Why five?

Our buildings are surrounded by five energy sources that are presently just going to waste, but given a means of storing their energy they could inexpensively supply all of the energy the buildings need. A single storage facility can handle all five energy sources and can deliver the energy when it is needed, even though there are four different demand loads to be considered, all of which fluctuate over a wide range depending on the type of building, the seasons, and the time of day. All five sources are needed because each will be called upon to at some point in the annual cycle to provide a substantial part of the energy. The five sources are:

1) heat from the surrounding air
2) solar heat
3) heat from the ground
4) heat extracted from the buildings
5) unutilized electricity generation capacity

The storage medium for both the heat and the electricity is the ground. Heat flows very slowly through the ground so we can take advantage of that property to inject energy at one (injection) point in the ground and collect it later when it reaches a second (extraction) point in the ground. Using that principal we can collect heat when it is abundantly available in the summer and then use it for heating in the winter, or we can use an electrically driven heat pump to boost the temperature of the collected heat so that the thermal energy is stored at the temperature that is needed for the application (heating, cooling or hot water). The latter requires a two step process: first you collect the heat during the day when the sun is shining and temporarily store it in the ground, then in the middle of the night (when electric power is abundant) you use the heat pump to boost the temperature and move the heat to the store's central volume (an innermost central volume is also used to provide a superheating capacity). The result is that electricity is drawn when power is abundant and the energy will be recovered six months later when the stored heat is utilized, so effectively the ground store is acting like a giant battery. To the operator of the power grid both a giant battery or the thermal store would be doing the same thing: absorbing electric power when it is abundant and returning the energy at a later time as needed.

The details of the heat store designs are covered in other articles that are available in the science literature (and in Sustainability-Journal.ca).

All five of these energy sources are currently being used in existing installations, but to only a very small fraction of their potential. In countries where the winter temperatures rarely go below freezing buildings are commonly heated by air-source heat pumps. Solar heat is sometimes used for hot water systems. Ground source heat pump systems are used for space heating and such systems commonly recover the heat extracted by air-conditioning facilities as well. Power dams can utilize a larger part of the available river energy by building higher dams to store more energy. Systems that use just one or a couple of the five sources are usually not capable of meeting the full energy loads. Since most still rely on energy storage they incur the costs of the storage facility without realizing much of the potential benefits. Using a single heat store for all five sources enables the sources to complement each other with very little increase in the costs of building the store. The result is a system that can be less expensive than conventional heating/power systems, that can grow from being used for a small number of buildings to handling 100% of the building stock, and that is permanently sustainable.

Considering the energy sources individually:

1) Air-source heat. In the summer the temperature of the periphery of the store is 4°C and the daytime air temperature is typically between 20 and 30 degrees. That temperature difference is sufficient to achieve good heat transfer into a heat exchanger that temporarily moves the heat into the peripheral boreholes. At night that heat is moved into the middle rings of the store, returning the periphery to its original 4 degrees, ready for the next day's heat collection. There is no practical limit to the amount of heat that could be extracted from the air but there are good reasons for wanting to use all four of the other sources so although the air will typically be the largest energy source its contribution will usually amount to less than half of the total.

Air-heat is locally available, free, abundant, and it provides a clean, permanently sustainable source of energy that is much easier to collect and utilize if heat pumps are used to move the heat to the cores of the heat stores and to raise its temperature.

2) Solar thermal. Domestic hot water (DHW) systems operate at 60°C and space heating systems operate at about the same temperature. Solar thermal collectors of the type that were developed for DHW systems can deliver heat at that temperature and they do not need any electricity to drive them. They provide a means of super-heating the air-source heat to achieve the 60 degree operating temperature. The air-source heat exchangers are much less expensive than the solar collectors so using the two together provides the most cost-effective way of reaching the desired operating temperature at minimal cost. However, the solar input tends to be irregular so a second heat pump is used to maintain the output temperature when the sun is not shining. It uses heat extracted from the middle ring of the stores.

Solar thermal collectors make the air-heat contribution more useful and they also reduce the power demand of the heat pumps, thus contributing more to the available grid power than the same area of solar PV collectors would.

3) Heat from the ground. The periphery of the store is at 4°C during the summer and is at 7°C during the remaining 9 months of the year. Chilling the periphery ensures that the direction of heat flow is always towards the store, ensuring that none of the store's heat is lost through the periphery. Heat flows into the peripheral boreholes for 12 months per year, not just for 6 months as in a conventional GSHP, so the ground heat collection per unit length of borehole is higher than that for a GSHP. Moreover, with this configuration these boreholes do not need to supply energy at high rates on a cold winter night, when the peak heat demand is met by stored heat. During the first year of operation the starting ground temperature is the ambient ground temperature (typically about 10°C) and that provides much of the energy that will be needed to quickly bring the core up to its normal operating temperature even if the start-up occurs in the fall or winter. Moreover, if there should ever be a need for extra energy in the winter the ground provides a large standby capacity.

The peripheral holes also provide the heat sink needed for cooling in the summer. They are chilled at night in the early summer, when the hydro power is at its maximum. That stores cold that provides the cooling in August when the hydro power falls to its minimum.

4) Heat from the buildings. At the present time most buildings dump the extracted summer heat into the air, losing its energy (and creating the "thermal island" effect that makes some cities very uncomfortable in the summer). The conventional heat pumps that dump the summer heat into the outside air exacerbate that problem because they consume electricity and they operate inefficiently because they are dumping the heat into a sink that is already hot. The store's periphery is maintained at

4 degrees so it can be used as the heat sink without requiring the use of a heat pump, thus avoiding both the loss of the summer heat and the heat pump losses. Air conditioning systems are the cause of Ontario's principal peak power demand, adding about 10,000 MW to the demand.

The cost of power is primarily determined by the capital costs of the facilities needed for generation and distribution. For the cooling capacity those costs are reduced nearly to zero in a thermal storage system so the impact on the general price of electricity is very large. Each heat store will typically reduce the summer peak demand on the grid by about 1 MW.

5) Unutilized electricity generation capacity. Hydro power presently accounts for about 60% of Canada's power generation. The four heat sources described above could provide most of the heating and cooling for buildings (and their DHW) so the peak demands would be greatly reduced. However, the power needed for the heat pumps needs to be considered. The power for the heat pumps would all be drawn at night, when the power demand for other applications is at its minimum, and most of the electricity will be needed in the spring when the stores need to be recharged. That corresponds nicely with the extra power that is potentially available from run-of-the-river power stations due to the spring river run-off. That unutilized power is presently wasted via by-passing of the turbine water flow, but it would be more than enough to provide all of the extra electricity demand of the heat pumps, so Canada could progressively move to 100% hydro without actually building any more power stations.

The annual output of run-of-the-river hydro stations is typically less than 70% of what they could deliver if they operated at full power, day and night, throughout the year. The implication is that they could deliver nearly 100% of their full-power capacities if the excess power could be stored, and that would not require any changes to the dams, generators or transmission lines. Moreover they could deliver yet more power if the turbines were bigger, enabling them to utilize the spring run-off of the rivers, using the extra power to recharge the stores. The limit for that addition is not the amount of energy that is available from the rivers but rather the amount of power that we need from the grid.

Utilizing this concept does have one disadvantage - it does not lend itself to the popular concept that each house could have its own thermal store. The stores are physically too wide to be accommodated within a typical house lot. For large buildings that is not a significant deterrents but for homes the most attractive option would be to have a single store that is shared by most of the homes in a city block or those that are in condominiums. Such a configuration would be cost effective but it raises the issue of who should build and operate the stores. The cost advantages mostly go to the power suppliers, the energy outputs go to the building owners, and the GHG reductions go to the public at large so there is a need to consider how to share the costs and benefits.