1. BACKGROUND

Most population centers in Canada receive a significant amount of solar radiation – more, in fact, than some countries such as Germany, Italy and Japan, where use of solar energy is becoming common; in particular, southern Alberta receives only slightly less than such areas as Arizona and Israel. This relatively high availability of solar energy has recently led to annual growth rates of 30 – 40% in sales of solar energy equipment in Canada – although only a small portion of this equipment is used for space heating. However, due to Canada’s geographic location and climatic conditions, the bulk of the solar radiation is received in the summer months, and is relatively low during the winter months, when the demand for space heating reaches a peak. The ability to effectively store thermal energy for a period of months provides an opportunity to substantially increase the use of solar energy in Canada.

A large-scale solar seasonal storage project is currently in the early months of operation in Okotoks, Alberta. The Drake Landing Solar Community (DLSC) is a community of fifty-two modern detached homes that derive most of their heat requirements from solar energy, using borehole thermal energy storage (BTES) to store heat collected in the summer, for use in the winter. DLSC is the largest seasonal thermal energy storage system of its kind in North America and is designed to have both the highest annual solar fraction (90%) and the highest peak storage temperature (80°C) of any solar-based seasonal storage system in the world. Thermal energy is stored in 35,000 m³ of soil and rock under a corner of the neighborhood park; the heat is transferred to and from the earth by water flowing through U-tubes in 144 boreholes, each 35 meters deep.

One of the noteworthy aspects of the DLSC project is that a single design team was responsible for the complete energy system, from energy collection, through storage, transport, conversion and final use. This allowed a much wider scope for optimizing overall system performance than is generally available in energy system design, where it is common to have separate sub-systems designed independently, with each design group responsible only for optimizing their portion of the total system.

As of the date of this paper, the heating system is in operation, delivering heat to those homes which have been occupied. Construction of the remaining homes and garages continues; the remaining solar collectors will be installed as the garages are completed.
2. **SYSTEM DESCRIPTION AND PERFORMANCE TARGETS**

Drake Landing Solar Community consists of fifty-two homes located on four streets running east-west. Each home has a detached garage behind the home, facing onto a lane. The garages have been joined by a roofed-in breezeway, creating a continuous roof structure the length of each of the four laneways, to support the 1.4 MW\(_{TH}\) of solar collectors. The BTES field has been installed under a corner of the neighbourhood park, and is covered by a layer of insulation, plus soil and sod. The 144 boreholes of the BTES field are plumbed in 36 circuits of 6 series strings boreholes each. Each series string conforms to a radial flow pattern, with the water flowing from the centre to the outer edge when storing heat, and from the edge towards the centre when recovering heat.

Most of the mechanical equipment (pumps, gas boilers, etc.) is housed in a dedicated building (Energy Centre), which also houses the short term thermal storage (STTS) tanks. The STTS acts as a buffer between the collector loop, district loop and BTES field, accepting and dispensing thermal energy as required. The STTS tanks are critical to the proper operation of the system, because they can accept and dispense heat at a much greater rate than the higher capacity BTES storage. During intense summer sunshine, the BTES field cannot accept energy as quickly as it can be collected; thus heat is temporarily stored in the STTS tanks, with transfer to the BTES continuing through the night. This situation is reversed in the winter, when heat cannot be extracted from the BTES field quickly enough to meet peak heat demands, typically in the early morning hours.

The overall intent of the DLSC project was “to demonstrate the technical feasibility of achieving green house gas emission reductions by using solar energy collected during the summer to provide residential space heating during the following winter (seasonal storage).” Specifically, the primary performance target for the completed system was that “the annual solar fraction for the space heating load must be kept as high as practical, preferably exceeding 0.9 within 5 years.” The annual solar fraction of the system is defined as the ratio of energy from solar to the total delivered energy, as measured at the entrance to the homes. A simplified schematic of the system is shown in figure 1.
Any BTES system takes a few years to “charge”, before optimum performance is achieved. This is because much of the initial heat transferred into the soil cannot be recovered, as it is required to raise the temperature above the initial ground temperatures of 5 – 10°C. In the case of DLSC, it is expected to take approximately three years of operation before typical behaviour will be observed. At this time, the soil temperatures in the core of the BTES are expected to approach 80°C at the end of summer, the annual solar fraction is expected to vary between 0.85 and 1.00 (depending on weather) and the overall system energy flows are expected to be as shown in figure 2.

Figure 2: DLSC energy flow in a typical year

3. CONTROL SYSTEM CHALLENGES

Simply stated, the control system has been designed to collect solar energy whenever it is available, and deliver heat to the homes whenever it is needed. Optimizing the control strategy was a significant challenge, developing into a balancing act between the two primary goals of assuring occupant comfort and maximizing the solar fraction. A high operating temperature within the district loop would allow user comfort to be easily achieved. However, solar collector efficiency decreases at higher temperatures, and thermal losses from the BTES field also increase at higher temperatures. Add to this the fact that the weather causes large, unpredictable changes in both the solar energy available, and the heat demand from the houses, and one has a complex system. Thus the two primary objectives of the control system became:

- Operate the district loop at the lowest possible temperature that would still ensure occupant comfort, and;
- Always be capable of responding appropriately to changing weather conditions.

In order to operate the district loop at the lowest possible temperatures, and still ensure occupancy comfort, the air ducts within each home are larger than normal, the air handlers incorporate a higher capacity heat exchanger, and the internal control algorithm of the air handlers was modified. The forced air systems within the homes will move
greater air volume, at lower temperatures, to deliver the same amount of heat as conventional furnaces – while still keeping the air velocity low to minimize drafts.

Naturally, the control system must also carry out all of the tasks required to ensure that the system operates in a safe manner during all conditions, including equipment failures.

4. **CONTROL SYSTEMS APPROACH**

The basic operation of the system relies on the STTS tanks to act as the central control centre for heat movement. They:

- Receive heat from the collectors when available
- Supply heat to the district loop for the houses when required
- Send heat to the BTES when excess is present
- Retrieve heat from the BTES when deficient

The discussion of the control strategy will examine the other three major subsystems (collection, seasonal storage and delivery), and then review how the STTS is controlled at the centre of the system.

**COLLECTOR SYSTEM**

Several options for starting and operating the collector circuit were considered. The first was to have the collectors started based on solar radiation as measured by a pyranometer. The collectors were then to be operated at a single speed in bypass mode until the supply temperature was sufficiently high to provide heat to the STTS. This approach was not followed for two reasons. First the cost of a pyranometer was deemed to be unnecessary as a temperature sensor inside the collector is essentially a pyranometer. Second, operating the collectors when no useful heat is available was deemed a waste of electricity running the pump unnecessarily.

A second option was to operate the collectors with a standard differential controller where the collectors are started based on the collector temperature being sufficiently above the cold storage temperature to ensure heat was available to be stored, operate the collectors at constant speed and shut them off when the collector temperature and storage temperature are close to the same. Again this would not provide an optimized system.

Because a computer-based automation system was installed it was easy to increase the sophistication of the collector controls. To maximize the energy gain from the collector system and minimize the pumping energy used it was decided to use variable pumping speed on the collector pump. The control starts the pump at low speed when the collector temperature rises above the storage return temperature. The collector pump speed is then ramped up and down to maintain a constant temperature difference between the hot fluid from the collectors and the cold fluid from storage. This strategy allows maximum heat delivery from the collectors with minimal pumping energy.

**BTES**

Operating the BTES efficiently was also a challenge of competing interests. It required:

1. Minimum heat be sent and only as required to the BTES, and the temperature be maintained at the lowest possible levels to minimize losses
2. Maximum heat be available from the BTES, and maximum temperatures be available in the coldest part of the winter to ensure minimum back-up heat be used

Operating the BTES required keeping track of BTES temperatures in the centre and at the edge. These temperatures are the parameters required to determine when it was possible to send heat to the BTES and when heat was available to be drawn from the BTES.

BTES water temperatures are used “as available” without the aid of heat pumps for a boost. Computer modeling revealed that heat needed to be drawn from the BTES at lower temperatures than required to ensure 100% of the heating load would be met. The temperature at which heat is recovered needed to be determined based on maximizing the fraction of the load met over the year rather than just ensuring that the current load would be met.
An interesting feature of the BTES controls is that it does not rely on any measurement of earth temperatures. Buried temperature sensors were considered too expensive to install, and not sufficiently durable to last the 50-year design life of the BTES system, without replacement. Thus the BTES field’s capacity for accepting and delivering energy is based on the water temperature entering and leaving the field.

DISTRICT LOOP SYSTEM
Control of the District Loop was optimized for two operating parameters, minimum operating temperature to ensure maximum usefulness of the solar energy, and variable pumping speed to ensure minimum electricity use for pumping.

The biggest challenge with the District Loop was to ensure the greatest temperature drop through the system. Two outcomes were expected from a high temperature drop. The first was ensuring efficient operation of the STTS by maintaining stratification. And the second was the best efficiency in the solar collectors by maintaining the lowest inlet water temperature. Obtaining a high temperature drop required designing a fan-coil that provided a temperature drop of about 25°C. The second was to operate the District Loop so that the temperature drop was realized. To maintain maximum simplicity in the house controls that system was based on a two-position valve. When a house calls for heat the valve opens and full flow is provided. The fan speed is immediately ramped up to maximize the heat removed and therefore the temperature drop across the coil.

To minimize pumping energy requirements the District Loop pump operates on a VSD controlled by system pressure. If no houses are calling for heat the system maintains minimum flow through the Loop via bypass valves at the end of each run. The VSD then operates the pump at minimum speed. As houses call for heat the system pressure starts to drop and the variable speed pump increases speed to maintain a constant pressure in the system. Use of the VSD minimized the pump energy required.

The temperature of the district loop varies with outdoor ambient temperature. In warmer weather (above 5°C), when heating demand is low, the air handlers can operate with water at 35°C. As the weather gets colder, higher water temperatures are required to meet the increased loads; thus the district loop temperature is raised to a maximum of 55°C, at outdoor temperatures of -20°C and below.

STTS
Having the STTS operate efficiently was a challenge of balancing several competing interests. Efficient operation meant three things:
1. The largest volume of the coldest possible water was available when solar heating was available
2. Sufficient hot water at the temperature required was always available to send to the houses for heating
3. A minimum of heat was sent to the BTES for
4. The tanks were maintained at as cool a temperature as possible to minimize heat loss from the tanks

The solution involved:
1. Determining the house load for the next six hours based on outdoor temperature
2. Determining the STTS charge available based on the temperature profile throughout the stratified tanks
3. Comparing the house load to the STTS charge available
4. Projecting the potential for solar gain based on time of day
5. Based on the load/charge comparison and the solar potential decide on shedding excess load to the BTES or supplementing a deficiency in STTS from the BTES

All parameters are checked and updated hourly.

OVERALL PERFORMANCE
Total system overall performance was eventually boosted to over 90% solar fraction for space heating by a series of parametric runs that balanced all of the parameters for the four systems discussed. One significant potential error revealed during modeling was the ability of an assumed outdoor reset schedule to adequately maintain indoor comfort conditions based on an assumed outdoor reset curve for the District Loop.
System operation was first optimized based on TMY weather data. After that an actual 50 year weather data file was used to examine year to year variations. Based on this data it was found that system performance varied between about 87% in the worst year and 100% in the best years.

Consideration was given to incorporating actual weather forecasts (predicted ambient temperatures, wind speed, and sky conditions). Although system operation could benefit if the near-future weather conditions were known, it was decided that knowing the date, time of day and current air temperature were adequate for reasonably predicting the heat load in the next 6 – 8 hours, and the date and time of day also provided some degree of knowledge of solar radiation. It was decided that the increased assurance from actual weather forecasts would not boost performance enough to justify the added expense and complexity of incorporated weather forecasts into the control algorithms.

5. CONCLUSION

The system began delivering heat to the first occupied homes only in February, 2006. Although it is expected that there will be some adjustments to the control system over time, it is too early yet to predict what improvements are possible.

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REFERENCES