Saucer shaped temperature profiles

An exergy store consists of three concentric circles of boreholes for which the lateral temperature profiles are designed to take the form of shallow saucers. The outer ring of saucers needs to have an individual diameter that is large enough to prevent heat from leaking out from inside of the ring. For example, if the diameter of the entire array is 20 metres and the number of boreholes in that ring is 8 then the individual saucers need to be at least 7.85 metres in diameter. Their size is determined by the velocity of heat flow, so if that velocity is 1 m/month it will take 3.9 months to get to the point where the saucers are just touching. Since the inter-seasonal period is 6 months there should be a substantial overlap of the saucers and that will ensure that initially all heat flowing from the center of the facility will be intercepted by a saucer, and once it enters the saucer it will flow towards the borehole since heat can only flow from hot to cold.

In that particular example the middle ring of boreholes would have a diameter of 8m so the spacing between saucer centres need only be 6.28 metres if there are 4 boreholes in that ring as proposed in previous reports, and again that would initially be adequate to prevent heat leakage. However, a more conservative design would add an extra ring of 4 boreholes with a ring diameter of 10m. That will achieve three purposes:

1) it doubles the length of the boreholes that supply heat during the periods of peak demand, increasing their heat delivery capacity and reducing the ground temperature swing caused by a spike in demand

2) it reduces the spacing between the boreholes to about 3.6 metres which makes it easier to maintain the saucer profile shape during periods of high demand

3) it provides a place to dump the heat from the heat pump on very hot days, when the peripheral boreholes will be at a much lower than normal temperature. Ideally, the heat pump should operate at a reasonably constant lift, and the best efficiency will be achieved if that lift is minimized while still achieving the functional objectives.

Why is the saucer shape for the temperature profile so important? The temperature dip at the center of the profile needs only to be a few degrees or less to maintain the basic requirement that entering heat be redirected to the borehole. That is what makes it possible for a ring of boreholes to perform like a continuous shell. However, it does two other very important jobs:

1) it regulates the temperature. If you either add heat or extract heat via the borehole there will be a brief rise or fall in temperature but the difference will soon move away from the borehole and the temperature will return to its nominal value. A huge amount of heat can be injected without materially affecting the temperature if the rate of addition is low.

2) it makes the heat accessible. If you inject heat via the borehole it will initially move away from the borehole but because of the saucer profile it will soon stop moving because it reaches a point where the temperature gradient is zero. That means that the heat will remain in place for a very long time and it can readily be extracted because it remains close to the borehole. That ability to deliver heat is radically different from what is achieved with a GSHP, for which the source of heat moves away from the borehole over time. One direct consequence is the the borehole lengths of an exergy store are much shorter than those of a GSHP, and since boring holes is expensive that also reduces the costs.

How is the saucer profile generated? For the centre hole the base temperature is generated by the heat pump that surrounds the central area with ground for which the temperature is raised to about 50 degrees. Without that support the central borehole would never be able to reach the 60 degree objective because the heat would always flow away too fast. The solar collector should be sized so that it provides (on average) just enough heat to maintain the central temperature at 60 degrees in the winter, which implies that during the summer there will be a substantial excess of heat. Most of that excess will naturally flow away from the borehole, and any surplus that remains can be shunted to the middle rings, where it will be used for space heating. The result will be a broad central peak in the summer. It will have a flat top at a controlled temperature of about 63 degrees. In the fall the heat injection will be greatly reduced but the heat extraction for the DHW will continue, gradually forming the shallow saucer profile. A central column of 2m to 3m diameter has a very large capacity to supply heat for both hot water and for peak demands for the space heating, and it is inherently self-regulating. It should be noted however that the DHW system does not absolutely depend on the temperature regulation because the water heater tank in the homes will still incorporate an electric heater for safety reasons.

For the outermost ring of boreholes the shallow profile is again engineered. In the summer the air-heat injector is dumping heat into the boreholes during the day and the heat pump extracts that heat at night. By making the daily extraction slightly greater than the injection the saucer shape will gradually be created. By late fall heat will begin to flow from the center into the saucers but since there is always a diurnal need to store electricity (exergy) the balancing act can continue throughout the winter, thus maintaining the general saucer shape, although it will be distorted because the heat will be coming from the periphery of the saucers rather than from the center. By late winter this distortion will permit some heat to leak out but to a first approximation that leakage will balance out the ground heat absorption that occurs because the ring is below the ambient temperature during the balance of the year. These counteracting effects are small enough that there is no need to try to exactly balance them.

For the middle (space heating) rings the strategy is similar. During the summer heat is injected into those rings, and with the double ring pattern the peak will have a flat top. As winter approaches heat will be withdrawn, creating the temperature dip around the boreholes. However, in this case there is much less control over the balance, with the fall and winter heat injection from the heat pump (supplemented by solar heat from the center) being much less than the heat extraction. As a consequence the temperature of the middle zone will fall from a high value of 50 degrees at best to a low value of perhaps 30 degrees. During this period most of the heat will come from the zone between the middle and outer rings. Ideally, the temperature of that zone should always be slightly greater than the borehole temperature in order to maintain the saucer shape that is needed to ensure that the heat from the heat pump is retained in the middle zone. By the spring heat for space heating is being drawn from all three rings and because the solar collection zone is much hotter the system will still be able to handle spring cold spells. The result will be an overall "deflation" of all of the stored heat, getting ready for a replenishment of all of the zones as the air warms in the spring.

Note that in the event of an exceptionally cold winter there is a very large reserve of heat available. The heat pump can extract heat from the peripheral holes, much as a GSHP extracts heat from the ground, and that heat can keep the heating system in operation for many weeks. The rate of heat extraction from the inner two zones can be considerably greater than the power capacity of the heat pump so this mode of operation does not imply that the heating system's operation will be deficient - it just implies that the air-heat injection systems should have a reserve capacity so the system will recover in the following summer. Drawing heat from the core also implies that the hot water tanks will need some extra electricity, but the amount will still be much less than is normally needed for conventional hot water tanks.

What about air conditioning? In most Canadian cities the summers are relatively cool so the nominal 10 degree temperature of the outer boreholes will usually be adequate for cooling. When the weather forecast indicates that a hot spell is coming the air-heat injector can be turned OFF so that the heat pump will chill the ground around those holes. The temperature profile will have a narrow spike that can drop to as low as 4 degrees, which is sufficient to handle the extreme cooling needs. The hot spell will re-flatten the temperature profile so such a practice does not affect the normal functions of the system. The effect is that the heat extracted from the house replaces the usual air-heat on a transient basis. Since the source heat for the heat pump will temporarily be at a lower temperature than normal the output from the heat pump can be fed to the extra ring of middle boreholes to maintain the heat pump lift. By the fall that extra zone will be warmer than the inner zone so it won't matter that the injection temperature for those boreholes will be lower.