Exergy storage - temperature objectives

Exergy storage systems can be designed for small buildings like homes or for large buildings, and they can optionally provide for domestic hot water (DHW). This note outlines some of the design objectives that are appropriate for stores that serve blocks of small buildings, including the DHW provision.

Exergy storage systems employ a single heat store that serves three different purposes:

1) to store heat (or cold) for use for space heating and cooling in the opposite season
2) to store heat at a higher temperature for DHW
3) to store electricity to match electric power demands with the available supply sources

For the outermost ring (OR) and the central ring (CR) the design temperatures are determined by their functions. In order to provide cooling without the need for heat pumps in the homes the summer ground temperature needs to be reduced to about 4 degrees C. That means that heat will flow into the store from the surrounding ground in the summer so in order to balance that inflow (to meet the objective of minimizing the thermal disturbance) the winter temperature needs to rise above the ambient ground temperature by approximately the same amount, so for Ottawa that sets the winter OR temperature at a nominal value of 16 degrees. However, some heat is lost through the top and bottom of the heat store so to compensate for that loss the winter temperature can be reduced to 12 to 14 degrees.

In the summer the temperature of OR can be directly controlled by the operator. The ground is chilled by the extraction of heat by the exergy heat pump, which primarily operates at night. During the day heat is injected by the air-heat exchanger so the operator can balance the two by adjusting the dwell times of these two processes.

In the winter heat flowing out from the hot center of the store is pumped at night to MR so the operator can still set the OR temperature to, say, 13 degrees. There is ample time to make the transition back and forth between 4 and 13 degrees between the heating and cooling seasons without interfering with either the cooling or heating operations.

The temperature of CR is similarly well defined. It should ideally be a few degrees higher than the DHW temperature which is conventionally set at 60 degrees C. Heat losses from the hot water tank and fresh water fed to the tank can be brought up to 60 degrees using a parallel plate heat exchanger. (*Note: an alternate strategy would be to feed heat from the solar collectors directly to the hot water tank, with any surplus going to the heat store.*) The electrical heating element in the hot water tank is the primary control, ensuring that the hot water will always be at 60 degrees irrespective of the central ground temperature. During the winter there are often long periods of dull weather so the ground temperature will fall, and moreover some of the heat will be withdrawn from CR to support the space heating so the central ground temperature can vary over quite a wide range (about 20 degrees) without compromising the system performance in a major way.

The heating elements in conventional systems operate at relatively high temperatures, typically 60 to 100 degrees but by choosing low temperature air handlers, fan-boosted hydronic distribution or underfloor heating the element temperatures can be dropped to the range 30 to 45 degrees, which is much more appropriate for long term storage systems. The challenges in such systems are to cope with the drop in the ground storage temperature as the heat is withdrawn through the winter and to cope with the extremely cold periods that can occur even late in the winter.

The electricity storage function of the system calls for heat to be pumped from the OR ring to the MR ring at night throughout the year. That means that the MR heat is being constantly replenished from that source and moreover by the onset of winter heat is also flowing into MR from the solar core. Those effects stabilize the temperature of MR so that its drop in temperature is gradual. Heat that is injected into both MR and CR during the winter is being fed into ground that is colder than the surrounding ground so there is no loss of heat and no loss of exergy due to ground conduction. Nonetheless we will need to live with a heat source that might reach 45 degrees at the end of summer but will drop to about 32 degrees by the end of the winter. During the latter part of the winter that may not be hot enough to deal with very cold days, especially with small systems.

In large systems the capacity of the solar storage can be increased so that it can provide most (or all) of the higher temperature (augmentation) heat that is needed by the building heat exchangers on cold days. The Okotoks system, for example, provides over 90% of the building heat without relying on heat pumps (it uses natural gas for peaking) so it demonstrates the feasibility of using solar heat without heat pumps. An exergy storage system is much less reliant on the solar input so it can be much smaller than the Okotoks system and the heat that escapes from the periphery of the solar store is very efficiently utilized by the space heating system so that further enhances the solar efficiency. The consequence is that a relatively small solar contribution solves both the problem of how to provide DHW and the problem of how to deal with the gradual ground temperature drop-off during the winter.

At the end of the winter OR will be at 13 degrees and MR will be at 32 degrees, a difference of 20 degrees. The heat pump needs to first raise the temperature of MR by 13 or more degrees, raising MR to above 45 degrees, and then retain that temperature as OR drops to 4 degrees by early June. Through July and August the air temperature will be high and at 4 degrees the ground temperature will be low so the system will be accumulating energy at its highest rate, in effect charging the "battery" - the large mass of ground between OR and MR. At the end of the summer the air-source input will drop off but by that time heat from the much hotter CR area will reach MR, abetted by the continuing diurnal cycle of the "electricity storage" mechanism. The consequence is that the temperature of MR will remain stable at 45+ degrees until the "battery charge" is withdrawn by extracting heat from both MR and OR through the winter, with the latter tending to sustain the temperature of MR.

The strategy for preventing heat loss at the periphery ensures that the amount of stored heat will be sufficient to heat the building provided enough heat is collected from the air in the summer. However, such a system does not retain 100% of the exergy. Most of the heat that is injected at 45+ degrees in the summer will be utilized at a much lower temperature and that represents a loss of exergy of the summer heat injection. However, the heat that is pumped from OR to MR in the balance of the year does not suffer any exergy loss because the thermal gradient around the MR boreholes prevents that heat from flowing away from the boreholes. To calculate the exergy storage you need to integrate the exergy inputs and outputs through the annual cycle. All of the solar heat is used at a temperature of roughly 60 degrees (for heating the water) or at 32 to 45+ degrees (contributing to the space heating) so its exergy recovery is high. If the strategy ensures that most of the heat pumping is done during the non-summer period when there is no loss of stored exergy then the recovery of that exergy will also be high, but it will be less than the input power to the heat pump multiplied by the heat pump's COP.

Maintaining the temperature of MR at 45+ degrees during the summer makes it relatively easy to raise the core temperature at that time by a further 20 degrees via heat from the solar thermal collectors. That sets up the basic capability of surrounding CR with a shroud that is above 60 degrees to prevent any loss of winter solar heat. Thus, although the amount of insolation during the winter is much lower than that during the summer the winter heat will be retained so the DHW system will function properly in the winter providing the collectors are not covered by snow. As previously noted the temperature of the solar core can fluctuate without having much impact on the system performance - the water will still be at 60 degrees and the core can still boost the space heating loop temperature and the exergy heat pump is available to meet the most extreme demands (see below).

The exergy storage system has one more trick up its sleeve. It provides the option of using the exergy heat pump to directly heat the buildings instead of feeding the heat to MR. The temperature of OR is much higher than that of a GSHP, indicating that it is capable of supplying both a large amount of heat and providing a comparatively high output temperature so it is ideal for coping with extreme space heating demands. Most of those extreme demands occur at night so this function does not materially compromise the "electricity storage" function of the system, and it makes it possible for a small (and therefore inexpensive) system to handle big peak loads.

The general design objective should be to reduce the daytime operation of the exergy heat pump to nearly zero, since that is the component that uses the most electricity. In Ontario it is actually advantageous to increase the nighttime power demand because the nuclear stations and wind turbines often create a nighttime power surplus that is hard to handle. It is the daytime power consumption that we need to reduce.