Adding solar thermal power to residential AE systems

This note considers the potential for adding solar thermal collectors to AE systems.

NRCan have an Internet site that provides data on solar insolation for all parts of Canada, including monthly insolation values. It covers various collector orientations and can be found at:

http://pv.nrcan.gc.ca/

History The AE testbed facility in the home of Volker Thomsen in Kingston, ON incorporates a conventional hot water solar panel that is not connected to the AE system itself. No data for the solar panel's operation has been collected as part of the AE data logging operation so all of the values in the following comments are based on generic results and not on the performance of that particular system.

The Thomsen home also incorporates a Solar PV array that is likewise not connected to the AE system or AE data collection facility. The house also has a standby power generator. Potentially all of these components could be linked together to make the home largely self-sufficient for its energy requirements. Moreover the house has a large "wintergarden" that is used for growing plants in the winter, including vegetables that are transplanted to outdoor plots in the spring. These facilities are described in:

http://volkerthomsen.com/ae-atmospheric-energy-storage-system/

The reference provides links to the various components of this system.

Potential The heat injection rate of the AE systems falls off late in the summer because the ground temperature rises to a value that is close to that of the air. The solar collector operates at a much higher temperature so it is capable of delivering heat for an extended period, including the winter.

Conventional solar hot water systems derive about half of their energy requirements from the solar panels with the balance coming from electricity. The problem is that there are extended periods of low insolation. The storage capability of AE systems opens up the potential for using renewable energy for nearly all hot water needs.

Solar PV systems produce about 8000 kWh per year from a standard 10 kW (microFIT) system. If they operated at a steady 10 kW throughout the year they would generate 87,600 kWh so their output is about 9% of the "full time" potential. If there is a large number of Solar PV systems in use then they will need a backup capacity approaching 10 kW per unit and if the power load is steady the backup would be providing 91% of the energy. In practice the power load drops at night when the solar output is zero so the backup requirement is substantially lower but it is still much larger than the energy output of the solar cells. In most countries that doesn't matter because most of their power production comes from coal-fired generators so there is always a reduction in GHG emissions when solar power is added. However in Canada most of our power comes from hydro and nuclear sources that have only a small capacity to serve as the backup for solar power so the backup needs to be provided by fossil fuelled stations. Ontario is presently building natural gas powered generators to fill this need. Those generators would not be needed if enough homes were self-sufficient for their energy needs (large buildings offer an even larger potential for GHG reductions if they switch to AE).

All three of the energy sources in a combined AE/solar thermal/solar PV system thus have the potential to be mutually supportive.

Solar thermal efficiency The solar thermal panel in a combined system would deliver heat to a hot water tank in a conventional fashion but the output line would be thermally linked to the ground heat injection line in the summer and the heat pump's input line in the winter. Since both of the latter operate at much lower temperatures than the panel the efficiency of the heat transfer would be very high at all times of the year. A small thermal panel can therefore deliver 5 to 6 times as much energy as a Solar PV panel of the same size.

Air-source vs. solar thermal One available option is to provide 100% of the stored energy from the solar panel instead of extracting the heat from the air. The solar panel is capable of delivering a substantial amount of heat in the winter so the size of the ground store cold be reduced. Since the ground store is the most expensive component of AE systems that is a major consideration. The system design is otherwise not much affected by which source is used so for this review it will be assumed that both sources are used.

Okotoks AE systems are sometimes confused with the Drake Landing system in Okotoks, Alberta. That system collects solar heat, stores it in the ground and then delivers it to a group of 52 homes in the winter. The homes do not use heat pumps in the winter because the storage temperature is high enough to permit direct heat transfer. However, in the summer the homes need heat pumps if they want air conditioning. High temperature storage results in heat losses (and expensive lines) for the heat collection, heat distribution and especially for the heat storage components. Such systems must be large to keep these losses at acceptable levels whereas the AE concept can be applied to single homes or to combinations of building of any size. AE systems are more flexible (they can provide cooling and DHW as well as heating) and they are much less expensive.

http://www.dlsc.ca/

Heat exchangers The heat exchangers in this system would be parallel plate or tube-to-tube heat exchangers that enable the source and acceptor lines to be thermally connected but otherwise independent. Amongst other advantages that enables the two lines to operate at different temperature ranges; for example, the solar collector loop might operate at 30 to 70 degrees while the lines it thermally feeds are operating at 0 to 20 degrees.

Hot water loop The solar thermal collector loop could have a variable flow rate pump that would adjust the flow rate to maintain the output temperature at a value that is suitable for the DHW supply. The temperature of the hot water tank would determine when the loop should feed more heat to the tank. The output from the tank's input heat exchanger (or the output from the collector) would feed the remaining heat to the ground heat injection loop (in the summer) or to the heat pump's input (in the winter). There would at all times be a substantial temperature difference across the solar panel, ensuring that it will always collect heat efficiently, and between the supply line and the ground loop or heat pump line, ensuring that they would always accept the heat.

DHW energy supply There are times when the solar input will be low or zero so it is still necessary to provide a source of energy for those periods. One way of doing that would be to collect some heat from the home's air, augment that heat by extracting some of the heat from the greywater output, and add the electrical heat from a small heat pump that is dedicated to DHW. If the DHW load is H kWh and half of it is met directly by the solar heating and two thirds of the greywater heat is recovered then the electrical contribution will be H/(2*4), where 4 is the heat pump's COP and the greywater contribution is H*2/3 leaving a residual of H/5 to be extracted from the home's air. That typically amounts to about 0.2 kW of extra cooling in the summer and an extra heat load of 0.2 kW in the winter that is ultimately provided from the stored heat. Such a system could supply hot water for very long periods in the event of a long sunless period.

Home totals In Ontario the residential consumption of energy is (Stats Canada data for 2009):

Space heating	63.0%
DHW	18.5%
Cooling	2.1%
Other	16.4%

If we take as an example a home that has an annual energy consumption of 30,000 kWh then the consumption distribution would be:

Space heating	18,900 kWh
DHW	5,550 kWh
Cooling	630 kWh
Other	4,920 kWh
TOTAL	30,000 kWh

Let us choose a solar thermal panel that delivers the same amount of power (10 kW) as a standard microFIT Solar PV panel and the same amount of energy (8,000 kWh) and design the heat store so that 20% of the space heat comes from natural ground heat (i.e. 3,780 kWh) bearing in mind that the ability to trap the heat is dependent on ensuring that the direction of heat flow is always towards the collectors. The air-source provides the heat for space heating less the ground heat contribution, the heat pump power and the solar heat that is not used for DHW. That results in a total annual energy collection of:

Ground heat	3,780 kWh
Solar heat	8,000 kWh
Air-source heat	5,560 kWh
Solar PV energy	8,000 kWh
TOTAL	25,340 kWh

Overall such a home would thus meet most of its annual energy requirements. That does not mean, however, that it is almost completely self sufficient. There are times when it will depend on the grid for power and other times when some of the solar power can be exported.

There are 4.6 million private households in Ontario. If they all used such systems the total energy production would be 117 billion kWh. Moreover such systems deliver the energy exactly when it is needed, not just when the resource happens to be available, and none of the four sources produce any GHG.

The solar panels would be particularly attractive for high density housing. In that case the size of the solar thermal collectors would be roughly doubled and the air-source collectors would be eliminated. The larger solar thermal panels would provide most of the annual heat, including heat collected in the winter, and they would enable the systems to operate at a higher temperature, reducing the borehole depth (and the capital cost) and improving the COP of the heat pumps.