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An integrated model for designing a solar community heating system with borehole thermal storage

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ABSTRACT

Borehole thermal energy storage (BTES) is found to be a favorable method for storing a large amount of thermal energy, and suitable for seasonal solar thermal storage, especially for large communities. Drake Landing Solar Community (DLSC), built in 2006, is the first such solar community in Canada. DLSC has achieved a 97% solar fraction after five years of operation. Although the DLSC project has been a success technically, the cost of the system is not attractive. In this study, an alternative design approach for a similar community is presented. The primary goal is to develop a system that not only achieves similar or better performance but also costs less. TRNSYS 17, along with a novel custom BTES component, is used for the system design and simulation. With the alternative design, the annual community thermal load of 2350 GJ is mostly met by solar thermal collectors via BTES and after five years of operation a 96% solar fraction is predicted. The simulation results are compared with published results for DLSC. It is estimated that the proposed system offers a 19% saving in initial cost in addition to reductions of BTES area of 38% and solar panel area of 25%.

Introduction

Solar thermal collectors with underground thermal storage system have been used to heat buildings and communities for many years. The first solar heating plants were constructed about 30 years ago. From 1979 to the middle of 2011, a total of 141 heating plants were built in Europe. Each plant has more than 500 m^2 of solar collector area or greater than 350 kW thermal capacities (Dalenback and Werner, 2012). Among these are several examples of large scale pilot solar plants in Germany and Sweden, each of which has achieved a solar fraction (SF) of at most 50 to 60% (Pavlov and Olesen, 2011a). The purposes of all these plants are storing heat at times when it is not required and using it at times when it is needed. Schmidt et al. have reviewed in detail advances in seasonal thermal energy storage in Germany (Schmidt et al., 2003).

Seasonal thermal energy storage normally stores heat in a sensible form. The main parameters for determining the heat transfer and losses for the storage are thermal properties of the storage medium, time of storage, storage temperature, storage geometry and volume. In community and district solar energy heat storage, the storage volumes are relatively large. Therefore, ground storage due to its low cost, as well as ability to deal with the large time scales, makes this storage technology the most promising (Nordell, 2000).

Four main types of seasonal storage have been presented by researchers (Schmidt et al., 2003, 2004; Socaciu, 2011; Pavlov and Olesen, 2011b). Those are: 1) hot water thermal energy storage, 2) aquifer thermal energy storage, 3) gravel-water thermal energy storage and 4) borehole thermal energy storage.

Schmidt et al. (Schmidt et al., 2004) provided an extensive study and some advice about how to design an optimized system to make the system more efficient and economical. Bauer et al. (Bauer et al., 2010) also described the different thermal storage types related to the solar district systems and compared the specific characteristics of different storage types. Hesaraki et al. (Hesaraki et al., 2015) conducted a comparative review of different types of seasonal energy storage systems integrated with the heat pumps for heating and to some extent cooling applications. The paper presented the systems with low temperatures suitable for running heat pumps to satisfy heating rather than cooling loads mostly. In their study, the implications of storing excess heat generated by the heat pumps in cooling season and the storage of solar heat at the same time, have not been investigated. Rad and Fung (Rad and Fung, 2016) also presented an extensive review of different types of thermal energy storage used for heating and cooling for solar communities, including the systems with a distribution system other than the heat pumps, e.g., fan coil, for both heating and cooling.

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In borehole thermal storage (BTES), the ground itself is the storage medium, and heat exchanges occur through a number of vertical boreholes in the ground. The storage volume is not exactly defined and separated. Geological formation plays a significant role in determining the thermal capacity of the storage. The vertical borehole lengths are usually in the range of 30 to 100 m with approximately 3 to 4 m separations (Schmidt et al., 2003). The borehole depths in recent installations can go up to 200 m (Pavlov and Olesen, 2011b).

In the borehole, heat is typically exchanged through double or single U-pipes or concentric pipes. The pipe material is commonly made of synthetic material like high-density polyethylene (HDPE). The fluid in the tubes is usually water although in some cases, to avoid freezing, the water is mixed with ethanol or glycol. The boreholes are often filled with grout, which normally is bentonite, quartz with sand or a water mixture (Northern Europe). Quartz gives the grout a higher thermal conductivity whereas bentonite provides sealing and plugging characteristics. The heat-transfer properties of grouted boreholes have been studied theoretically by Bennet et al. (Bennet et al., 1987) and Hellstrom (Hellstrom, 1991). They have also been tested in the laboratory by Paul (Paul, 1996) and using field measurements by Austin (Austin, 1998). The thermal conductivities of typical filling materials follow: stagnate water (0.6 W/mK), bentonite (0.8–1.0 W/mK), thermally enhance grout with quartz (1.0–1.5 W/mK), and water saturated quartz sand (1.5–2.0 W/mK).

For the thermal analysis of BTES, many tools have been developed. The main purpose of these tools is to design the requisite complex systems optimally, including cost effectively. The available tools vary from uncomplicated design tools to advanced simulation modeling with hourly climate data and detail load data. The model should consider a relatively high heat flow in the ground and the heat transfer in and adjacent to the boreholes. Therefore, with a suitable time resolution, the relation between the temperature of the heat-transfer fluid and the total storage heat-transfer rate is captured (Nordell, 2000).

Eskilson and Claesson proposed a model in finite-difference, a superposition borehole model (SBM), which is a detailed model that can accept arbitrarily placed vertical or horizontal boreholes (Eskilson and Claesson, 1988; Eskilson, 1987). This model is examined and validated in several field experiments (Hellstrom, 1991; Eskilson, 1987). It has been used to calculate the thermal performance of a heat pump-coupled system, with software such as EED (Hellstrom et al., 1997; Hellstrom and Sanner, 1997) and GLHEPRO (Manickam et al., 1997). This model calculates the dimensionless thermal response functions for various borehole configurations.

Hellstrom introduced another simulation model called, duct-ground heat storage (DST) (Hellstrom, 1989). This is a simulation model for multiple boreholes with uniform borehole spacing. It has been used extensively for both detailed design and field experiment evaluation. Both the SBM and DST models have been modified for use as a TRNSYS component. The TRNSYS version of DST can also investigate problems within the stored volume. It can check for radial stratification of the ground temperatures and assess the effect of the flow conditions in the borehole pipe on the thermal performance of the system (Pahud and Hellstrom, 1996).

In Canada, Drake Landing Solar Community (DLSC) in Okotoks, Alberta, the first large scale BTES designed as a part of a solar community, was built in 2006. DLSC has achieved a 97% solar fraction after five years of operation (Sibbitt et al., 2007). The primary objective of the DLSC project was to demonstrate that substantial energy cost savings are achievable compared to conventional systems by storing solar heat from summer for winter uses.

DLSC consists of 52 detached houses having a total annual heating demand of 2120 GJ (SAIC Canada, Science Applications International Corporation, 2012). From the central energy center, hot water is distributed through a two-pipe system to each of the 52 houses. Each house is equipped with an individual air handler with a water-to-air fan coil. All the houses, having an efficient building envelope, were built and certified based on the R-2000 standard developed by Natural Resources Canada (NRCan) (Natural Resources Canada Office of Energy Efficiency, 2012). A total of 2293 m^2 of flat-plate solar collectors was installed on the roof of the connected garages of the houses, facing south. The community energy center contains two short term storage tanks (STSTs) with a total 240 m^3 volumetric capacity, pumps, heat exchangers and controls. A borehole thermal energy storage (BTES), located next to the energy center, containing 144 boreholes of 35 m depth installed in 24 parallel circuits, is used as a seasonal thermal storage. Fig. 1 depicts the DLSC simplified system schematic (Sibbitt et al., 2007).

The DLSC maximum design borehole temperature is 80 °C. Sibbitt et al. describe how the high-temperature storage has two disadvantages, 1) during the charging time, the return fluid temperature to the solar panels is relatively high, which reduces the solar panel efficiencies, and 2) the storage heat loss is relatively high, calculated to be almost 60% (Sibbitt et al., 2007).

To minimize the thermal storage heat losses, Chapuis and Bernier, offered an alternative design approach for the Okotoks like system, to keep the storage temperature relatively low (Chapius and Bernier, 2009). The approach was based on using heat pumps to raise the temperature as per space heating demands. The proposed system was simulated using TRNSYS with its DST module. It was concluded that by keeping the average storage temperature slightly above the annual average ambient temperature, the return water temperature to the solar collectors would be relatively low. Therefore, higher efficiencies can be achieved from the solar collectors by solar collectors with correspondingly reduced areas. By considering heat pump electricity usage in the system, a 78% solar fraction could be obtained (Chapius and Bernier, 2009).

The DLSC's technical feasibility and system performance have been shown to be successful in terms of reducing energy costs (Sibbitt et al., 2011). However, the system's capital cost is substantially higher than conventional heating systems and does not offer any payback over the lifetime of the project.

The objective of this work is to use DLSC as a base case and then propose a new design with a similar, but more efficient, configuration. The proposed model can have different components and possibly smaller sizes, to achieve a lower initial cost and a better payback. The new design is constrained to produce the same solar fraction (SF) as DLSC and simulated with an integrated model using TRNSYS software (Klein et al., 2010).

System characteristics

System configuration and community thermal load

Fig. 2 shows the system configuration and equipment. The solar collectors transfer the harvested solar energy to a short term storage tank (STST) through a heat exchanger all year around. In the mid-spring and summer when there is no space heat demand from the community, the stored thermal energy is transferred to the ground for seasonal storage. The ground storage type is vertical borehole thermal energy storage (BTES). During the heating season, the stored heat in the Earth is extracted and transferred to the STST when the solar collectors cannot maintain the required temperature needed in the tank to meet the community heating load.

The selected community comprises a combination of single and multi-family residential units with 10% more heating load than the DLSC (Sibbitt et al., 2007, 2011). Fig. 3 shows the hourly thermal load profile for the selected community calculated by eQuest software (James J. Hirsch and Associates). The peak heating load is 457 kW and the total annual heating demand is 2350 GJ. Heat is supplied to the community through the distributed fan coils connected to the hot water distribution loop fed from the STST. The community water loop temperature is maintained on average at 40 °C. An auxiliary boiler is connected

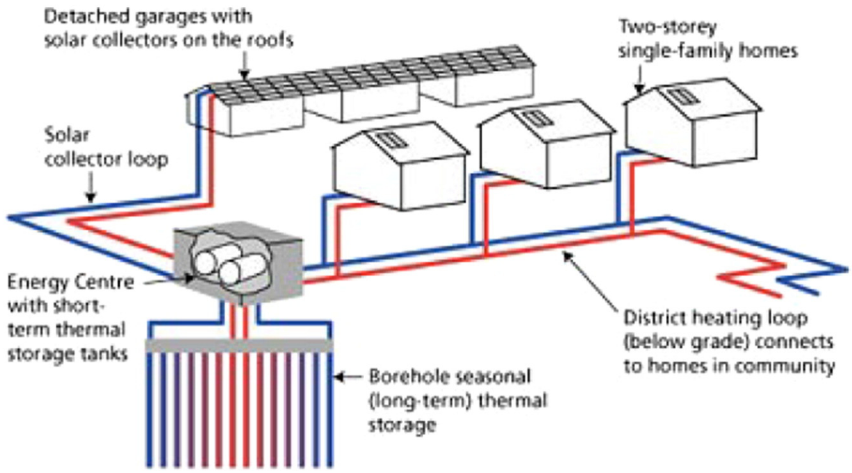

Fig. 1. Drake Landing Solar Community (DLSC) simplified system schematic (Nordell, 2000).

to the district water loop in case the STST temperature falls below the set community loop temperature.

The STST and the pumps plus controls are all located in one location called the Energy Centre. For efficient use of pump electricity, the pumps in all loops, i.e., solar, BTES, and community loop, are equipped with variable flow devices to maintain the required flow in each loop.

System major equipment configuration and model

An integrated system is modeled using TRNSYS 17 software. Fig. 4 shows the TRNSYS model layout. One focal point of the system is the short term storage tank (STST), where all three of the system's main loops, i.e., community, solar and BTES, meet and interact. The liquid flow through the solar collectors transfers the solar heat gain to the solar loop connected to the STST through a heat exchanger. The model receives the community hourly heating load from a spreadsheet resulting from eQuest community load calculations. A boiler is connected to the community supply flow to maintain the desired temperature needed for the fan coils in the community. Sections Solar collector to Backup boiler and climate data describe the system's major components.

Solar collector

The selected solar collectors are of a flat-plate type. The total collector area is 1772 m^2, which includes 600 solar collectors in three parallel arrays with 200 panels connected in series. The solar collectors face south and have a 45° surface inclination. The efficiency of the collectors as per the manufacturer's "Solar Rating and Certification Corporation" evaluation, SRCC™ (Enerworks Inc., 2015), is calculated as follows:

$$\eta = 0.762 - 3.2787\left(\frac{T_i - T_a}{G}\right) - 0.0129\left(\frac{(T_i - T_a)^2}{G}\right) \quad (1)$$

where, T_i and T_a are the solar collector inlet and ambient air temperature in °C and G is the global radiation incident on the tilted-surface of the solar collector. The collector's incident angle modifier (IAM) is also

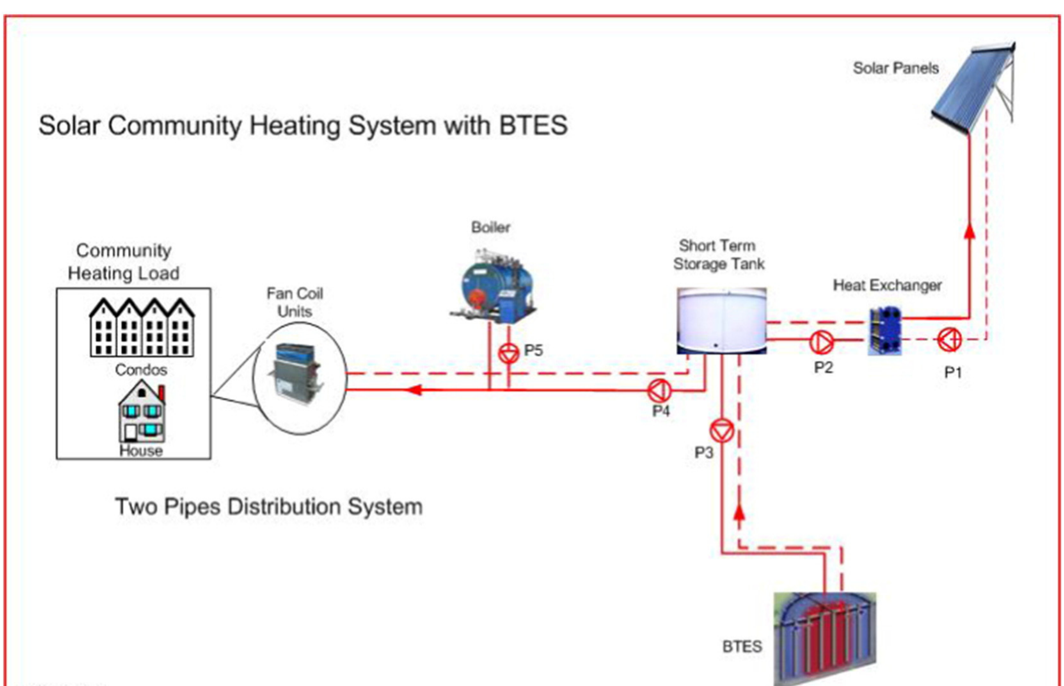

Fig. 2. System schematic.

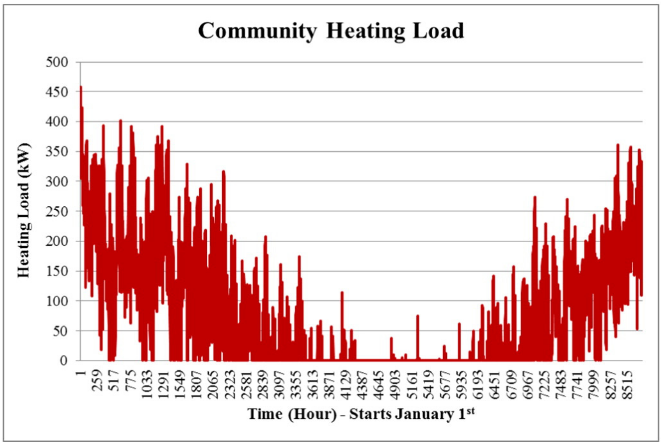

Fig. 3. Community hourly heating load.

selected from the manufacturer's SRCC™ certified data. The selected solar collectors are similar to the solar collectors used in DLSC and in the proposed TRNSYS model, Type 1 for the flat-plate solar collectors is chosen.

Borehole thermal storage (BTES) system

The BTES incorporated into the system has 90 boreholes each of 59 m depth. The boreholes are configured in a circular field with an average of 3 m borehole separation. Comparing to the DLSC, which has the BTES of 144 boreholes each of 37 m depth with 3 m borehole separation, the proposed community has almost the same total borehole length, but 54 fewer boreholes (90 boreholes) and 22 m longer depth (59 m) with the same separation (3 m). The selected number of boreholes for the proposed community (i.e., 90) has come out as a result of trial and error method by repeated attempts in reducing the borehole numbers in the system's model from 144 boreholes until the system fails to perform similarly to the DSLC experimental performance results.

The cylindrical shape storage that contains the boreholes has a volume of 34,017 m^3 with a coverage of 580 m^2 ground surface area. The nominal HDPE pipe size comprising the U-tube ground heat exchanger is 32 mm in diameter. The thermal conductivities of the borehole grout and the ground comprising the storage volume are 1.5 W/mK and 2 W/mK respectively. The ground comprising the storage volume is composed of the wet shale and sandstone selected from the drilling records in the DLSC's area.

Fig. 5(a) shows the borehole layout, which consists of 10 circuits connected in parallel to the main header. Fig. 5(b) depicts each circuit, which consists of nine boreholes connected in parallel.

An advanced simulation modeling tool, Ground Heat Exchanger Analysis Design and Simulation (GHEADS), developed by Leong et al. (Leong and Tarnawski, 2010; Tarnawski and Leong, 1990; Rad et al., 2014) is used for the BTES design. GHEADS is a detailed modeling program for ground heat exchangers and is flexible in terms of borehole layout design. GHEADS produces more favorable results than the existing TRNSYS built-in duct-ground-storage (DST) model (Hellstrom, 1989) which was used in the DLSC design. However, the simulation running time in GHEADS is substantially longer.

GHEADS has the following advantages over the DST model:

1- Incorporates coupled heat and moisture flow in the ground heat storage

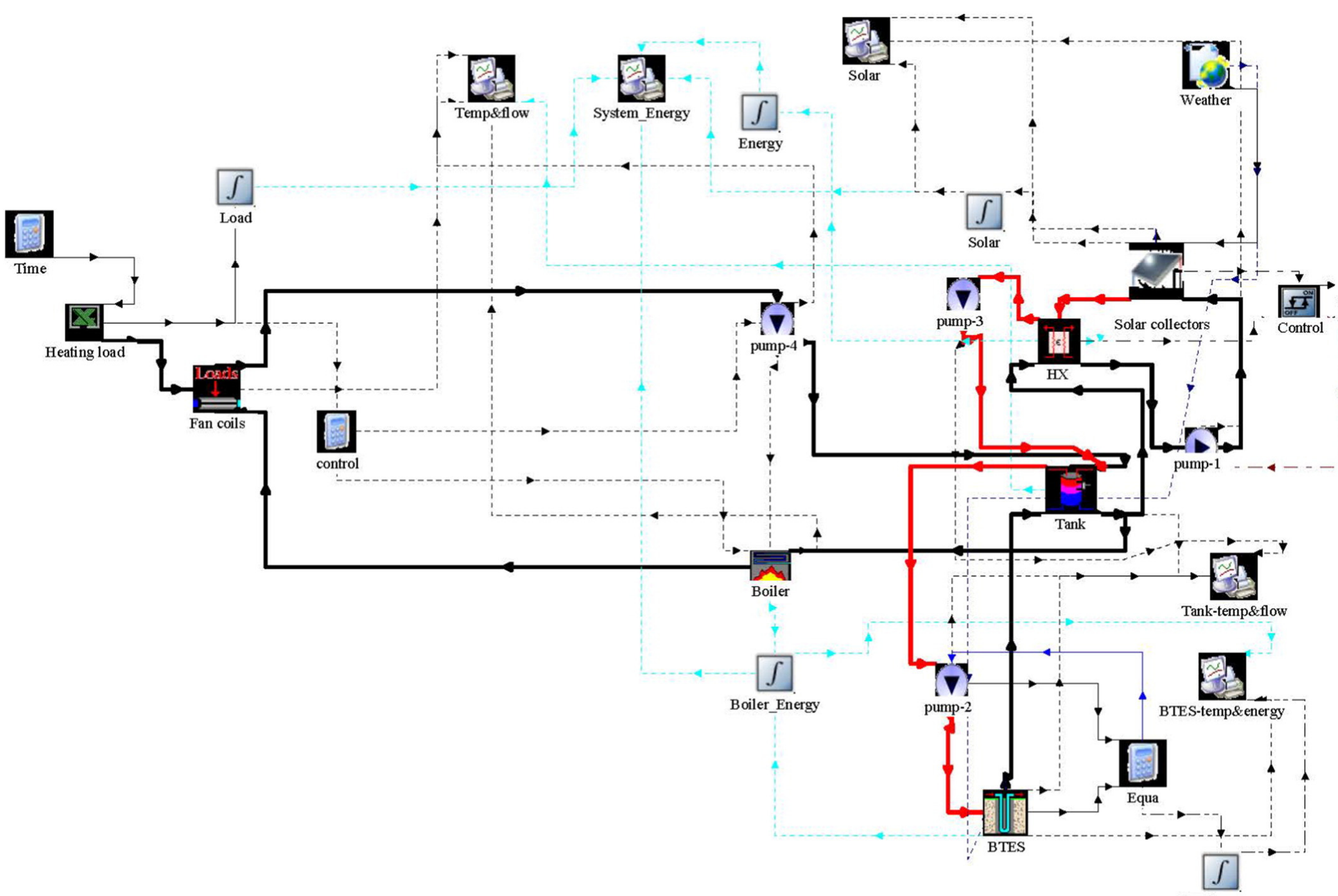

Fig. 4. TRNSYS model schematic.

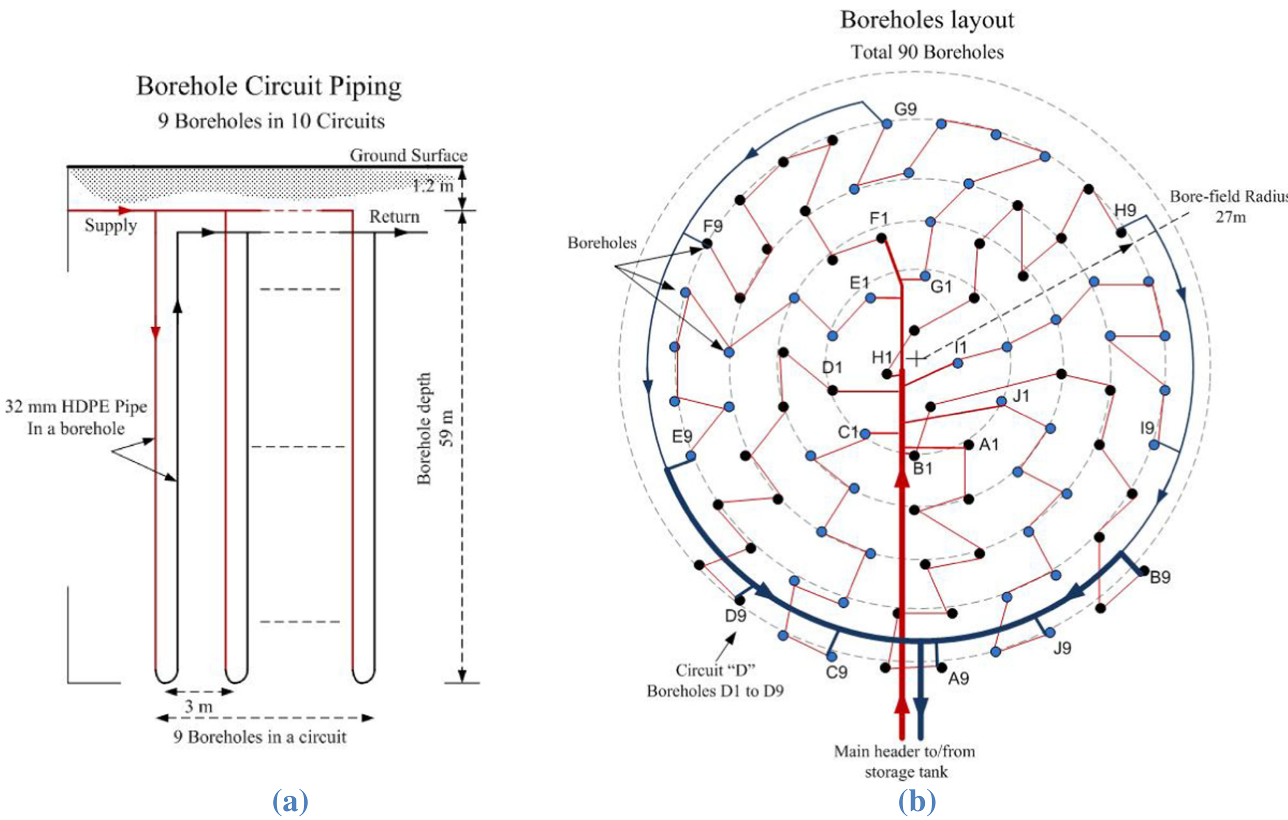

Fig. 5. (a) Borehole circuit piping schematic, (b) borehole field layout.

The performance of a BTES depends strongly on the moisture content and soil type (mineralogical composition). Alteration of soil moisture content from 12.5% of saturation to complete dryness increased the BTES performance and any reduction of soil moisture within this range has a positive effect on the BTES efficiency. A light dry soil can deliver the highest storage efficiency because of the small storage losses through the BTES. However, the same soil also significantly limits the ability of the BTES to receive and deliver heat effectively (Leong et al., 1998).

2- Provides flexibility in the design of the borehole layout by considering the heat and moisture interactions between the boreholes.
   The TRNSYS default BTES model (DST) has the limitation on the borehole layout design. In this model boreholes need to have same separation distances which restricts the optimum use of available real estate for the bore field.
3- Accounts for soil freezing–thawing and drying–rewetting due to heat extraction and heat deposition.
4- Can consider the presence of a ground water table.

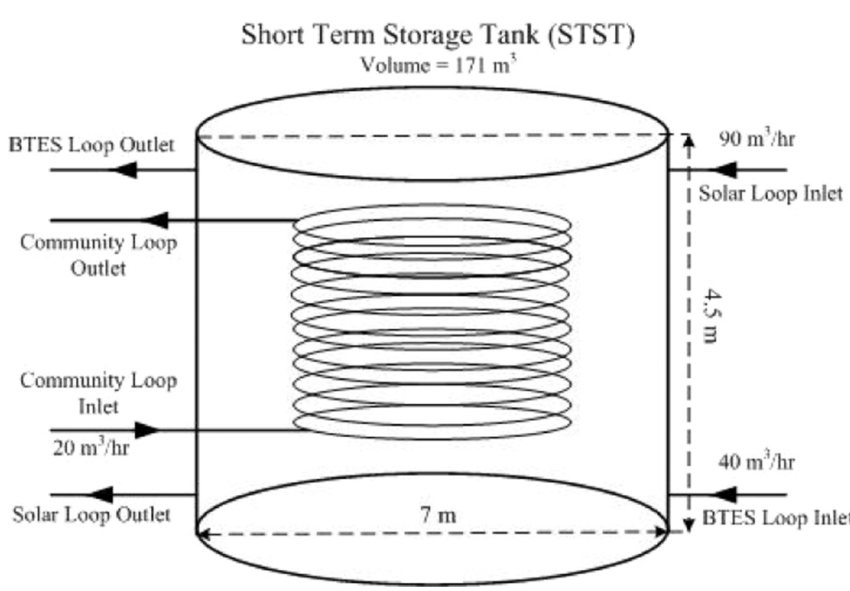

Fig. 6. Simplified schematic of short term storage tank.

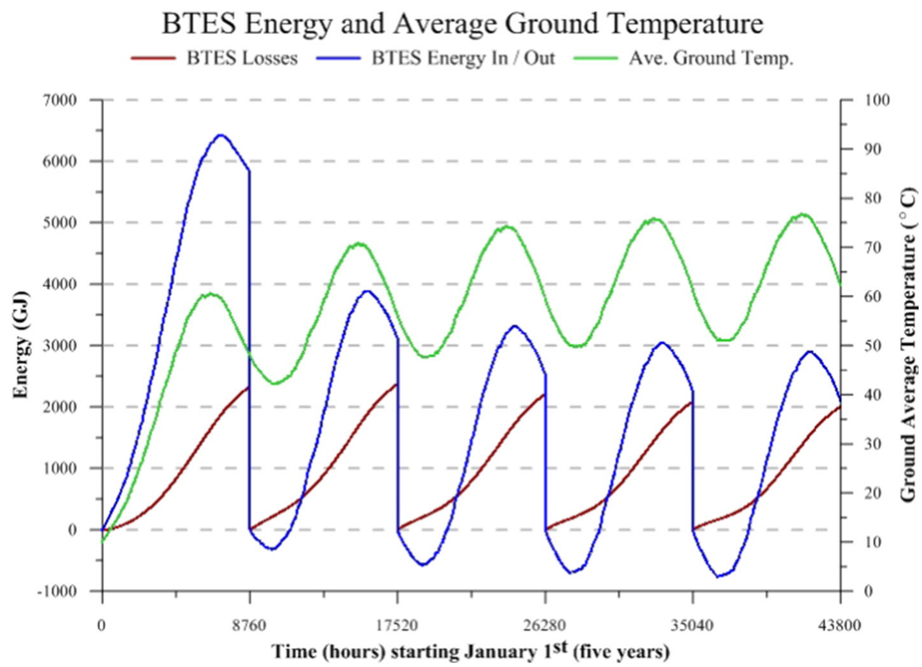

Fig. 7. BTES system accumulated energy and average temperature.

5- Accounts for dynamic ground surface effects (radiation, convection, advection, evapotranspiration, snow cover, etc.)

GHEADS model requires comprehensive weather data that is not found in the existing TRNSYS weather data files. As a result, weather from Environment Canada was used to supplement existing TRNSYS weather data.

Short term storage tank (STST)

The STST is a stratified liquid storage tank. In addition to the stratified tank with multiple inlet and outlet, which is used in the DLSC's model, a more advanced tank type is selected. The new tank model allows for a heat exchanger within the reservoir and also allows unmatched inlet and outlet flows. The model type used in TRNSYS (Type 60) is a vertical tank with two inlet and two outlet streams and an internal heat exchanger. By introducing an internal heat exchanger, the glycol–water community loop of the tank is not mixed with the tank's water.

The overall heat exchanger heat-transfer coefficient of the heat exchanger is determined iteratively. The outside natural convection coefficient of the internal heat exchanger (h_0) is determined from:

$$h_0 = \frac{NuD \times k}{D}, \text{where } NuD = CRa^n \tag{2}$$

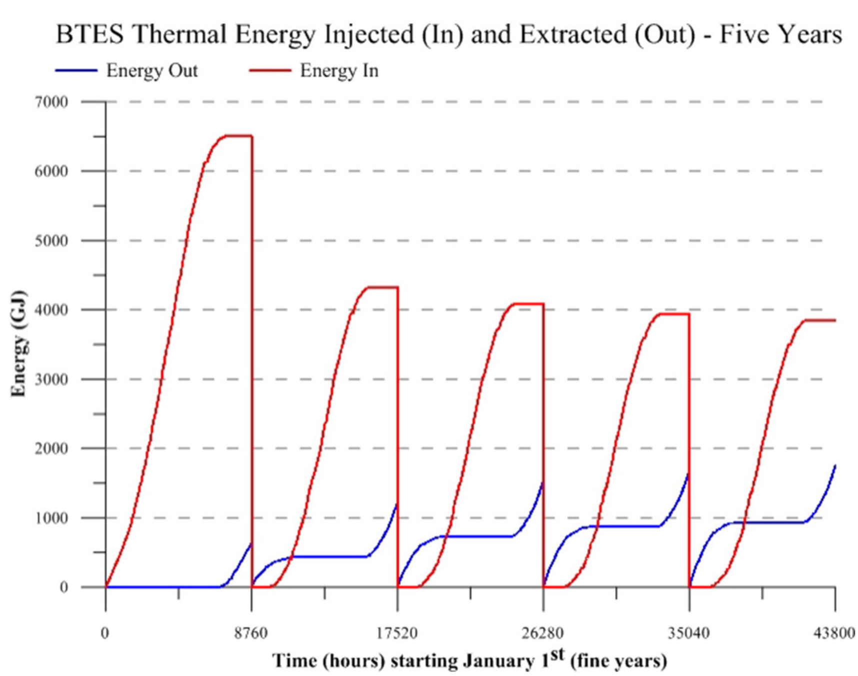

Fig. 8. Annual accumulated thermal energy injected into and extracted from the BTES.

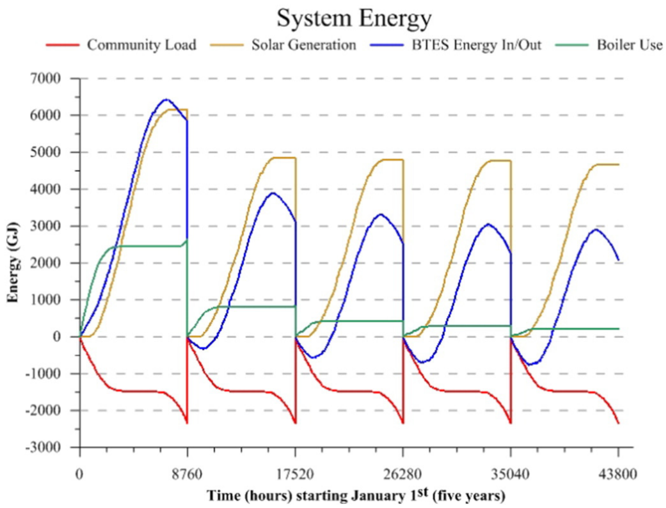

Fig. 9. Five-year annual accumulated system energy.

C is constant in Nusselt number correlation, *Ra* is Rayleigh number, *n* is exponent in Nusselt number correlation, *k* is the tank fluid thermal conductivity, and *D* is the outside diameter of the heat exchanger tube. Based on the geometry selected for the heat exchanger, the value for *C* and *n* are 0.5 and 0.25 respectively (Klein et al., 2010). Due to the relatively small size of internal heat exchanger, compared with the tank volume, the relatively low average velocity of the water in the tank justifies the use of natural convection correlations in the analysis.

The internal convection heat-transfer coefficient of the heat exchanger pipe are calculated based on the pipe dimensions plus inside fluid flow rate, temperature, and thermal properties.

Fig. 6 shows a simple schematic of the STST. The selected STST volume is 171 m^3 with a height of 4.5 m. The two inlets and outlets of the tank are connected to the solar and BTES loops respectively. The maximum flow rates to the reservoir from the solar, BTES and community loops are 90 m^3/h, 40 m^3/h, and 20 m^3/h respectively.

For the community load loop, a 2.1 m high heat exchanger in the tank is selected. The pipe of the heat exchanger is made of copper with the outer diameter of 16 mm and thermal conductivity of 400 W/mK. The internal heat exchanger comprises of 40 parallel pipes with 20 m length each. The Reynolds number, corresponds to the internal flow and is calculated to be 15,800.

Heat exchangers and pumps

Variable flow pumps with dedicated controls are used for the three main hydronic loops, i.e., the solar, BTES and community loops. For transferring heat harvested from the solar collectors to the tank, a plate-and-frame heat exchanger is selected. The maximum flow rate of the solar loop heat exchanger on the load (tank) side is 90 m^3/h selected based on the tank output flow rate required to meet the community load. The maximum flow rate of the source (solar collectors) side is 60 m^3/h calculated as per the flow rates required by the solar collector system based on the manufacturer's recommended flow rates.

Backup boiler and climate data

The supplemental heat source selected for the community is a 500 kW natural gas boiler. The boiler is mostly in operation for the first few years of system operation, before the BTES becomes fully charged and will be redundant then after. The boiler set-point temperature is 41 °C.

The community thermal load and solar heat are calculated based on the Canadian Weather Year for Energy Calculation (CWEC) hourly data for the City of Calgary, 46 km north of Okotoks. The BTES model, mentioned in Section Borehole thermal storage (BTES) system, uses extended weather data with climate parameters such as ground surface albedo, snow cover depth, snow depth density and rainfall (Rad et al., 2014). These parameters are extracted from Environment Canada and defined in an additional weather data file. The Supplementary weather data was used as a separate input file for the BTES model.

System simulation results

BTES performance

Fig. 7 demonstrates the five-year simulation results for the BTES system. It shows the annual BTES energy losses plus energy injected to and extracted from the ground, which is renewed each year starting January 1st. The average ground temperature (AGT) at the beginning of year one

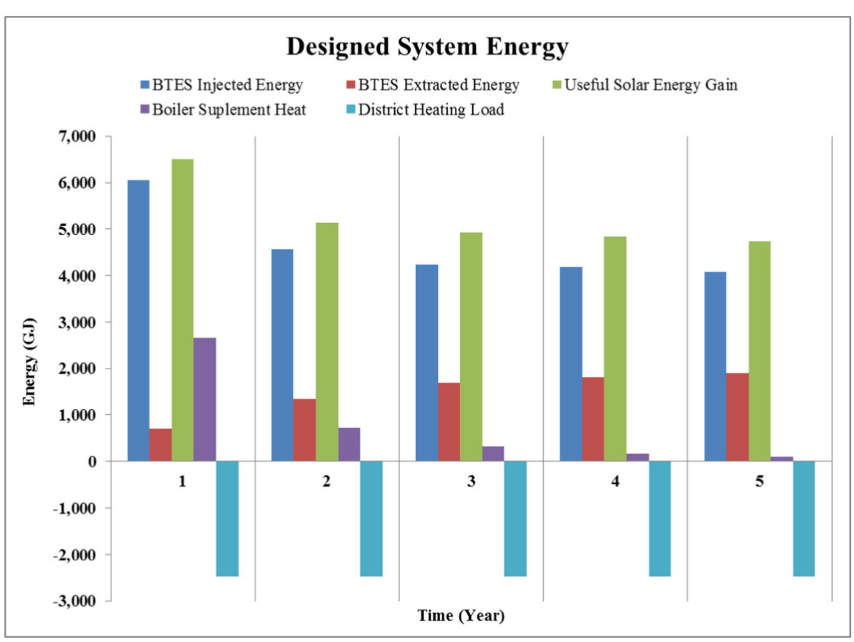

Fig. 10. Annual system energy.

Table 1
Year one and year two simulation summary.

	Year 1		Year 2	
	DLSC	Proposed	DLSC	Proposed
Community thermal demand (GJ)	−2530	−2349	−2530	−2349
Solar energy gain (GJ)	4480	6511	3830	5133
Boiler supplement heat (GJ) (eff = 0.85)	860	2655	600	729
Solar energy into the BTES (GJ)	3030	6044	2390	4563
Solar energy extracted from the BTES (GJ)	273	705	550	1339
BTES losses (GJ)	NA[a]	2538	NA[a]	2478
BTES average temperature (°C) at year end	40	49.0	41.4	57.0
BTES efficiency	9%	12%	23%	29%
Solar fraction (SF)	66%	0%	76%	69%

[a] Not available.

is 10 °C, which is the initial ground temperature. After two years, the average ground temperatures start exhibiting almost the same annual fluctuations for subsequent years. From year three, at the beginning of January, the AGT is 57 °C. Moving forward a year, as heat is extracted from the ground, the AGT drops to the minimum 50 °C until around the end of March. Then the AGT starts to rise and reaches a maximum temperature of 76 °C around mid-October.

Fig. 8 also shows the accumulated energy injected to and extracted from the BTES. During heat extraction from the ground, the stored energy starts to decrease until the system reaches the point where it does not require the heat from the ground, and the solar heat is injected into the ground. The heat extraction period is from mid-October to the end of March. The solar heat injection is mainly from the rest of the year, i.e., the beginning of April to the middle of October, which includes the entire summer and the shoulder seasons.

During the first year of operation, the ground is mainly becoming charged via heat from the boiler and solar energy injection. In the fifth year, the total annual solar heat injection to the ground is calculated to be around 4000 GJ. Of this, 1800 GJ is extracted during the heating season. The difference is due to the BTES heat losses; the BTES overall thermal efficiency is calculated to be 46%.

System energy and performance

Figs. 9 and 10 show the system annual accumulated energy in five years. The curves represent 1) community heating load, 2) BTES energy injection and extraction, 3) solar thermal collectors' energy generation, and 4) boiler auxiliary heat.

In year five, 4700 GJ of energy is generated from the solar panels, and about 4000 GJ of that amount is directed into the ground to the seasonal storage. As can be observed, the total annual community thermal load of 2350 GJ is mostly met by the solar thermal collectors via BTES. In this year, the heat supplied by the auxiliary boiler is only 103 GJ. The solar fraction (SF) of the community at the end of year five is 96%. In other words, almost all the space heating demands by the proposed community are met by the solar thermal system with BTES.

Table 3
System specification summary.

System specifications			
		DLSC	Designed
Number of boreholes		144	90
Borehole depth	m	37	59
Borehole spacing	m	3	3
BTES volume	m^3	34,133	34,017
Total borehole length	m	5328	5310
Number of solar panels		800	600
Total solar panel area	m^2	2293	1722
Short term storage tank	m^3	240	171

Results validation and comparison

The annual simulation results, for five years, are tabulated in Table 1 and Table 2. For comparison of the results, published DLSC calculated performance parameters are also included in the two tables (SAIC Canada, Science Applications International Corporation, 2012). The proposed system specifications versus the DLSC system are shown in Table 3. The proposed system's results, compared to the DLSC's calculated results, shows that with both systems having an almost same community heating load, the proposed configuration performs better. In year five, one important observation is the ratio of the useful solar energy gain that goes to the BTES. This ratio in the DLSC is 60% whereas for the proposed system it is 85%. Therefore in the proposed system more heat is injected into the ground. In the same year, the average ground temperature (AGT) in the proposed system is 64 °C and in DLSC is 55.6 °C. In the proposed system, in year one as the ground is not charged, the inlet fluid temperatures to the solar collectors are lower compared to the later years. Therefore, more solar energy is collected due to the higher fluid temperature differences between solar collectors' inlet and outlet flow (i.e., 4926 GJ in the year one versus 4087 GJ).

Fig. 11 compares the solar fractions (SFs) of the DLSC and the proposed system for five years. It is seen that, after three years, the SFs of the proposed system are higher than for the DLSC.

System cost comparisons

By using the same cost index which was used for the DLSC in 2005–2006 (Hellstrom and Sanner, 1997), the initial cost of the proposed system is estimated to be $1.9 million, which is 19% less from the initial cost of the DLSC. Based on the natural gas price of $6.17 per GJ (Enbridge Gas, Enbridge Gas Distribution Inc., Ontario, Canada, 2016), the simple payback for the proposed systems is approximately 38 years.

Table 4 shows the costing for the main system components and provides comparisons. Other than the initial cost, by eliminating 25% of solar thermal collector area and 38% of the borehole footprint area,

Table 2
Year three to year five simulation summary.

	Year 3		Year 4		Year 5	
	DLSC	Proposed	DLSC	Proposed	DLSC	Proposed
Community thermal demand (GJ)	−2530	−2349	−2530	−2349	−2530	−2349
Solar energy gain (GJ)	3630	4926	3550	4843	3520	4746
Boiler supplement heat (GJ) (eff = 0.85)	390	327	300	171	290	103
Solar energy into the BTES (GJ)	2200	4239	2110	4185	2080	4087
Solar energy extracted from the BTES (GJ)	770	1692	844	1818	853	1892
BTES losses (GJ)	NA[a]	2268	NA[a]	2172	NA[a]	2089
BTES E (°C) at year end	44.3	60.0	51.9	62.0	55.6	64.0
BTES efficiency	35%	40%	40%	43%	41%	46%
Solar fraction (SF)	85%	86%	88%	93%	89%	96%

[a] Not Available.

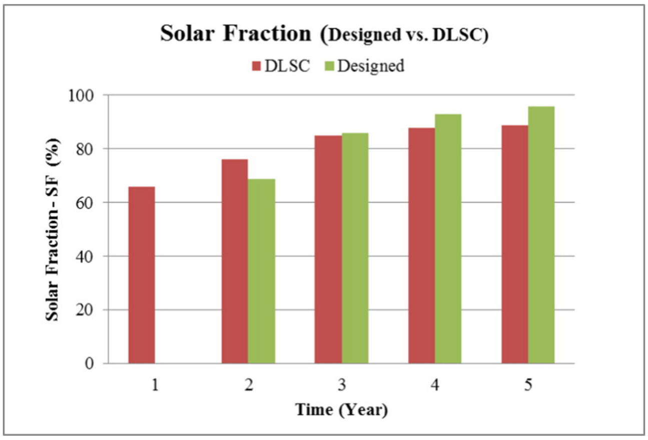

Fig. 11. Solar fraction comparison, DLSC vs. proposed system.

more flexibility in layout planning is available. With possibly more unoccupied roof area with high solar radiation levels, solar PV collectors could be installed for offsetting the system electrical demand, i.e., pumps, controls and air handlers.

Conclusion

An integrated model for heating a solar community similar to the DLSC with 52 homes is designed and simulated. It is shown that by using almost the same system configuration as in DLSC and an advanced integrated simulation model, a smaller system with the same or better performance can be designed, which ultimately leads to a less expensive system.

The main improvements in the proposed system compared to the DLSC system are summarized as follows:

1) Efficient BTES design with less heat losses, using GHEADS, an advanced simulation tool. GHEADS, with more capability, compare to the TRNSYS default component, provide more cost effective design. The new design achieves a 38% reduction of the BTES footprint and the number of boreholes.
2) By selecting a more detailed STST module with an internal heat exchanger for the community loop, in contrast to the simple stratified tank, the STST efficiency and the size requirement compared to the DLSC was reduced. A new STST combined with the BTES designs leads reductions in total solar panel area and STST volumetric size of 25% and 29% respectively.
3) Active hourly integration of the thermal loads with all of the system components for five year simulation period. The optimum hourly interactions of the community thermal load with all system equipment and controls eliminate the unnecessary full-capacity operation in the sub-systems, i.e., BTES, solar and community loops. The proposed system showed better results comparing to the five year actual operation of the DLSC. During the five year DLSC operation, both model, and physical system gone through the changes and modifications to improve the system performance.
4) Lower initial system cost. The new system requires approximately 19% less capital cost to build. In addition to the initial cost, the reduced footprints and real estate requirements are significant added benefits.

Table 4
Comparison of costs for the DLSC and proposed systems.

System initial costing (incremental)			
DLSC cost index		DLSC	Designed
Number of boreholes		144	90
Borehole depth		37	59
Number of solar panels		800	600
Cost of BTES	116 ($/m)	$618,048	$615,960
Cost of solar panels	497 ($/m^2)	$1,139,621	$855,834
Short term storage tank Including the energy center	2500 ($/m^3)	$600,000	$427,500
Total initial cost		$2,357,669	$1,899,294
Initial cost saving		Base	19%
BTES land area saving		Base	38%
Solar area saving		Base	25%

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