Published as: C.D. Elifrits and A.D.S. Gillies, Design of air-tempering facilities, *Earth Sheltered Living*, St. Paul Minnesota, November/December 1983, pp.26-27.

Design of Air Tempering Facilities

Conclusion of two-part series on the use of earth pipes

by C. Dale Elifrits and A.D.S. Gillies

To harness the advantages of preconditioned air systems for ventilating either above grade or subsurface building space, two approaches are proposed.

a) Air is passed from the outside along a buried pipe or rock-lined tunnel and blown directly into the building ducting system; or, alternatively, is passed through a heat pump unit which allows energy transfer to the building's ventilation system. This approach is illustrated in Figure 3.
b) A closed-circuit buried pipe or tunnel system is developed for continuous air passage. A heat pump placed in the passageway extracts or dissipates heat from the air and transfers energy to the building. Air in the continuous passageway will never reach the extremes of temperature induced by surface conditions but rather reacts to the load placed on it by the heat pump unit and transfers energy to or from the adjacent ground mass. A schematic for the system is shown in Figure 4.

The system using outside air blown directly into the building has advantages of simplicity and low operating cost. Power costs to run a fan are not high. However, a number of disadvantages are presented.

a) Pipe or tunnel length will be considerable if air is to be suitably conditioned in periods of extreme temperature variations.
b) In most climatic locations, a large airflow along the pipe will be needed if sufficient energy is to be available for heating or cooling the house. This will have to be exhausted from the house creating problems of drafts.
c) With a suitable system, air can be tempered to a temperature approaching average subsurface soil/rock temperature. Further heating or cooling using mechanical plant will then be necessary to bring conditions to suitable interior comfort levels.
d) Odors, muskiness and dampness from the tunnel will be brought into the building.

A heat pump system overcomes many of these problems as it separates the building air system from that in the buried pipe or tunnel. Pipe lengths in closed-circuit systems will be much shorter and pipe diameters smaller. Power to operate a fan might be needed in addition to the cost of running the heat pump. Heat pumps operate extremely inefficiently in extreme winter or summer weather and need auxiliary boosters, but are ideal for tempered air conditions where the ambiant (feed) air temperature has little variation.

The principal disadvantages of using a heat pump in either an open or closed circuit system are:

a) the capital cost, power costs and maintenance costs of operating the mechanical unit, and
b) the lack of fresh air brought into the building.

The costs of using a heat pump can be more than outweighed by designing a closed circuit system in which construction, excavation, and liner placement costs of the conduit are markedly reduced. Fresh air intake into a dwelling will generally not be a problem, although a special intake for underground space will need to be considered.

Empirical results have been interpreted in an endeavor to develop design criteria for preconditioning pipe or tunnel systems attached to domestic dwellings. Results so far have only been developed for heating load conditions and are based on the following assumptions.

a) The building being heated is a domestic dwelling of 140m^2 (1,500 sq. ft.) enclosed floor space.
b) House construction incorporates modern insulation and heat loss is 3.25 kW/°C (6200 BTU/°F).
c) Air velocity along the pipe is 1.0 m/s (3 ft/s).
d) The heat pump operates at a maximum efficiency.

Results

Results have been calculated using a formula developed from empirical results and for accuracy checked against those obtained using a formula developed by Goch and Patterson (1940) from mining ventilation experience. Values for both pipe diameter and length are given:

a) for 3 U.S. climatic locations, i.e. Rolla, MO: Birmingham, AL; and Freeport, IL,
b) for three subsurface rock types and three different soils (average values for material properties for each material have been used for density, and thermal conductivity and specific heat constants),
c) for a closed circuit system incorporating a heat pump unit and for an open circuit system making use of heat pump, and
d) for air saturation level in flow entering the heat pump "evaporator" of 100 per cent. Results are given in Tables 1 and 2.

These results emphasize the size difference in pipe diameter and length between the closed circuit and open circuit system design. The open system designs demand dimensions capable of handling extremes in climatic condition. The air energy changes needed are accommodated by increased volumetric air flow through tube lengths. Pipe lengths needed in the coldest climate of Freeport, Il, which exceed 400m (1,320 ft) for the various soil types are somewhat impractical for normal residential situations. However, those calulated for the closed circuit systems demand lower volumetric air flow and most designs are of dimensions which are compatible with the size of a normal building lot. Some lend themselves to being buried beneath

Figure 3: Schematic of open-circuit air-flow tube or tunnel.

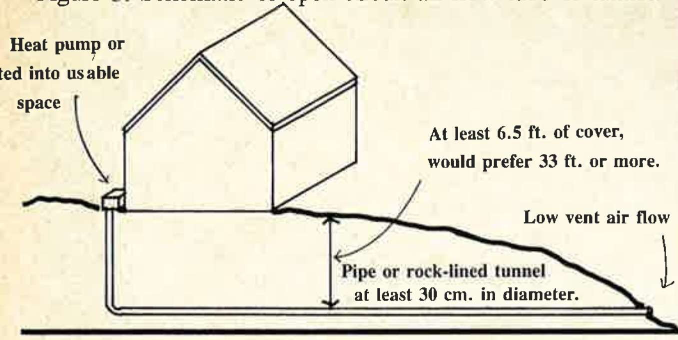

Figure 4: Schematic of closed-circuit air-flow tube or tunnel.

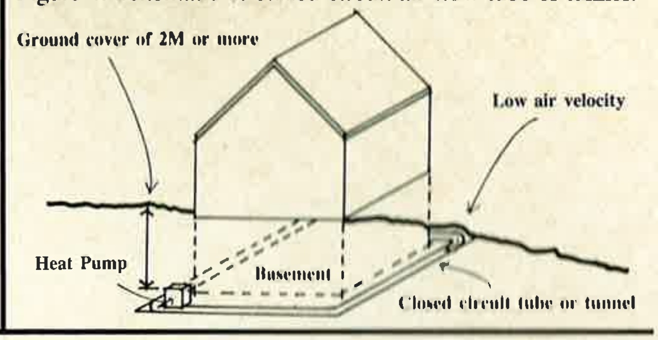

Table 1. Design criteria for closed circuit earth pipe or tunnel system utilizing heat pump unit for three U.S. locations and varying ground material types.

LOCATION	ROLLA, MO.		BIRMINGHAM, AL.		FREEPORT, IL.	
Average Ground Temp.	13° C (55°F)		17° (62°F)		10° (50°F)	
Winter Average Minimum Design Temperature	-18°C (0°F)		-7° (16°F)		-28°(-20°F)	
Design Domestic Heating Power	10kW		7kW		12kW	
Ground Material	**Diameter** (m)**	**Length** (m)**	**Diameter** (m)*	**Length** (m)*	**Diameter** (m)*	**Length** (m)*
Dolomite	0.66	68	0.56	33	0.73	185
Granite	0.66	48	0.56	23	0.73	133
Sandstone	0.66	64	0.56	31	0.73	175
Sandy Soil	0.66	78	0.56	39	0.73	220
Clay	0.66	78	0.56	38	0.73	215
Loam	0.66	74	0.56	36	0.73	202

*Conditions for air entering heat pump evaporator at 10° and exhausting at 2°.
**Multiply by 3.28 to convert to feet.

Table 2. Design criteria for open circuit earth pipe or tunnel system utilizing heat pump unit for three U.S. locations and varying ground material types.

LOCATION	ROLLA, MO.		BIRMINGHAM, AL.		FREEPORT, IL.	
Average Ground Temp.	13° C (55°F)		17° (62°F)		10° (50°F)	
Winter Average Minimum Design Temperature	-18°C (0°F)		-7° (16°F)		-28°(-20°F)	
Design Domestic Heating Power	10kW		7kW		12kW	
Ground Material	**Diameter** (m)**	**Length** (m)**	**Diameter** (m)**	**Length** (m)**	**Diameter** (m)**	**Length** (m)**
Dolomite	1.33	309	1.33	247	1.38	380
Granite	1.33	225	1.33	172	1.38	283
Sandstone	1.33	292	1.33	232	1.38	361
Sandy Soil	1.33	363	1.33	300	1.38	439
Clay	1.33	354	1.33	292	1.38	430
Loam	1.33	335	1.33	273	1.38	409

*Conditions for air entering heat pump evaporator at 10°.
**Multiply by 3.28 to convert to feet.

or at a distance of no influence of 2-3m (6-9 ft) outside the outer walls of excavated basements.

The approach adopted for calculation of the above results in adaptable for use in the design of cooling systems in hot climates. Under these situations airflow along the later sections of a pipe system will be saturated. Heat pumps operating at higher temperatures will have slightly different characteristics and exhibit different coefficients of performance.

Results from this empirically based study demonstrate that design calculations for a pipe system are complex and the cost of investment in a suitable subsurface system will not be cheap. However, the potential for obtaining long term savings from installation of a carefully thought out and carefully designed and constructed system are apparent.

Dr. Dale Elifrits is an assistant professor of geological engineering at the University of Missouri-Rolla. He can be reached at the School of Mines and Metallurgy, Department of Geological Engineering, 125 Mining Bldg., Rolla, Mo., 65401. Dr. Stewart Gillies is a lecturer in mining engineering at the University of Queensland, St. Lucia, Queensland, 4067, Australia.

REFERENCES

Boileau, G. G. and Latta, J. K. (1978). *Calculation of Basement Heat Losses*. Underground Utilization University of Missouri-Kansas City.

Gillies, A.D.S., Elifrits, C. Dale, Erten, Y. M., and Aughenbaugh, N. B., "An Analysis of Air Heating During Flow Through Ground Passages" in: Proc. Intl. Earth Shelter Conf. Australia, August 1983, Boyer, L. L., ed. Oklahoma State University, Stillwater.

Goch, D. C. and Patterson, H. S. (1940). "The Heat Flow in Tunnels", *Journal of the Chemical, Metallurgical and Mining Society of South Africa*, September.

Lorentzen, G. (1978). *The Design and Performance of an Uninsulated Freezer Room in the Rock*. Underground Utilization, University of Missouri-Kansas City.

Stauffer, T. (1978). *Efficiency in the Use of Energy has been Effected Through Industrial Use of Subsurface Space*. Underground Utilization, University of Missouri-Kansas City.

Wells, M. (1977). Underground Designs, Box 183, Cherry Hill, N.J.