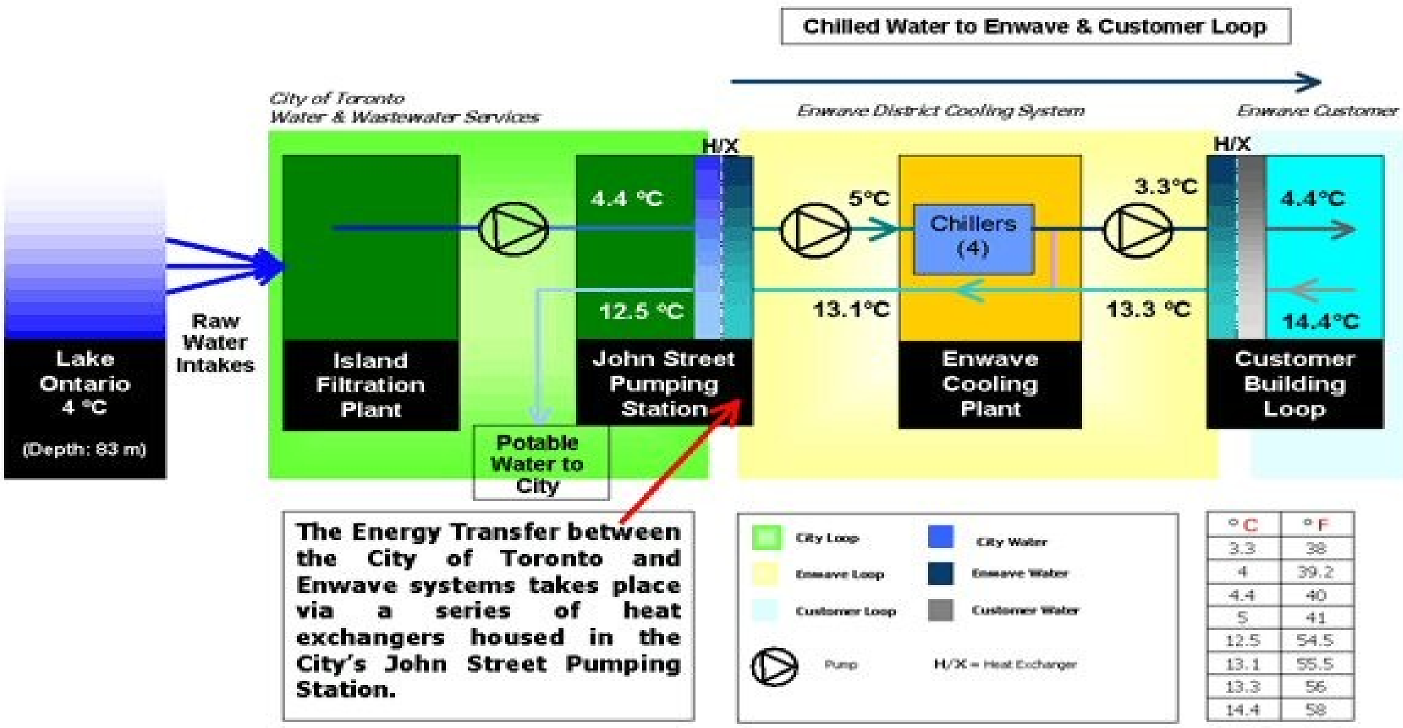

Cooling Large Buildings

Large buildings typically require much more cooling than heating. That has led to the development of systems that only supply cooling, leaving the heating requirements (including the supply of hot water) to other means. In the City of Toronto the primary example of such a system is the Enwave ® system, which cools many of the large buildings in downtown Toronto, including the buildings that house the Ontario Power Authority and (soon) the Energy Ministry. The above diagram symbolically illustrates the Enwave system with particular emphasis on the temperatures at key points in the system.

Note that the HVAC system that serves each building operates with a fixed input temperature of 4.4 degrees C and a fixed return temperature of 14.4 degrees. Since the load of the HVAC system will vary depending on how hot the day is, that variation is handled by varying the flow rate.

The Enwave system can be emulated with a Mid Size heat store. Such a store has three outer extraction borehole rings so the design objective is to ensure that the output temperature is always 4.4 degrees and the return temperature (which is not as critical) averages about 14.4 degrees. Since the flow rate is used to handle varying loads it should not also be used to control the output temperature as otherwise the control loop would be ambiguous.

The article on Boreholes shows how the vertical temperature gradient can be controlled, and in this case we would like the top of the tubes to be 3.33 degrees warmer than the bottom. At each ring the heat exchange fluid will thus drop by 3.33 degrees for an overall drop of 10 degrees as required, and providing the temperature difference between the rings is also 3.33 degrees the rate of energy flow per unit of length of the heat exchange tubing will remain constant, which ensures maximum efficiency. The surrounding rock must of course always be cooler to make the heat flow. If the ambient ground temperature is 10 degrees at the starting point then that differential will be nominally 4.7 degrees along the whole length of the tube which means that the rock temperature should be -0.29 degrees at the bottom of the innermost ring (3.04 degrees at the bottom of the middle ring and 6.37 degrees for the outer ring). The core temperature will be well below zero but the narrow frozen zone will be deep underground and will never come close to the surface.

The cold is injected into the center of the heat store, and the system relies on the very slow transport of heat in rock to delay the time of arrival of the injected cold (or extracted heat to use more precise terminology) at the three extraction rings. In the ideal case the three extraction rings are spaced so that the temperature drop will be 3.33 degrees between them, so ideally the cold will be extracted at the same rate as it flows into the outer area from the cold core. Since each of the extraction rings extracts the same amount of heat the temperature difference between the rings is primarily determined by the extraction process so they will tend to stabilize at the intended temperatures.

What happens if there is a hot day in the Spring? In this case the injected cold will not have reached the extraction rings, but there is ample cold available in the central region of the store so cold is extracted from that region on a temporary basis.

What happens if the summer temperatures do not conform to the normal trend? There is nothing that we can do to change the rate of heat flow within the store, but its outer rings are slightly elliptical in shape, which means that we can control the injection to extraction distance by selecting the boreholes that provide the required temperature. A variable bypass bridging rings 2 and 3 enables the cooling to be throttled back when needed.

What happens on the hottest days of the summer? Since the injection boreholes are not operational in the summer they can be used as extra extraction points, gaining a dual advantage because the store is colder there and because the length of the heat extraction lines can be doubled. The effect is like a gear change that more than doubles the peak load capacity.

Doesn't the cold leak out of the store? In fact the opposite happens. The outermost circle of boreholes is above the ambient temperature along their entire length so they will normally lose 15% of the building's discarded heat to the surrounding ground. However, the cold storage capacity must be sufficient to handle the warmest possible summer which implies that there will usually be a surplus of cold that must be disposed of in the fall. At that time the variable bypass will be operating so the temperature of the periphery will fall, enabling the excess cold to leak out. Note that the building's input and output temperatures are not affected. Ideally, the core of the store should be chilled with about a 15% surplus of cold, which means that the excess cold will just balance the heat that escapes during the normal operation, resulting in a zero net long term heat output from the store to the surrounding ground. Very little energy is needed to inject that much extra cold into the ground so the impact on the overall efficiency is negligible.

How is the cold injected into the center? The cold is extracted from the winter air and transferred into the ground via the central group of boreholes. That will only operate on cold nights (when electrical power is cheap). The injection process is the same as the extraction process, so in both cases there must be a sufficient length of heat exchange tubing to affect the transfer. In the injection step there is an additional requirement that the rate of injection must create the 3.3 degree temperature differential from top to bottom, but that rate is directly controlled.

Aren't the boreholes expensive? Although the boreholes add a cost that is not encountered in conventional cooling systems that cost is countered by the elimination of the very expensive chillers, the cooling tower that is needed to dispose of the heat from the chiller, and the equipment needed for the water for the cooling tower, which must operate over a wide range of temperatures and be protected from contamination. The electrical power demand is reduced by about 90% and the need for the water is eliminated. Within the building, all that is needed is the trunk cooling line and a distribution loop on each floor.

Why is the Enwave system being emulated? The HVAC systems in the buildings can be identical, which means that the only new design element is the cold store itself. So long as the cold store is capable of delivering a constant 4.4 degrees and can provide a varying flow to handle building load variations then the heat store performance will be the same as that for the Enwave system. In both cases the return temperature of 14.4 degrees is determined by the HVAC system, not the cooling source, so it is a given factor.

How much power is consumed? The Enwave system uses 4 huge and long circulation loops, and each branch requires a chiller, plus the loop for the building itself. The heat store requires only the building loop plus the cold injection loop. The latter requires very little energy because it only runs for short periods. The Enwave system reduces the energy demand by 75% and the consumption reduction of the cold store should in most cases be considerably greater.

Are there other advantages? The Enwave system is only useful in downtown Toronto since it requires access to the cold water at the bottom of Lake Ontario. The cold store systems can be located almost anywhere. They can be installed quickly since they only require drilling 72 boreholes. They do not require the installation of trunk lines to the cold source, or the extra loops for filtering and chilling, etc. Both systems rely on the same fundamental cold source (the winter air) and on the use of seasonal storage, and at the delivery loop they operate identically, but it is much less expensive to drill and fit the 72 boreholes than to build the huge infrastructure of an Enwave system.

What about smaller buildings? As explained in previous notes the Mid Size heat store can be adapted to provide both cooling and heating, and there is a smaller version (the Minimalist heat store) that is suitable for smaller buildings or small communities. Moreover, since such dual purpose systems do not lose heat they can be used in conjunction with cogenerators that can operate throughout the year (since the heat is stored), so the systems can also deliver electricity, and they also facilitate the use of other renewable energy sources such as wind power.

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