conditioning or water evaporation may be considered. These alternatives, however, require continuous electrical power and/or water supply. This requirement, along with the associated electrical cost, poses a severe challenge for buildings on an unreliable power grid.

The chosen alternative to active, expensive cooling seeks to fulfill the cooling goals by using the thermal inertia of the ground to pre-cool air prior to its introduction into the building. The technique used here is to be contrasted with the standard geothermal heat pump, the prospects of which have been growing substantially in recent years (Lund and Freeston, 2001; Fridleifsson, 2000). Most installed heat pumps use liquid as the working fluid and extend to depths far greater than those proposed here (Hepbasli, et al., 2001). Even small-scale systems are far more extensive than that which could be utilized in the present study (DiPippo, 1999; Allen and Milenic, 2003). The corresponding energy recovery for liquid-based systems are expected to be greater than with an air-cooling system however the initial installation costs and the long-term operating costs are prohibitive for the present application. The device described in this article bears resemblance to other applications which rely on the thermal inertia concept to effect cooling. Some applications used above-ground inertia storage containers (Rainbow, 2004) which are manufactured from contained rock piles or water tanks. While effective in lowering the temperature of air, these external storage containers exceed the cost limitations for the present application.

GEOTHERMAL COOLING

As mentioned in the foregoing, typical geothermal heat pumps utilize boreholes that extend deeply into the ground (Lund and Freeston, 2001; Teklemariam et. al, 2000). These pipes are usually installed during the building construction and are designed to provide continual cooling/heating which is predicated by the local ground temperature. For deeply laid pipes, the ground temperature is remarkably constant in time, varying only slightly through daily and yearly cycles.

Deep installation of piping was not possible due to the hardness of the ground and the lack of digging machinery. Instead, a shallow, shortened underground pipe was designed.

This pipe, approximately 65 ft (20 m) long was installed horizontally, 20 inches (50 cm) beneath the earth's surface. The underground duct was constructed of 7.9 inch (20 cm) diameter round PVC pipe. The choice of diameter was motivated by the need to provide adequate flow with a minimal pressure drop. The air was drawn through the pipe by low-power axial fans that function effectively in low-pressure piping system. The desired volumetric flow rate of 200 cfm ($5.7 m^3$/min) was designed to provide between two and three air changes per hour for the structure.

A priori calculations to predict the required length of underground piping are difficult to make because the temperature of the underground pipe is generally not known with certainty. In fact, the presence of underground piping with associated air flow disturbs the ground temperatures in the near-pipe region. Of particular concern is the possibility of thermal exhaustion. Thermal exhaustion refers to a situation where hot air flowing through underground ducting heats the ground and limits future use of geothermal air cooling. Experiments investigating the ground temperature variations and the potential for thermal exhaustion were carried out during the experimental phase of this work.

GROUND TEMPERATURE MEASUREMENTS

The potential cooling effect of the underground ductwork was studied by ground temperature measurements that were made during the five-day testing period. Five thermocouples were installed at depths of 33, 27, 21, 16, and 10 inches (85, 70, 55, 40, and 25 cm).

Surprisingly, noticeable timewise and spatial temperature variations were observed. The temperature measurements for a complete daylight cycle are presented in Figure 2, with the legend indicating the depth at which corresponding temperatures were measured. The uncertainty in ground temperature measurements, based on calibration experiments involving the thermocouple wire and datalogger is +/- 0.5˚F (0.3˚C). Also shown in the figure are air temperature measurements which were recorded in the shade. As seen from the figure, the ground temperatures reach a minimum at approximately 2 pm while air temperatures peak at approximately 4 pm, indicating that the air and ground temperatures are almost completely out of phase.

The cyclical temperature variation, which was repeated for a three-day duration, is obvious from the figure. As expected, a phase shift exists between the air temperatures and the ground temperatures. In fact, the ground temperatures peak during the nighttime and decrease to a minimal value during the day. This behavior enables daytime cooling to occur when the ground temperatures are at a minimum.

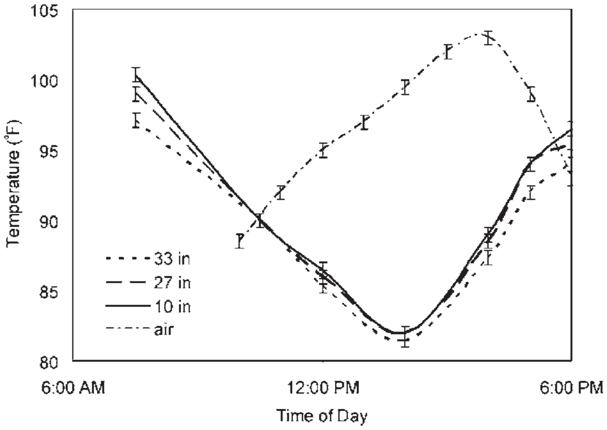

Figure 2. Timewise temperature variation of ground at depths of 10, 27, and 33 inches (25, 70 and 85 cm) and air temperatures during daylight hours

MEASUREMENTS OF THE DUCT AIR TEMPERATURES AND FLOW RATES

Upon completion of the duct construction and installation of ground thermocouples, the ductwork was connected to an axial fan which operated in the suction mode. Air temperature measurements were made at the inlet and exit of the air duct. The resulting data is presented in Figure 3. The temperature decrease of the air flowing through the underground duct is indicated in the figure. The temperature decrease is a direct measure of the cooling effect of the geothermal device. During the early afternoon, when cooling is most critical, the temperature decrease of the air is approximately 11˚F (6˚C). As the day progresses into evening, the cooling effect diminishes as evident by the convergence of the inlet and exit air temperatures. During the night time, the air flowing through the duct is actually warmed. This warming effect is visible by the morning data of Figure 4, where the air outlet temperature is higher than the air inlet temperature and, as a consequence, the ground is actually heating the air.

It may be noticed that the peak inlet air temperature of Figure 3 exceeds that of Figure 2. This is due to the fact that the inlet to the underground duct was unsheltered and exposed to direct sunlight, leading to slightly elevated inlet temperatures.

From the results presented in Figure 3, it is seen that during the majority of the day, the air exiting the duct is notably cooler than the entering air. On the other hand, during times when the ground is hot and the air is cool (the early morning), it is seen that the ground actually heats the air. This behavior makes possible the regeneration of the ground during the night time by a continual air flow, thereby reducing the possible thermal exhaustion of the ground.

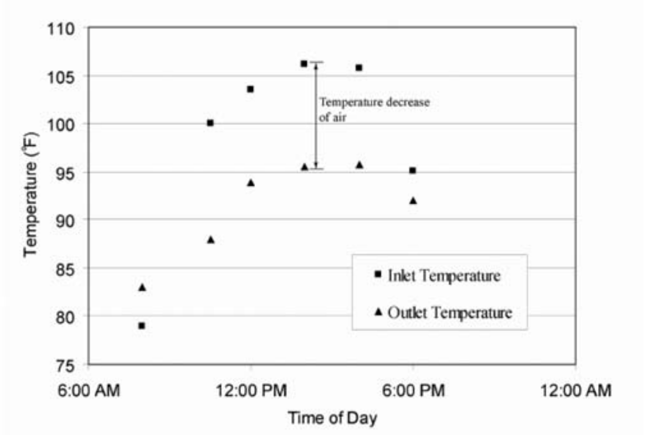

Figure 3. Inlet and outlet temperatures for air flowing through micro-geothermal air-cooling duct

During the present experiments, this approach was taken and airflow through the duct was provided 24 hours a day, for three days. Throughout this duration, no noticeable thermal exhaustion occurred, raising the possibility of long-time use of the micro-scale geothermal air-cooling system without deleterious exhaustion effects.

ENERGY SAVINGS FROM GEOTHERMAL COOLING

Air flow rate measurements in the duct were made frequently during the experimental investigation. The flowrate was generally steady in time and varied between 164 and 191 cfm (4.6 – 5.4m^3/min), slightly lower than the desired flowrate of 200 cfm (5.7 m^3/min).

The economic viability of the proposed cooling methodology was evaluated by determining the energy savings due to the conditioning effect compared to the expenditures of the flow-powering device. At any moment in time, the energy extracted from the air is calculated from the first law of thermodynamics for a flowing fluid. During the peak usage (between 10 am and 5 pm), the micro-geothermal duct extracts energy from the air at a rate.

$$\dot{W}_{cooling} = \dot{m}c_p\left(T_{inlet} - T_{exit}\right) = 14\frac{\text{lbm}}{\text{min}}\cdot 0.24\frac{\text{Btu}}{\text{lbm}-{}^o\text{F}}\cdot 11^o\,\text{F} = 37\frac{\text{Btu}}{\text{min}} = 650\text{watts}$$

where 11˚F (6˚C) is the average temperature decrease of the air flow through the duct during this eight-hour period. The energy extraction of 650 watts from the air had an appreciable effect on the comfort level in the building.

This result or Eq. (1) is to be compared to the energy investment of the required fan power of 114 watts. The total energy savings can be compared with published data on typical large-scale geothermal devices which typically range from a few kW to over a hundred kW (Lund and Freeston, 2001). The net energy savings represented by the geothermal cooling system is

$$\dot{W}_{net} = \dot{W}_{cooling} - \dot{W}_{required} = \dot{W}_{required}\left(COP_{geothermal} - 1\right) = 536\,\text{watts}$$

For the duration of the dry period, it is expected that approximately 680 – 790 kW-hours of power would by saved by the continuous operation of the geothermal air-cooling device.

CONCLUDING REMARKS

The development, implementation, and evaluation of a micro-geothermal air-cooling system for the conditioning of buildings in desert climates has been described. In contrast to typical geothermal cooling systems which extend far beneath the earth's surface, the present system was situated 20 inches (0.5 meters) deep. At this shallow location, the underground duct was subjected to timewise temperature variations throughout the day. An axial fan was used to provide a volumetric airflow that varied between 164 and 191 cfm (4.6 – 5.4m^3/min). During the hottest portion of the day (10am-6pm), the ducting system cooled the air approximately 11˚F (6˚C), resulting in a cooling effect equivalent to 650 watts and a net energy savings of 536 watts during its operation.

This project has demonstrated the capability providing low-cost cooling in hot climates through the use in small, shallow geothermal cooling systems. It is believed that the techniques described here can be applied worldwide in similar hot, dry climate for the conditioning comfort in residential and small commercial buildings.

REFERENCES

Allen, A. and D. Milenic. 2003. "Low-enthalpy geothermal energy resources from groundwater in fluvioglacial gravels of buried valleys." *Applied Energy, Vol. 71(1)*, pp. 9-19.

DiPippo, R. 1999. "Small geoethermal power plants: design, performance, and economics." *Geo-Heat Center Bulletin June*, pp. 1-9.

Fridleifsson, I.G. 2000. "Prospects for geothermal energy worldwide in the new century." *Proceedings World Geothermal Congress 2000 May 28-June 10*, Reykjavik, Iceland.

Hepbasli, A., M. Eltez, and H. Duran. 2001. "Current Status and future directions of geothermal heat pumps in Turkey." *Geo-Heat Center Bulletin March*, pp. 13-15.

Lund, J.W. and D. H. Freeston. 2001. "World-wide direct uses of geothermal energy 2000." *Geothermics Vol. 30*, pp. 29-68.

Rainbow, M. 2004. "School of hard rocks: lessons out of Africa." *SET2004 – 3rd International Conference on Sustainable Energy Technologies June 28-30*, Nottingham, UK.

Teklemariam, M., K. Beyene, Y. AmdeBaerhan, and Z. Gebregziabher. 2000. "Geothermal Development in Ethiopia." *Proceedings World Geothermal Congress, 2000, May 28 - June 10*, Kyushu, Japan.