# Storing exergy

Storing thermal energy in the ground can be accomplished by designing a ground store in which there is no net heat flow out of the storage volume into the surrounding ground. That could be accomplished by simply insulating the storage volume, or it can be done by devising a strategy for trapping the heat as is done in AE systems. Storing exergy imposes two additional requirements: there must be two or more storage zones and the temperature difference between the zones must be largely retained over the storage time.

For short term storage all three conditions can be met by placing two rings of ground heat exchangers in a concentric pattern and using a heat pump to extract heat from the outer ring and moving it to the inner ring. That could be done at night and as the heat is extracted from the outer zone it could be replaced by heat extracted from the air during the day. During the summer such a system could build up a substantial storage capacity, with the outer zone remaining at the normal ground temperature so that there is neither a loss nor a gain of heat from the surrounding ground. The inner zone could simply be insulated, with the option of changing the inner zone storage medium to water (which would facilitate rapid extraction of the heat). Such a configuration is viable, and is in practice a good way to achieve dirunal storage of exergy. The heat pump would be operated at night or whenever it is desirable to store excess electricity and the heat could be extracted during the day to replace heat that would otherwise require the consumption of electricity. The amount of heat recovered would be the heat of the drive motor plus the heat moved by the heat pump. If the heat pump has a COP of 3 then the system has not only stored the exergy from an electricity-surplus period for use during a deficit period it will also deliver 3 times as much energy as was used to drive the heat pump, with the difference being the energy extracted from the air.

**Adding insulation**

The use of an insulated container is less attractive for seasonal storage, partly because of the heat loss through the insulation and partly because seasonal storage normally needs a high storage capacity that would call for an impossibly large container. However, it is possible to employ trapping procedures that are similar to those used for AE systems.

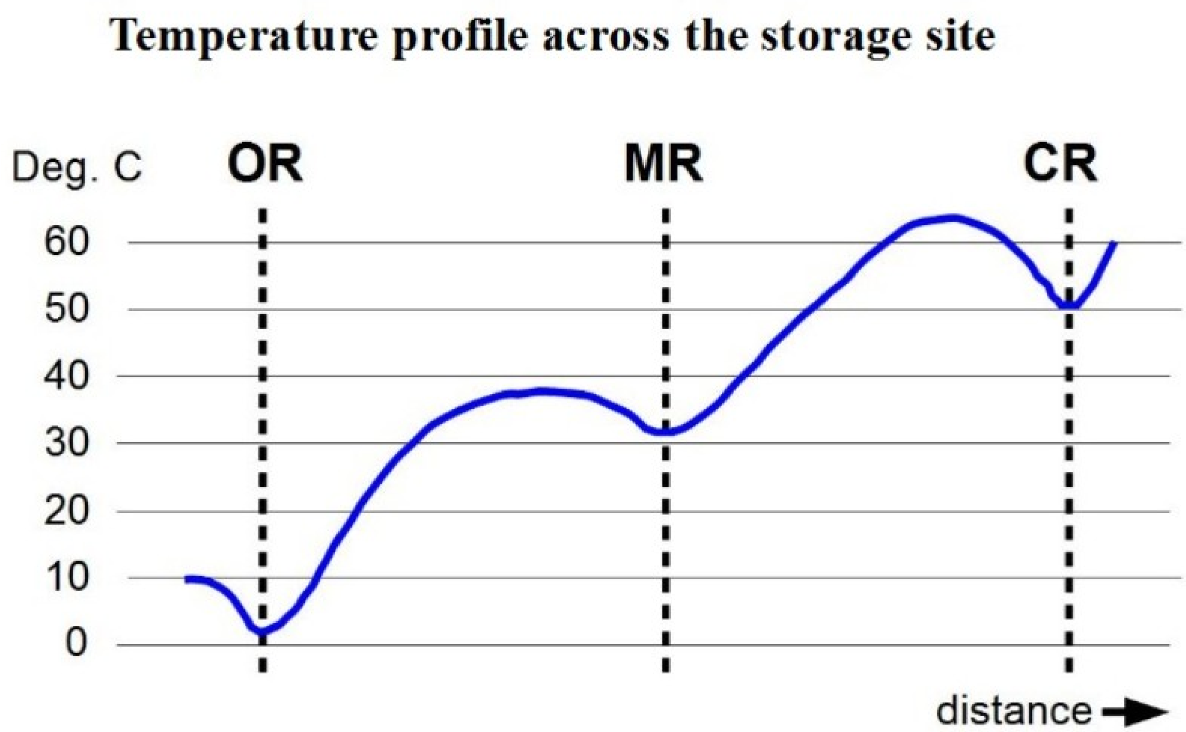
**An alternative to insulation**

If there is no insulation to contain the central heat then over time the heat will flow out from the center and its temperature will drop. There is no loss of energy because none of the heat actually escapes from the facility (ignoring small effects at the ends of the cylindrical store) but there is a loss of exergy because the temperature difference between the two zones is reduced. The loss of exergy is equivalent to the loss of 'stored' electricity. Thanks to the air-source input and the heat pump the amount of stored exergy is initially about 3 times greater than the electricity input so even with a substantial loss of the stored exergy it is theoretically possible to achieve the goal of recovering as much electricity (in the form of demand reduction) as was expended in the first place but there is another problem: the central ground temperature will have dropped to a value that would require the use of a second heat pump to raise the temperature to the value needed by the building's HVAC system.

This second heat pump is shown in the system diagrams previously shown in the Sustainabilty-Journal.ca articles but it is not needed if there is a relatively small amount of heat available at a higher temperature. Solar heat is an attractive candidate because it helps the operation of the space heating system and at the same time the storage system can nearly double the efficiency of a solar hot water system so they work very well together.

**Trapping heat and exergy**

The following is an illustration from the Hydro Ottawa presentation. It introduces a third ring of heat exchangers in the center of the storage facility (in practice this may be just a single central borehole). The new ring is designated CR, with the outer ring being designated OR and the other ring MR (for Middle Ring). The graph show the temperature profile across the storage facility.




**During the heating season heat is being withdrawn from OR, MR and CR, depressing their temperatures. Since heat cannot flow from cold to hot the high-temperature heat is trapped in the central zone and the balance is trapped in the outer zone. The heat that is injected into MR by the upgrade pump is trapped at MR and its temperature cannot fall. Solar heat collected during this period is likewise trapped at CR. At times of high demand the temperature of OR can be raised by drawing some heat from MR and the temperature of MR can likewise be stabilized by drawing heat from CR.**

The temperature of the periphery can be directly controlled by the heat pump. In the summer heat is added via the air-source heat exchanger and by the wintertime heat from the core will have reached the periphery so the heat pump will be extracting heat from the periphery at all times of the year. The timing of its operation is controlled by the grid operator who is interested in the short term grid demand fluctuations without interfering with the longer term needs of the building operator.

In the summer the average temperature around the periphery should be controlled at about 7 degrees C with the heat exchange fluid operating a few degrees lower, at 4 degrees, which is a suitable temperature for cooling the building without the need of a heat pump within the building. In the winter the heat flowing out from the center will warm the periphery to about 13 degrees and the fluid temperature will be controlled at about 10 degrees. With this symmetrical swing in the periphery temperatures there will be no net heat flow over the year.

A heat pump can achieve a temperature differential of more than 40 degrees between its input and output temperatures providing the output load is not excessive. Since the average input fluid temperature is 7 degrees that would correspond to a theoretical capacity to heat the output fluid to over 47 degrees. However the ground temperature will be slightly lower in the grout. Through the summer the temperature profile will have a peak that broadens as heat is transferred from the air into the ground. At the end of the summer the air-heat injection will stop and the temperature profile will flatten into a mesa shape with a lower maximum temperature but the heat pump will continue to inject some heat into MR throughout the fall. Once the heating season starts the heat withdrawal from MR will cause its temperature to drop.

The problem is that in order to maintain a comfortable room temperature of 22 degrees the buildings' heating systems will need to operate with an exchange fluid temperature of 32 degrees on a mild winter day, typically rising to 42 degrees on a very cold day. Even those temperatures will require very efficient air handlers (or underfloor or hydronic loops) - most conventional heating systems work at significantly higher temperatures. The ground storage system has no problem in storing enough heat in kWh, it just cannot deliver it at a high enough temperature. The amount of heat that is needed to meet the peak heating demands is relatively small so any source of heat at a higher temperature would be of interest, and solar heat is particularly attractive because about a quarter of a home's energy demand is for DHW so the solar option is doubly attractive.

**Heat pumps in the buildings**

A viable solution to handling the peak heating requirement is to use a heat pump in the building. However, that would draw power during the very period when we want to minimize the power load. It also adds a substantial capital cost, it takes up space and it requires maintenance. The solar option is more elegant, more comprehensive and potentially cheaper on a life cycle basis.

Using heat pumps has one major advantage - the grid operator can choose to turn the buildings' heat pumps ON or OFF, thus controlling the demand. Without that control the system will permanently eliminate the corresponding cooling and heating demands, which achieves the broad objective of reducing the peak demands but without the direct control.

**Using solar heat**

With even a single central borehole it is feasible to store enough solar heat in the central zone to meet the peak demand periods. If the radius of the central zone is the same as the gap between the outer rings then the travel time will ensure that the heat from the solar borehole will reach MR just before the heating load starts so the ground heat flow will be used efficiently and all of its contribution goes to the high-exergy side of the operation (i.e. it cannot leak out to the outer zone). The ground heat flow rate is constant so the fluctuations in heat demand would mostly be met by drawing heat directly from CR. The outputs from MR and CR can be modulated to meet the current demand, drawing from MR as much as possible. The volume of the central zone is one quarter of the total volume, so for a given delta T its heat storage capacity is also 25%, which is more than enough to meet the peak needs. The solar collectors will be delivering useful amounts of heat even in the winter and at that time there will be a strong depression in the central profile so any heat injected in the winter cannot move away from the center and will not lose its exergy.

**Heat trapping**

After the summer season the temperature profile between MR and OR will quickly flatten out into a mesa shape. The temperature at the periphery will fall off sharply because of the heat extraction of the heat pump. Once the heating season starts heat will begin to be extracted from MR and the temperature profile will fall sharply at that end too. As the winter progresses the extractions from OR and MR will eat away at the two sides of the mesa until it becomes a peak that will shrink as shown in the diagram. So long as the temperature of that peak is greater than that of MR the temperature gradient will prevent any outward heat flow and the gradient on the inner side of MR similarly prevents any inward flow as well, so both the energy and the exergy are trapped. For more than half of the year the exergy boost provided by the heat pump is trapped and none of it is lost. During the summer heat will flow away from the center as the storage zone is charged but all of that heat is recovered and used for space heating and much of it flows back to MR so its exergy is not lost. If the COP of the heat pump is 3 and half of its output is trapped without any loss and one third of the remaining half of the exergy is recovered then for every kWh of electricity that is used by the heat pump 2 kWh of energy demand reduction will be realized.

**Temporarily extending the capacity limits**

There are two ways in which the planned capacity limits might be temporarily exceeded :
1) The total amount of heat extracted might exceed the design objective
2) The rate of heat demand (i.e. the power) might be deficient on a cold night

There is a very large reserve capacity in this type of system. Normally in the winter the ground temperature of the periphery of the store will be about 14 degrees (the heat exchange fluid will be colder). However the heat pump will continue to function down to a ground temperature of about 0 degrees. The amount of stored energy corresponding to a 14 degree temperature change of the store is very large. If OR drops in temperature then MR is also going to drop, making it more difficult to heat the buildings but the system would not fail altogether and the operator can resort to choice 2) (below) on very cold nights. The system will return to its normal operating temperatures in the following year providing the cause of the excess load is fixed.

If the ground store is not delivering enough heat on very cold nights the output of the exergy boost heat pumps can temporarily be fed directly to the buildings instead of to MR. If the periphery temperature is 14 degrees (loop temperature 10 degrees) and the heat pump is capable of raising the temperature by 40 degrees this measure should deliver an operating loop temperature of 50 degrees to the buildings. The system should be capable of working for weeks in this mode. No energy is lost while operating in this mode. The average annual temperature of the periphery will drop so the ground store will extract heat from the surrounding ground to make up for the extra heat that is withdrawn.

**Do such homes and buildings qualify as 'net zero' buildings?**

Buildings using the technology described above do not use any GHG-emitting sources at all for heating, cooling and domestic hot water. They use a small amount of electricity for circulation pumps (and for fans in some cases) but that power could be supplied by batteries that are charged at night so that the only electricity used for the building itself is drawn at night, and mostly under the direct control of the grid operator. On most nights increasing the nighttime load is a positive advantage, not a drawback. If there is a power deficit the operation of the heat pump can be deferred without interfering with the heating, cooling and DHW. If there is a total power failure the buildings can continue to function normally, even if it happens on a frigidly cold night. The solar collectors could be dual-function panels that incorporate solar PV collectors, in which case the buildings will be exporters of energy in the form of electricity.

In the frenzy to develop new ways to generate electricity it is commonly forgotten that in Canada most of our electricity is already produced by hydro and other sources that do not produce GHG emissions. Such emissions come from the fuels that we use to heat our homes and to operate our vehicles. Natural gas is widely promoted as a 'clean' source for those applications on the shaky grounds that it produces only half as much GHG as coal but North America is in the process of switching over to shale gas for which the upstream losses will cancel out that questionable advantage (see the accompanying articles on the bizarre proposal that has been made by the NEB).