UNIVERSITY OF FLORIDA

Florida Cooperative Extension Service

Fact Sheet EES 78
May 1993

Use of Underground Air Tunnels for Heating and Cooling Agricultural and Residential Buildings[1]

D.Y. Goswami and K.M. Biseli[2]

INTRODUCTION

Soil temperature, at a depth of about 10 feet or more, stays fairly constant throughout the year, and is approximately equal to the average annual ambient air temperature. The ground can, therefore, be used as a heat sink for cooling in the summer and as a heat source for heating in the winter.

A simple method of using this concept is to pass air through an underground air tunnel. The air thus cooled or heated can be used directly for the conditioned space or indirectly with air conditioners or heat pumps. The methods, their applicability, and the necessary information for the design of systems based on this concept are described in this document.

UNDERGROUND AIR TUNNEL SYSTEMS

An open loop, underground air tunnel system cools or heats the ambient air passing through it. This air is then introduced directly into the conditioned space of a building. In order to reduce the required tunnel length, a closed loop system may be used. In this system, the air from the conditioned space, with some ventilation air, is recirculated through the underground tunnel. Open and closed loop systems can be useful for air conditioning agricultural buildings. However, the threat of air contamination from any possible bacterial growth or radon in the tunnel casts doubts upon public acceptance of such systems for residential buildings.

A system that makes indirect use of an underground tunnel alleviates any concerns about air contamination. In this system, the tunnel is used to temper the ambient air, which is then used for heat exchange with a heat pump. This can improve the coefficient of performance of the heat pump and increase its capacity for heating and cooling.

The systems described above have the potential to give very high coefficients of performance (COP), and therefore high energy savings. COP is a term used in refrigeration and air conditioning to describe the performance of a system (Equation 1).

Normally, heating and air conditioning systems have average year-round COPs of about 2.0. However the COPs of the systems utilizing underground air tunnels are much higher. For open and closed loop systems, the COP can be as high as 10. By doubling the COP over a conventional system, the energy input (energy that one pays for) is reduced by 50 percent.

In addition to energy conservation, this technique also increases the capacity of a conventional system.

1. This document is Fact Sheet EES 78, a series of the Florida Energy Extension Service, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: May 1993.
2. D.Y. Goswami, Professor and K.M. Biseli, Graduate Student, Mechanical Engineering Department, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville FL 32611.

The Florida Energy Extension Service receives funding from the Energy Office, Department of Community Affairs, and is operated by the University of Florida's Institute of Food and Agricultural Sciences through the Cooperative Extension Service. The information contained herein is the product of the Florida Energy Extension Service and does not necessarily reflect the view of the Florida Energy office.

Eqn. 1
$$COP = \frac{EO}{EI}$$

where: EO = Energy Output of the System as Cooling or Heating Effect
EI = Energy Input (energy that you pay for, normally as electricity)

The capacity of a system is the maximum amount of heating or cooling that can be obtained from a system under specified ambient conditions.

SOIL TEMPERATURES

Knowledge of soil temperatures is important in the design of underground air tunnel systems, for example, the soil temperatures at depths of 6, 9, and 12 feet below the surface for Gainesville. These temperatures can be used for all locations in Florida without significant error.

DEMONSTRATION SYSTEM DESCRIPTION

A demonstration system was set up at the Energy Research and Education Park at the University of Florida. This demonstration system consisted of a 12-inch diameter, 100-foot-long corrugated plastic pipe buried 9 feet deep, a ¼-horsepower blower fan to move air through the pipe, a 2½-ton heat pump, and a sheet metal enclosure for connecting the pipe to the heat pump.

This system demonstrated the open loop, underground air tunnel system as well as an indirect air tunnel system to improve the COP of a heat pump or a refrigeration system. The demonstration system was fully instrumented to conduct test runs and verify the performance of the system. The system was tested in a number of configurations, and its performance was monitored. The following sections describe the installation procedure, the instrumentation, the test results, and the energy savings from the system.

CONSTRUCTION OF UNDERGROUND AIR TUNNEL

A backhoe can be used to dig the trench in air tunnel construction. Because of the high moisture content of the Florida soil, the walls of the trench must slope to prevent cave in. The bottom of the tunnel should be leveled by shovel or by filling with sand and should slope toward the air inlet end to allow water to be pumped out of the pipe.

The pipe assembly should be performed above ground as much as possible, before lowering it into the trench. Pipe connections can be sealed with roofing cement. To keep the pipe straight in the trench, 1-foot-long stakes (1" x 2" nominal size) can be used on both sides of the pipes every 3 feet. The space around the pipe must be backfilled by hand using sand or soil. This is needed to prevent the pipe from collapsing or shifting during the backfill. A backhoe can then be used to backfill the rest of the trench.

A number of studies (Goswami et al., 1981) have shown that the pipe material has very little effect on the overall heat transfer. Therefore, galvanized steel, clay, or plastic pipes can be used for the air tunnel. Corrugated plastic drain pipes have been used successfully at a number of sites.

Care must be taken to prevent collapse of the pipe during backfill. For soils that make it difficult to prevent collapse, more expensive galvanized steel pipe can be used. The complete construction of a 100-foot-long underground tunnel can take about 8 to 12 hours using a backhoe and two additional persons.

The underground air tunnel is fitted with a properly sized blower fan. Preferred location for the fan is at the exit end of the tunnel. However, other practical considerations may determine whether the fan is installed at the entry or the exit.

SYSTEM PERFORMANCE

Performance of Open Loop Tunnel

The demonstration tunnel system was operated to measure the exit air temperature when the ambient air temperature ranged from about 75°F to 91.5°F. The results from the computer program were fairly accurate and were, therefore, used to predict the performance of the system. Pipe length, pipe diameter, air flowrate, and initial soil temperature affect the exit air temperature and the fan power required.

Performance of Tunnel with Heat Pump

This system was operated in a number of configurations to find the optimum configuration for maximum performance. The system was operated with the

Table 1. Cost of construction of a 12-inch diameter, 100-foot tunnel system (retail costs).

Component	Quantity	Cost	
		Corrugated Plastic	Galvanized Steel
12" Corrugated Pipe	4 @ 20 ft. long 2 @ 10 ft. long	$380	$625
12" Tee	2	$48	$625
12" Caps	2	$14	$625
12" Connectors	3	$27	$27
90° Bend	2		$200
Backhoe Rental (including operator)	12hr @ $55/hr	$660	$660
Labor	12 hr @ $15/hr	$180	$180
Total		$1,309	$1,692

fan pushing the air and with the fan pulling the air through the tunnel. Of these configurations, the one with a trap door open and the fan pushing the air through the tunnel worked the best.

The performance of the system in this configuration, as compared to the heat pump COP without the air tunnel, can be shown at about 5.8 percent when the ambient temperature was 90°F. If the air from the tunnel is spread uniformly over the heat pump condenser, it is possible to improve the COP of the heat pump by about 8 percent and its capacity by about 4 percent.

ENERGY SAVINGS

Open Loop Tunnel System

Measurements showed that for 1000 cfm air flow through a 100-foot tunnel, the temperature of the ambient air was reduced from 90°F to 83°F. This translated to a cooling effect of 127 Btu/min. For this airflow through the pipe, a ¼-horsepower fan was needed, which is equivalent to a 186.5 W electrical power input. This power input was equivalent to 10.6 Btu/min.

Therefore, the system, operated as an open loop system, gave a COP of 127/10.61 or approximately 12. Compared with a COP of 3.0 for a typical air conditioning system, this system gave a 300 percent increase in the COP. For an average load of 2 tons or 24000 Btu/hr over a 24-hour cooling period, the open loop tunnel used 14 KWh of electricity, compared to 56 KWh using a conventional air conditioning system.

This represented a savings of 42 KWh over a 24-hour period in the summer. With an electricity cost of 8¢/KWh, the savings were approximately $3.36/day. For a period of 120 such days in the summer, the potential savings in energy costs could be $403. However, since the ambient temperature does not remain 90°F all the time during this period, the potential energy savings would be less. Assuming that the savings were only 60 percent of this amount, the system could save potentially $240 in a four-month, summer period. The system saves energy in the heating season also.

Assuming that it saves $100 during the winter, the system has the potential to save $340 per year. According to the above calculations, an open loop system using a corrugated plastic pipe can pay for itself in less than four years, and the same system using a steel pipe can pay for itself in less than five years (Table 1).

Tunnel with Heat Pump

For ambient temperature of 90°F, the COP of a 2½-ton heat pump can be improved by about 8 percent. Therefore, for an average cooling load of 2 ton or 24000 Btu/hr for a 24-hour period, this system consumed 52 KWh electricity, compared to 56 KWh using a conventional air conditioning system.

Analysis shows that this system would save $38 over a period of 120 days of summer. If similar savings were achieved in the heating season, it would take 17 years for the system to pay for itself if plastic pipe were used. By the same analysis, the payback period for the system using steel pipe comes out to over 22 years.

SYSTEM RECOMMENDATIONS AND DESIGN GUIDELINES

Open loop air tunnel systems or closed loop systems can operate with a coefficient of performance (COP) as high as 12. When compared to the COP of 1 to 4 for a conventional air conditioning system, these underground air tunnel systems can save enough energy to pay for themselves in a period of 4 years or even less.

These systems can reduce the ambient air temperature from 90°F to one in the range of 80°F to 83°F. Therefore, these systems are recommended for use in agricultural buildings where a drop in air temperatures of 7°F to 10°F is acceptable. The system could also benefit in the heating season.

An underground air tunnel connected to a heat pump improves the COP and the capacity of the heat pump; however, the payback period is approximately 20 years. Therefore, investment in such as system is not cost effective in Florida.

Design of an air tunnel requires knowledge of the soil temperature and the requirements of air flow rates and outlet temperatures. The required airflow rate and outlet temperatures depend on the application and the ventilation requirements. Once these parameters are established, the diameter and the length of the pipe can be determined.

These figures give very conservative values of the system performance. Although a smaller diameter gives higher temperature drop, it also increases the required fan power. In addition, one has to consider the cost of the pipe, which increases with diameter. If a single pipe is used, a 12-inch diameter pipe is recommended. If, however, multiple pipes are used in parallel, 8- to 10-inch diameter pipes can be used.

If plastic pipes are used, extreme care is needed to prevent collapse of the pipes during the backfill. Galvanized steel pipes overcome this problem, but add about 25 to 30 percent to the cost of the system.

REFERENCES

1. Goetsch, W., and Muehling, A.J., "Earth-Tube Heat Exchangers for Swine Buildings," Energy Tips No. 2, Dept. of Agricultural Engineering, University of Illinois at Urbana-Champaign, September 1981.

2. Goswami, D.Y., and Ileslamlou, S., "Performance Analysis of a Closed Loop Climate Control System Using Underground Air Tunnel," Journal of Solar Energy Engineering, Vol. 112, May 1990, p. 76-81.

3. Labs, K., "Underground Building Climate," Solar Age, Vol. 4, No. 10, p. 44-50, 1979.

4. Biseli, K., "Performance Analysis of a Heat Pump in Conjunction with an Underground Air Tunnel," M.S. Thesis, University of Florida, 1991.

5. Goetsch, W.D., and Muehling, A.J., "Evaluation of Earth-Tube Heat Exchangers as Air Tampering Systems for Swine Farrow-Nursery Housing," ASAE Paper No. 83-4073, Proceedings of the ASAE Meeting, Bozeman, MT, June 1983.

6. Goswami, D.Y., and Dhaliwal, A.S., "Heat Transfer Analysis in Environmental Control Using and Underground Air Tunnel," Journal of Solar Energy Engineering, Vol. 107, May, 1985, p. 141-145.

7. Goswami, D.Y., Sinha, R., and Klett, D.E., "Theoretical and Experimental Analysis of Passive Cooling Using Underground Air Pipe," Proceedings of ISES Meeting, Brighton, England, Aug. 1981.