DEVELOPING A DETAILED MODEL OF A LARGE SCALE SOLAR COMMUNITY WITH AND WITHOUT HEAT PUMPS

Samuel Letellier-Duchesne[1], Michaël Kummert[1]
[1]École Polytechnique de Montréal, Canada

ABSTRACT

The temperature level in seasonal thermal energy storage for solar communities can reach 60 °C to 80 °C if direct heating is to be provided to the buildings and a high solar fraction is desired. This is for example the case at the Drake Landing Solar Community (DLSC) in Okotoks, Alberta, Canada, which has successfully reached a solar fraction above 95 % after a few years of operation.

On the other hand, system designs relying on heat pumps to upgrade the temperature level of the heat provided to buildings can use much lower temperature levels in the seasonal thermal storage, even below ambient temperature (or the undisturbed ground temperature in the case of borehole thermal energy storage).

Between these two extremes, several designs are possible and the optimal choice will depend on the load (space heating only or space heating and domestic hot water), system design (type of auxiliary heating), design targets (solar fraction, energy or CO2 emissions savings), and economics. The system location has a significant impact on the climate-related design parameters, and it also affects other constraints such as the cost and CO2 content of auxiliary energy sources.

This paper investigates the energy, environmental (CO2 emissions) and economic performance (capital and life-cycle costs) of different system designs with and without heat pumps for future solar communities across Canada. The performance is assessed using detailed system simulations based on an initial model that was validated using the DLSC measured data. The most promising designs are identified for different contexts and presented in the paper.

INTRODUCTION

Solar communities with seasonal thermal storage use the power of the sun to heat up a fluid, store it underground during the summer, and then use the stored energy for heating during the winter. The Drake Landing Solar Community (DLSC) is an example of successful application of this technology (www.dlsc.ca). Its 2293 m² of solar thermal collectors installed on the roofs of garages collect enough heat to meet more than 90% of the space heating load of the 52 houses in the community. This high solar fraction has been reached thanks to a careful system design that relies on two forms of thermal storage: a Short-Term Thermal Storage (STTS), which consists of large water tanks, receives heat from the solar collector and dispatches it either to the long-term Borehole Thermal Energy Storage (BTES) or to the district heating loop. One characteristic of the selected design is that it relies on a relatively low water supply temperature, between 37 °C and 55 °C depending on the ambient temperature. This low operating temperature minimizes the thermal losses in all system components (STTS, BTES, and piping), and was only achievable thanks to custom-designed air handling units capable of providing space heating with such a low supply temperature.

A first challenge that must be tackled when designing the next generation of solar communities building on the success of DLSC is to address much larger communities. The challenges and opportunities of scaling up designs to the order of 1000 housing units are assessed in details in a recent study commissioned by Natural Resources Canada (SAIC, 2012). The study shows that significant cost savings can be achieved by scaling up from 52 houses to 1000 houses. The annual BTES efficiency improves with size, as the surface area to volume ratio decreases, and economies of scale lead to a reduction in installed cost for the larger cost elements: solar collector, BTES and STTS. Overall, the authors estimate a cost reduction in the order of 53 %, to reach a capital cost of 960 $ per GJ delivered annually. They also conclude that the Internal Rate of Return (IRR) obtained from such an investment would be attractive for utilities to invest in if the heat can be sold at a rate of 20 $/GJ (0.07 $/kWh) or higher.

A second challenge in replicating solar thermal community projects is to adapt the system design to different local contexts: climate parameters are significantly different across Canada, and the very successful DLSC community was located in the area that offers the best solar resource and high space heating loads. The energy and environmental context also vary across Canada: In Alberta, where the DLSC community is located, electricity is mostly produced from coal-burning plants, and can be up to 6 times as expensive as natural gas. In Québec, on the other hand, over 95 % of electricity is produced from hydro power plants, and the cost ratio between electricity and gas is much closer to one. These differences have an impact on optimal designs. Krebs et al. (2012) have for example assessed the potential of using decentralized heat pumps with a central solar thermal plant, in order to reduce the operating temperature of the district heating system. Their study shows that decentralized heat pumps have the potential to reduce the Life-Cycle Cost (LCC) in a community similar to DLSC. The LCC savings strongly depend on the solar fraction target, with reduced or canceled savings for higher solar fractions.

A third challenge for future solar communities is to address all thermal needs at the community level. The share of space heating in the current Canadian building stock is about 63% (NRCan-OEE, 2013), and it has been decreasing from 67 % in 1990. On the other hand, the share of Domestic Hot Water (DHW) is about 20 % and has been increasing from 16 % in 1990. As shown below, the share of DHW is above 35 % for the energy-efficient houses considered in this study. It is therefore necessary to consider DHW loads when assessing the performance of centralized thermal energy systems for future communities. But providing DHW at 55 °C or above implies district heating temperatures above that level at all times, which has a significant impact on storage and distribution thermal losses.

OBJECTIVES

This study is an extension of the DLSC project and looks to find the impact of different large-scale designs on system costs, solar fractions and CO_2 emissions. In addition, geographical considerations are explored. Therefore, two locations in Canada, Montreal and Calgary, have been chosen for their rigorous climate and extensive solar radiation yet for their very different primary energy source economics and environmental impacts. This study not only explores the economic portion but also takes on the CO_2 emissions.

Since domestic hot water energy consumption plays a big part (35%) in the total energy consumption of a typical household, this study explores the impact of providing such hot water at the community level. Two approaches are explored: the first is to extract heat directly from the district loop, which implies that the temperature must stay at a steady high temperature (65 °C) all year round. The second approach examines the use of a Heat Pump Water Heater (HPWH) installed in the homes and extracting heat from the room. Decentralized water-to-air Heat Pumps meet the heating loads.

Since water-to-air heat pumps can work well with a lower temperature fluid, it is believed economies can be achieved by lowering the temperature of the district loop. Furthermore, economies of scale can be achieved by increasing the size of the solar community.

METHODOLOGY

Heating loads and DHW loads are calculated using detailed models of selected house archetypes for two locations: Montreal, QC, and Calgary, AB. The "House Archetypes" section below provides more details on the building models.

The calculated building loads are then used in a TRNSYS model of the solar thermal central plant (solar collectors, STTS, BTES) an the district heating system. Some details are provided in the "TRNSYS models" section below.

A parametric study is performed with the TRNSYS model to assess different system sizing options. The **marginal capital cost** is used as an economic performance indicator to rank different designs. The marginal cost is the additional (capital) cost of providing solar heat instead of conventional heating (Supposedly natural gas).

A more detailed economic analysis is performed on selected system configurations for the two locations. In that study, the Levelized Life-Cycle Cost is used as an indicator of economic performance. The LLCC is the Life Cycle Cost or Revenues over the total energy supplied to the homes.

HOUSE ARCHETYPES

For the simulation of home heating loads, the energy-efficient residential housing archetype models developed by Delisle (2015) are used. The building envelope is adjusted for each location to achieve a level of energy efficiency close to 86 on the EnerGuide Rating System (ERS-86) (NRCan-OEE, 2005). Two archetypes of the 6 developed by Delisle (2015) are selected in the present study:

1. Medium bungalow, slab-on-grade, one-car garage, 177 m^2 (1900 ft^2) of heated floor area
2. Large two-storey home with basement, two-car garage, 242 m^2 (2600 ft^2) of heated floor area

Each house is modelled for the selected Canadian locations: Montreal (QC) and Calgary (AB).

Design choices resulted from the target ERS and from design rules for passive designs.

Houses are rectangular with an aspect ratio (length vs. width) of 1.3, and all homes are assumed to be South-facing.

The building envelope represents cost-optimal solutions adapted to the selected energy performance target. They are presented in Table 1 (MTL is for Montréal, CAL for Calgary).

Table 1
Optimal or near-optimal solutions set to achieve ERS-86 in the selected locations for this study

	MTL	CAL
Above-grade walls R-value [m².K/W]	6.5	9.2
Below-grade walls R-value [m².K/W]	3.5	3.5
Ceiling (roof) R-value [m².K/W]	10.6	14.1
Exposed floor R-value [m².K/W]	5.5	5.5

Slab perimeter insulation R [m².K/W]	2.1	2.1
Windows overall U-value [W/m²-K]	1.08	1.65
Windows SHGC [-]	0.44	0.51
Air tightness [ACH @ 50 Pa]	0.6	0.6

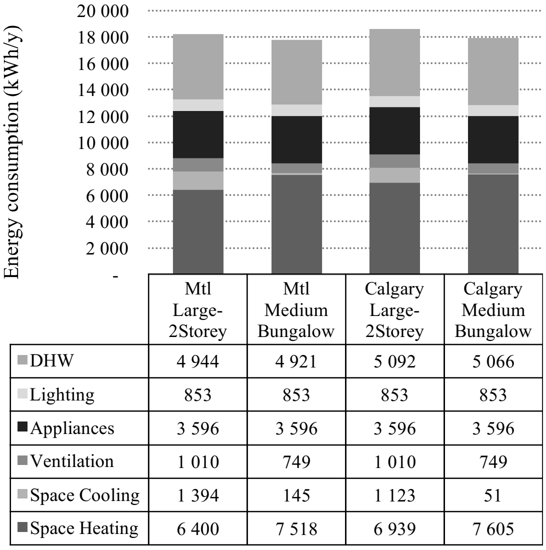
The archetype homes have an overall window-to-wall area ratio ranging between 17% and 22% as recommended by Canada's National Energy Code for Buildings (NECB) (NRC-IRC, 2011). A passive solar design is achieved with a fenestration area between 7% to 12% of the floor area on the south-facing façade.

Finally, overhangs on the south, east and west facing façades are designed to provide total shading on June 21st and no shading on December 21st.

The Sherman-Grimsud (1980) model is used to model the infiltration using the air tightness indicated in Table 1. The R-2000 standard for ventilation requirement is used to determine the required ventilation rates. They are a function of the house volume and are estimated at 37 L/s for the medium bungalow and 50 L/s for the large 2-storey home. The ventilation is assumed to be on at all times and is supplied by a fan with a power of 2.32 W/(L.s) The heat recovery system ventilator has an efficiency of 60 % at 0 °C and 55 % at -25 °C.

The lighting and appliances energy requirements are set at 2.34 kWh/d and 1450 kWh/y, respectively. Both the medium bungalow and large 2-storey homes are assumed to have 4 occupants doing light work. The domestic hot water (DHW) consumption is set at 225 L/day at 55 °C for both homes. The hourly lighting, appliances, occupancy and DHW draw profiles are all calculated using the NECB schedule "G" recommended for each specific load.

Annual Energy consumption



	Mtl Large-2Storey	Mtl Medium Bungalow	Calgary Large-2Storey	Calgary Medium Bungalow
■ DHW	4 944	4 921	5 092	5 066
■ Lighting	853	853	853	853
■ Appliances	3 596	3 596	3 596	3 596
■ Ventilation	1 010	749	1 010	749
■ Space Cooling	1 394	145	1 123	51
■ Space Heating	6 400	7 518	6 939	7 605

Figure 1: Energy consumption by end-use for the two archetypes in Montreal and Calgary

The annual energy consumption is obtained by simulating the archetypes in TRNSYS for a typical year using the Canadian Weather Energy Calculations (CWEC) weather data files for Montreal and Calgary. Figure 1 presents a summary of the energy consumption by end-use for both archetypes and cities.

SYSTEM CONFIGURATIONS

Two (2) system configurations are presented.

No HP

The first one, identified as "no HP", serves as a base model and represents a solar community providing space heating as well as DHW using only the district loop. Figure 6 provides more detail on this configuration.

With HP

The second model uses decentralized heat pumps for space heating as well as heat pump water heaters for DHW. Figure 7 provides more detail on this configuration.

TRNSYS MODELS

The model used in this study is a modified version of the Drake Landing TRNSYS model. The size of the community has been scaled up to 1000 homes, equivalent to a large suburban community. Space heating and DHW loads were calculated for the two archetypes and simply multiplied by 500.

Heat pumps

When included in the system configuration, water to air heat pumps providing space heating are modeled as a simple linear equation (1) that is representative of typical 3-ton (10.5 kW) heat pumps. (Bernier, Kummert, & Bertagnolio, 2007)

$$COP_{heating} = 3.49 + (T_{HP,in} \times 0.061) \qquad (1)$$

Where $COP_{heating}$ is the heat pump coefficient of performance and $T_{HP,in}$ is the water inlet temperature. Maximum heating loads are 9,21 kW for Montreal and 9.55 kW for Calgary.

District loop set point

When no heat pumps are present in the system configuration, the district loop must be capable of heating up the DHW to 55 °C, so the set point is set to a constant value of 65 °C.

With water-to-air heat pumps for space heating, the setpoint is varied linearly with the ambient temperature as shown in Figure 2. The figure shows that the district loop set point increases with the ambient temperature. This is opposite to the conventional adjustment of water supply temperature in heating systems, but it was shown by Krebs et al. (2014) to deliver a better performance for central solar systems with decentralized heat pumps. The selected variation takes full advantage of the heat pumps in very cold ambient temperatures (which correspond to winter time, when solar radiation is low), instead of relying more on stored solar heat or central auxiliary heat. This behaviour also reduces heat losses in the underground distribution pipes.

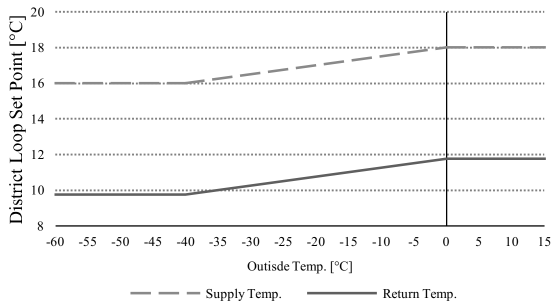


Figure 2
District Loop Set points

Solar Panels

Solar panels are modelled using performance parameters that represent high-efficiency solar collectors (Gluatmugl HT, SOLID, 2011). The cost data for solar collectors indicated in (SAIC, 2012) covers a large range and depends on different factors, including the expected discount obtained for such a large project. Within the same category of solar collectors (i.e. glazed collectors with selective surface), there is no indication that higher performance collectors would cost more than collectors offering a slightly lower efficiency. It was therefore decided to use high-efficiency collectors to obtain an upper bound of the solar thermal subsystem performance. Different classes of solar thermal collectors (e.g. unglazed collectors, possibly made of plastic) would result in very different performance parameters and different cost. This will be investigated in the future.

Heat Pump Water Heater

The Heat Pump Water Heater (HPWH) model uses a performance-map approach for the heat pump and separate TRNSYS components for other parts of the system (storage tank, auxiliary heater and controls). The TRNSYS component used to model the heat pump performance, known as Type 994, is presented in (Maguire, 2012). It relies on a performance map obtained from empirical data (Hudon et al., 2012). The performance parameters (air-side sensible and latent cooling, water-side heating, compressor and fan power) are related to the tank water temperature and to the inlet air wet bulb temperature.

The modeled unit has a rated heat output of 1.28 kW and a rated COP of 2.66, with 50 °C water and 14.1 °C inlet wet bulb temperature (e.g. corresponding to 21 °C dry bulb and 47 % relative humidity). Heat is rejected by a wrap-around condenser located around the bottom part of the tank. The HPWH is assumed to be set to maximize the heat pump operation. An auxiliary electric resistance heater (4.5 kW) located in the top part of the tank is only activated when the heat pump cannot maintain the setpoint.

The water heater used in the system configuration without heat pumps uses the same storage tank and assumes the same stand-by losses, but the heat is provided by the district heating loop.

RESULTS

No HP

For the “no HP” configuration, a parametric study provided results for 48 configurations. Three (3) parameters are tested: 1 – number of collectors, 2 – number of boreholes and 3 – volume of STTS. The range of the parameters is defined as such: (1) The number of collectors between 6 000 and 8 000, (2) the number of (100-meter deep) boreholes between 240 and 600, and (3) the STTS volume between 1 250 and 5 000 m^3.

For **Montreal**, the optimal solar BTES is defined as the design that would produce the lowest marginal cost while achieving a solar fraction around 60% (61 %).

The lowest marginal cost per energy delivered is 530 $/GJ for the system design with 8 000 collectors, 360 boreholes and 2 500 m^3 STTS tanks. The total project capital cost corresponding to the optimal design is 26.1 M$.

For **Calgary**, the optimal solar BTES is defined as the design that would produce the lowest marginal cost while achieving a solar fraction around 60% (59%).

The lowest marginal cost per energy delivered is 424 $/GJ for the system design 6000 collectors, 360 boreholes and 1250 m^3 STTS tanks. The total project capital cost corresponding to the optimal design is 14.5 M$.

With HP

For the “with HP” configuration, 48 cases are prepared with the number of collectors varying from 3 000 to 5 000, the number of (50-meter deep) boreholes from 240 to 600 and the STTS volume between 500 and 2000 m^3.

For **Montreal**, the optimal solar BTES is defined as the design that would produce the lowest marginal cost while achieving a solar fraction around 70% (72%).

The lowest marginal cost per energy delivered is 365 $/GJ for the system design 4000 collectors, 600 boreholes and 1000 m^3 STTS tanks. The total project capital cost corresponding to the optimal design is 13.5 M$.

For **Calgary**, the optimal solar BTES is defined as the design that would produce the lowest marginal cost while achieving a solar fraction of around 70% (73%).

The lowest marginal cost per energy delivered is 358 $/GJ for the system design 4000 collectors, 480 boreholes and 500 m^3 STTS tanks. The total project capital cost corresponding to the optimal design is 14 M$.

Results from the parametric study for the “with HP” configuration is shown in Figure 3 below. As expected, the Marginal cost increases when total energy is reduced. This is well represented for Calgary, but the Montreal data shows a less clear pattern. This could be explained by the lower solar radiation in Montreal for which larger equipment is necessary to provide the same amount of solar energy.

Figure 4 presents results using different metrics: annual energy cost, annual end-use energy and annual tons of CO_2 eq., Comparison shows that the cost of using heat pumps in Calgary can be higher and its impact on the environment more important. This is in part due to the high electricity prices and their primary source greenhouse effect.

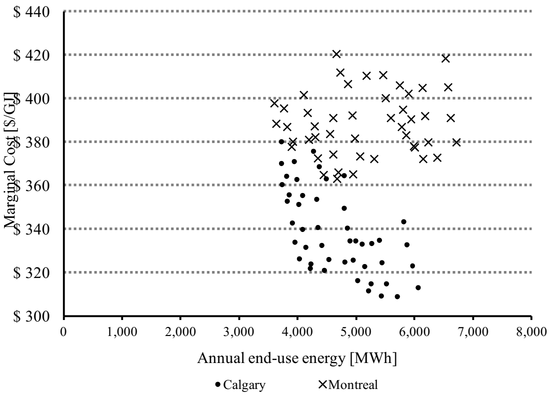


Figure 3
"With HP" parametric simulation results: Marginal cost as a function of the total required energy

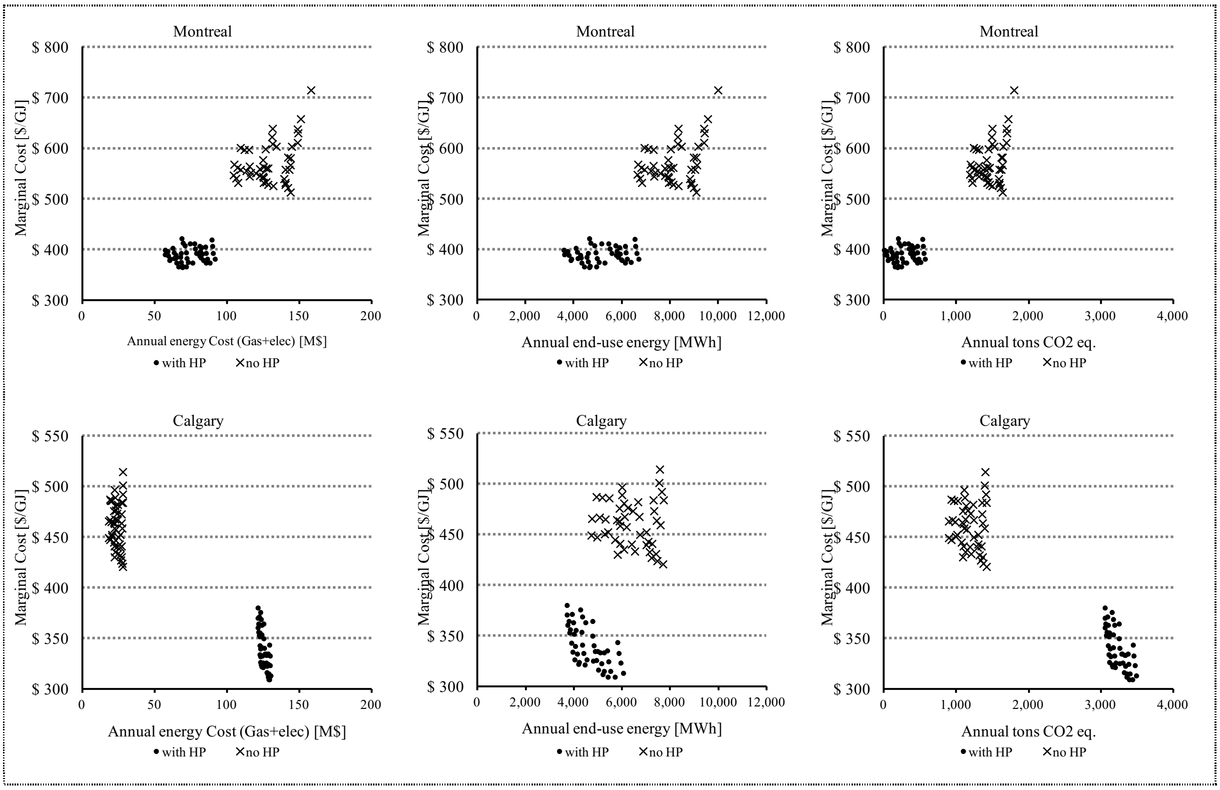


Figure 4 a,b,c,d,e,f
Results from parametric simulations – Comparison between "no HP" and "with HP" configurations

ECONOMIC ANALYSIS

Life Cycle Cost (LCC) and Levelized Life Cycle Cost (LLCC) are calculated using a detailed economic business scenario. The goal of the business case is to identify the sensitivity of the solar community's financial performance to the market value of gas and electricity for both regions over time.

Forecast data for energy prices is available for each province at the National Energy Board (National Energy Board, 2013). Since the data is available only through 2035, the prices are estimated using a simple inflation formula, adjusted for buy-prices and sell-prices.

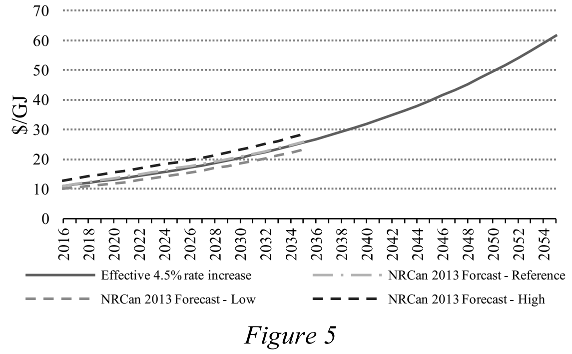


Figure 5
Example of annual increase of natural gas price – Data shown is for the province of Quebec

Business case scenario

The business scenario is based on a 40-year period including a 5-year build out period (time from start of project to final occupants). Consequently, the business scenario includes 35 years of operation. The simulations are run for 10 years and the 10th year of the simulation data is considered for years of operation 11 through 35. The following table presents the used economic analysis parameters.

Table 2
Economic analysis parameters - Montreal

CELL NAME	VALUE MTL	VALUE CAL	UNITS	DESCRIPTION
USD	1	1	$/$	Ratio of Canadian to US dollar
NG	11.080 $	$3.540	$/GJ	Price of natural gas, in first year of operation
ELBuy	15.880 $	$32.620	$/GJ	Price of purchased electricity, in first year of operation
ELSell	20.960 $	$39.630	$/GJ	Price of sold electricity, in first year of operation
HEAT	15.000 $	$15.000	$/GJ	Price that heat from system is sold at, in first year of operation
HEAT fix	3.000 $	$3.000	$/GJ	Fee charged to tenants related to avoid cost of in-building heating plant, amortized over GJ heat used
INT	7%	7%	%/yr.	Annual interest paid on loan
TERM	20	20	yrs.	Term of all loans
YEARS	40	40	yrs.	Period for life cycle cost analysis and NPV calculation
BLDper	5	5	yrs.	Build out period - number of years from project start to final occupant
WDA	20%	20%	%/yr.	Writing down allowance
PWF	10.594	10.594	-	Present Worth factor
ETR	0%	0%	%/yr.	Effective tax rate
INFL	2.0%	2.0%	%/yr.	Annual general inflation rate (applied to O&M costs
DISC	7.0%	7.0%	%/yr.	Discount rate used in NPV calculation
NGinc	4.5%	4.5%	%/yr.	Annual rate of increase of natural gas price
ELbuyINC	2.0%	4.0%	%/yr.	Annual rate of increase of electricity purchase price
ELsellINC	2.3%	3.0%	%/yr.	Annual rate of increase of electricity sell price
HEATInc	6.0%	6.0%	%/yr.	Annual rate of increase of heat selling price
ELE GHI[1]	2.0	820.0	gCO2eq./kWh	Greenhouse impact of electricity generation in Quebec
NG GHI	181.2	181.2	gCO2eq./kWh	Greenhouse impact of 1 kWh of natural gas

[note 1]: Data from Environment Canada, 2015

The potential application of a solar community in either Alberta or Quebec is dependant of residential heat prices. The business case scenario shows that the IRR is very sensitive to the price of natural gas and to the annual rate of increase of the heat selling price.

For instance, the reduction of the HEATInc parameter by 1% reduces the Internal Rate of Return (IRR), which is a measure of the profitability of an investment, from 10.9% to 9.2%. Of all the parameters, the Heat selling price is the most sensitive. A 10% increase in the selling prices provides a 15% increase in the IRR. It also increases the LLCC from 143 to 183 $/GJ (+28%).

COMPARISON AND ANALYSIS

The simulation and business cases are compared and summarized in Table 3. Data is shown for the selected configuration detailed at the beginning of this section.

Table 3
Summary comparison of
Montreal and Calgary systems

PERFORMANCE INDICES	MTL no HP	CAL no HP	MTL with HP	CAL with HP
Marginal cost per energy delivered in one year ($/GJ)	530	424	365	321
BTES efficiency (%)	61	63	88	86
Project internal rate of return, IRR (%)	8.0	12.9	9.5	10
Levelized life cycle revenues ($/GJ)	+40	+206	+100	+118

As expected, the marginal cost is higher for Montreal in both cases since the available solar radiation is lower, increasing the size of equipment in order to achieve a similar solar fraction.

Furthermore, the efficiency of the BTES is greatly increased for "with HP" configurations. This was expected since losses are reduced by a much lower temperature set point.

VISUAL REPRESENTATION AND RESULTS

Results for optimal configurations are presented in the following table.

Table 4
Results supporting Figure 6 and Figure 7

Values in MWh	MTL no HP	MTL with HP	CAL no HP	CAL with HP
Coll. Area	30 800	15 400	30 800	15 400
Nb. Boreholes	360 (100m)	600 (50m)	360 (100m)	480 (50m)
Vol. STTS (m^3)	2500	1000	1250	1000
Pumping Power [MWh]	46	141	44	125
Solar Loop				
Collected Energy [MWh]	13 731	8 341	12 986	9 230
HX Transferred [MWh]	11 808	7 639	11 221	8 239
Solar Loop losses [MWh]	984	646	495	915
BTES				
Charged [MWh]	2 871	3 749	3 018	3 898
Discharged [MWh]	1 743	3 293	1 906	3 343
Losses [MWh]	1 128	456	1 112	556
District Loop				
HX Transferred [MWh]	9 629	6 997	9 538	7 465
Boiler [MWh]	6 108	744	6 688	635
District loop losses [MWh]	4 359	792	4 383	792
Homes				
DH Heat input [MWh]	11 372	6964 Elec: 1 990	11 833	7 313 Elec: 2 089
Space heating [MWh]	7 059	8 954	7 302	9 402
DHW [MWh]	4 313	Elec: 1 494	4 451	Elec: 1 548
DHW losses [MWh]	282	282	278	278

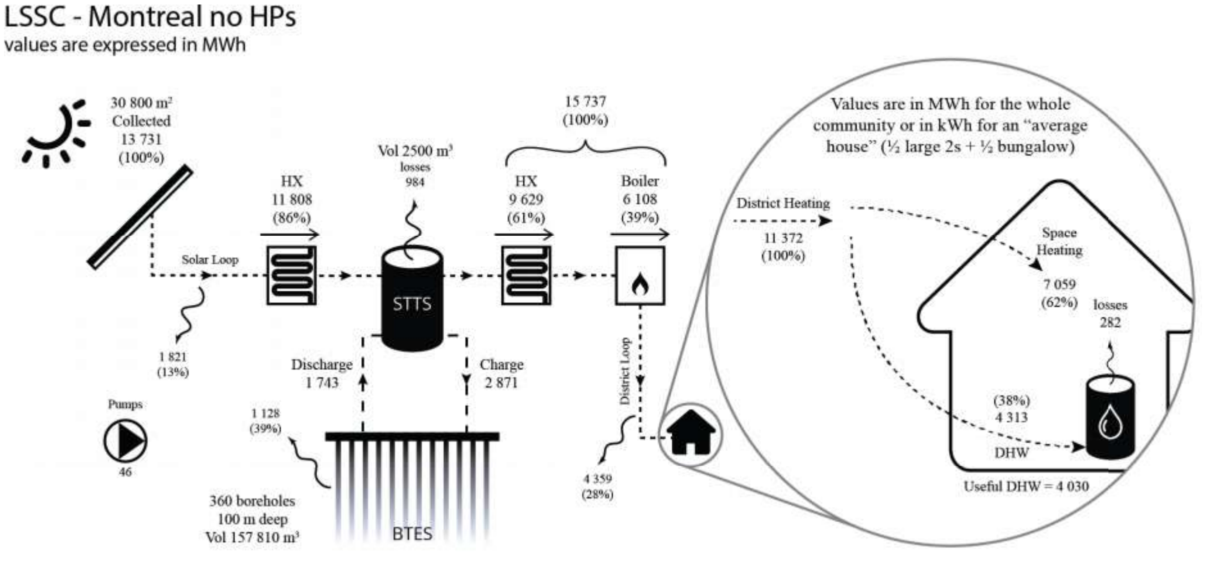


Figure 6
Model schematic and optimized results - Configuration "no HP"

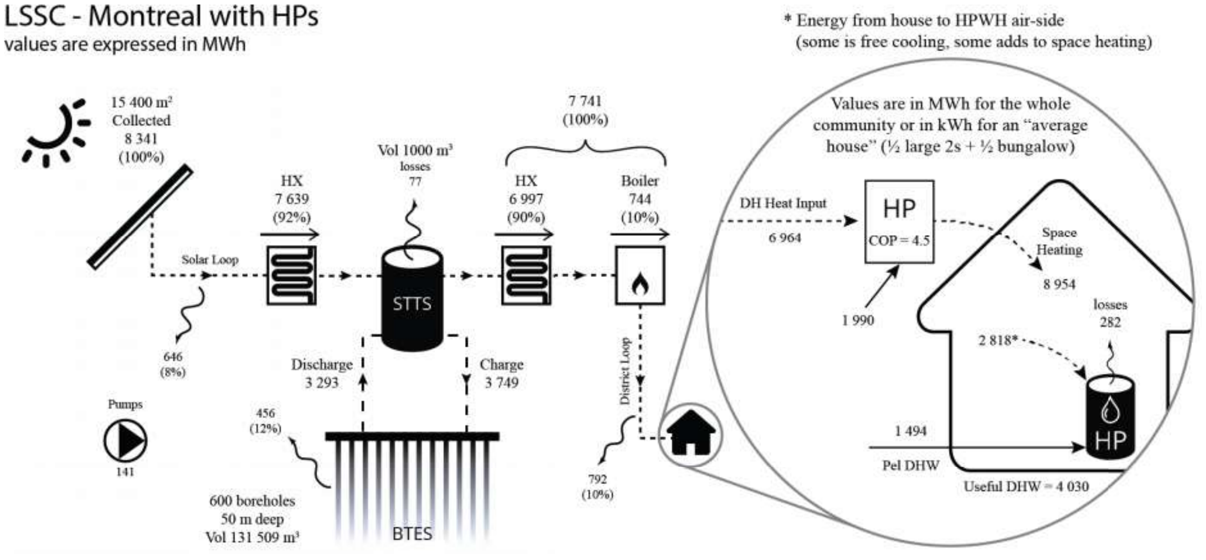


Figure 7
Model schematic and optimized results - Configuration "with HP"

CONCLUSION

A large-scale solar community model was adapted from the DLSC model to include 1000 units instead of 52 and also provide Domestic Hot Water from the district loop. Additionally, water-to-air heat pumps for space heating as well as heat pump water heaters were modelled to compare the energy and economic performance of both configurations.

Parametric simulations were performed to cover various collector areas, numbers of boreholes for seasonal storage and Short Term Thermal Storage sizes. Optimal configurations were based on marginal cost and solar fraction.

Results show that heat pumps increase the annual energy cost and increase the environmental impact in Calgary. On the other hand, in Montreal, heat pumps are favorable as they decrease both annual costs and CO_2 emissions.

A detailed economic analysis was performed to assess economic performance. Results show that the project profitability is sensitive to the residential market value of natural gas as well as the market value of selling heat. Calculated Internal Rate of Return range between 8 and 13%, which is low but could be acceptable in the context of renewable energy projects.

Further work is necessary to assess the impact of lower cost unglazed solar collectors and to refine modelling and analysis assumptions, e.g. to introduce diversity in thermal load profiles.

ACKNOWLEGMENTS

This project was funded by NSERC Smart Net-Zero Energy Building Strategic Research Network (SNEBRN).

The initial community-level TRNSYS model was provided by Jeff Thornton of Thermal Energy Systems Specialists (TESS), and the models for house archetypes were provided by Véronique Delisle (CanmetENERGY-Varennes).

NOMENCLATURE

DLSC: Drake Landing Solar Community

BTES: Borehole Thermal Energy Storage

COP: Coefficient of Performance

LLC: Life Cycle Cost

LLCC: Levelized Life Cycle Cost

REFERENCES

Bernier, M., Kummert, M., & Bertagnolio, S. (2007). Development and Application of Test Cases for Comparing Vertical Ground Heat Exchanger Models. In Proceedings of Building Simulation 2007: 10th conference of the International Building Performance Simulation Association, 3-6 Sep (pp. 1462–1469). Beijing, CHN: International Building Performance Simulation Association.

Delisle, V. (2015). Models of Energy-Efficient Canadian Home Archetypes – Report RP-TEC 2014-047. Varennes, QC, CAN: Natural Resources Canada, CanmetENERGY-Varennes Research Center.

Hudon, K., Sparn, B., Christensen, D., & Maguire, J. (2012). Heat Pump Water Heater Technology Assessment Based on Laboratory Research and Energy Simulation Models. Golden, CO, USA: National Renewable Energy Laboratory.

Environment Canada, 2015. National Inventory Report 1990-2013 – Greenhouse gas sources and sinks in Canada, Annex 11 – Electricity intensity tables. Ottawa, ON, CAN: Environment Canada.

Krebs, M., Quintana, H. J., & Kummert, M. (2014). Potential of Decentralized Heat Pumps to Improve the Financial Viability of a Solar District Heating System with Seasonal Thermal Storage. In Proceedings of the 2014 ASHRAE/IBPSA-USA Building Simulation Conference (SimBuild) (pp. 370–377). Atlanta, GA, USA: International Building Performance Simulation Association, USA affiliate.

Maguire, J. B. (2012). A Parametric Analysis of Residential Water Heaters. MASc thesis, University of Colorado.

NEB. (2013). Canada's Energy Future 2013 - Energy Supply and Demand Projections to 2035. Ottawa, ON, CAN: National Energy Board.

NRCan-OEE. (2005). EnerGuide for Houses: Energy Advisor Workshop Manual. Ottawa, ON, CAN: Natural Resources Canada, Office for Energy Efficiency.

NRCan-OEE. (2013). Energy Efficiency Trends in Canada 1990 to 2010, Chapter 3. Ottawa, ON, CAN: Natural Resources Canada, Office for Energy Efficiency.

NRC-IRC. (2011). National Energy Code for Buildings 2011. Ottawa, ON, CAN: National Research Council of Canada, Institute for Research in Construction.

SAIC. (2012). Large Scale Solar BTES Application Feasibility Study. Report for the town of Okotoks and Natural Resources Canada. Ottawa, ON, CAN: Science Applications International Corporation.

Sherman, M. H., & Grimsrud, D. T. (1980). Measurement of inflitration using fan pressurization and weather data (Report LBL-10852). Berkeley, CA, USA: Lawrence Berkeley National Laboratory.

SOLID. (2011). Summary of EN 12975 Test Results, annex to Solar KEYMARK Certificate. Graz, AUT: S.O.L.I.D. GmbH.