Heating Homes and Small Buildings

Homeowners and home builders can realize large greenhouse gas reductions if they stop using natural gas and furnace oil. A new alternative enables them to save money as well. The alternative extracts heat from the warm summer air and stores that heat in the ground for use in the winter. It can be used for either new homes or retrofits to existing homes, or blocks of houses, or small buildings like schools, churches and commercial buildings. On an annual basis the system doesn't alter the heat content of the surrounding ground and this makes it possible to use such systems in congested urban environments. (Previous articles in this series have described larger systems that are suitable for whole communities and large buildings, but those designs can not simply be scaled down for use for single homes).

Heat is extracted from the air and transferred into a heat exchange fluid for injection into the ground using borehole heat exchangers that are similar to those commonly used for ground source heat pumps (GSHP's), but the borehole length is 2 to 5 times shorter and there will be a commensurate reduction in the cost of boring the holes. The heat is injected over a long period, minimizing the size of the air heat exchangers.

The amount of electrical energy needed to operate the air-source system is 20-40% less that that needed for a GSHP because the system can operate 100% of the time (GSHP's typically revert to conventional heat sources during very cold periods). Because the heat delivered to the heat pump is always at a higher temperature the heat pump will operate at a higher efficiency.

Design The air-source system uses three boreholes arranged in a triangle plus a fourth borehole located near (but not at) the center of the triangle. A small air heat exchanger similar to that used for home air conditioners heats the exchange fluid in the warm seasons and injects that heat into the three outer boreholes in the spring, then into the central borehole in the summer and then in September the heat is again directed to the outer boreholes. The timing is important to minimize the loss of stored heat.

None of the heat injected during the spring is lost because the temperature of the outer borehole ground is just brought up to the ambient ground temperature (about 9 degrees in Ottawa) so there is no subsequent heat flow. Extra heat is injected into those holes in September but that heat isn't lost either because the temperature swing is not symmetrical. The injected extra heat initially moves slowly away from the boreholes but the direction of heat flow reverses shortly afterwards and the heat flows more rapidly back to the borehole because the heat extraction soon drops the temperature well below the ambient temperature. Heat flowing from the central borehole does not interfere with that part of the cycle because it takes months for the heat to flow from the center to the periphery.

During hot summer days the heat is injected into the central borehole, raising the surrounding ground to well above the normal ambient temperature. Initially that heat will rapidly spread out, but by mid winter the thermal profile will slump. By that time the three outer boreholes will have created “thermal wells” into which most of the heat from the center will flow. If the center is hot enough then some heat will escape at the mid points between the outer holes but those outer holes are absorbing heat from the surrounding ground (just as in GSHP's) so these opposing effects can be balanced out by adjusting the injection cutoff temperature.

Variations The heating requirement will vary from one year to the next. This variance is handled by designing the system so that at the end of the winter the temperature of the core is just below the ambient ground temperature. That leaves a substantial surplus of heat that is available for exceptionally long or cold winters by extracting more heat from the core. In that case there will be a drop in the heat pump efficiency.

The outer holes can deliver about twice as much heat as those of a GSHP because of the extra heat that has been injected via those holes in September and because of the heat pouring into their “thermal wells” from the core area throughout the winter.

The efficiency of the borehole heat exchangers is enhanced by using four pipes instead of the two commonly used in U-tube GSHP exchangers. The four tubes also reduce the thermal short circuit caused by running the hot and cold lines next to each other. The design creates a thermal gradient during the injection stage that makes the heat recovery more efficient.

In a GSHP the borehole heat exchangers must be long enough to extract sufficient energy on the coldest nights, particularly late in the winter when the ground's heat has been depleted. In this alternative system the heat is normally extracted from the three outer holes, leaving the core heat in reserve. On cold nights when the demand is high the central hole is brought into play, increasing the heat exchange capacity and utilizing heat that has been held at a much higher temperature. This ability to “switch gears” results in a substantial reduction in the required heat exchanger length. It also achieves higher heat pump efficiency and eliminates the need to fall back on a backup heat source (natural gas or electricity) during those cold periods.

In places like the southern US States air-source heat pumps are commonly used for home heating. That is possible because they rarely need to deal with sub zero temperatures. Because the alternative described here includes an air heat exchanger that exchanger should be used whenever the air temperature exceeds that of the ground feed to the heat pump. The efficiency of the heat pump will thus be higher, the annual load requirement for the ground storage system will be reduced, and the boreholes will operate more efficiently because heat can flow back into the ground around the borehole while the air-source heat input is in use. This mode can be used for about half of the heating season in Ottawa, and it requires only a switching valve for its implementation.

Noise Heat pumps operate quietly, especially if they are high efficiency units, and the air to ground heat exchangers are also very quiet because the fans operate at a low speed. Ideally the heat distribution within the homes should be via underfloor heating, which is common in Europe but less so in Canada. Besides eliminating drafts and noise underfloor heating operates at a low temperature, thus enhancing the heat pump efficiency.

Calculations In this type of system the amount of heat injected into the ground can be accurately measured and since 100% of it is returned it is not necessary to do complex calculations like those for GSHP's, which depend on nature to restore the heat that has been extracted. It is like putting gas in a tank, with the proviso that the tank must have enough capacity to hold the required amount of heat. That capacity can be estimated with adequate accuracy if the specific heat and density of the ground materials are known because the active volume in this type of system is well defined.

Air Conditioning Both GSHP's and air-source systems that incorporate ground storage can use the ground as the heat sink, resulting in improved AC efficiency. Both can also inject the AC waste heat into the ground. However, in the case of the GSHP's that heat is not very useful because it simply displaces heat that would otherwise have come from lateral heat flow in the ground. It is much more productive in the alternative system because the hot AC rejection heat can raise the temperature of the core to a higher value than might otherwise be achieved.

Multi-home installations This system reduces the cost of the ground storage but not the cost of the heat pump, which therefore becomes an even more prominent cost element. However, the cost of a 5 ton heat pump is not much greater than the cost of a 1.5 ton unit, which means that multi-home installations are particularly attractive. High efficiency heat pumps are much more expensive than those with lower efficiency, suggesting that high system efficiency might be traded off against a lower initial cost in some cases. The fundamental need in Canada is to find clean, reliable, and safe solutions that are less expensive (over a reasonable amortization period) than heating systems that use fossil fuels. This alternative system achieves that and it can optionally provide hot water as well as the heating and air conditioning.

Choices If we are to meet the commitments that most Canadian political parties have made, or our international commitments, or the IPCC objectives, then we must find a way to stop using fossil fuels for heating.

There are very few options:
(a) *Insulation* Adding insulation has been the standard policy response for the past several decades but it has not even kept pace with the demand increases caused by population growth. It is not likely that this “solution” would work even if we tore down every home in Canada and replaced them with super-insulated houses.
(b) *Electric heating* There is no provision in our government long term planning for generating the huge amount of electricity that would be needed for home heating. It is not feasible to build nuclear power stations that would be used just in the winter, or that could cope with the daily variations in power demand during the course of the winter.
(c) *Renewable energy* Without storage none of the sources of renewable energy – wind, solar, hydro, air, etc. could meet this demand.
(d) *Stored heat* This appears to be the only option that is feasible. There are several potential choices for the source of heat – solar collectors, natural heat storage in the ground, storage of heat from power generators, and storage of heat extracted from the air. This note makes the case for the last of those choices for the target market. Together with the large scale variants previously described it offers an approach that is both physically and economically feasible. It has the capacity to provide the heat needed in congested cities for both new homes and retrofits, it is immediately cost competitive with the fossil fuels presently used for heating, and it would reduce the power demand for the large number of Canadian homes that presently employ electric heating.

Previous notes are available in the electronic journal: http://sustainability-journal.ca

Ron Tolmie (tolmie129@rogers.com) Jan/08