Potential of sensible thermal storage systems with or without heat pumps for reducing peak and annual electrical demand for space heating and hot water heating in Canadian homes

Sébastien Brideau
Natural Resources Canada, Ottawa, Canada

Abstract

This paper presents a preliminary analysis of five simple methods of reducing annual electrical demand and/or peak electrical demand due to space heating (SH) and domestic hot water (DHW) heating in Canada. The five systems are compared against a baseline of electric resistance SH and DHW. Four of the systems are variations of sensible storage systems with and without heat pumps. The last system is a cold climate air source heat pump (CCASHP). These systems are evaluated across three Canadian climates (Winnipeg, Toronto, and Vancouver) and three archetypes (pre-1980, post-1980, and Net-Zero Energy Ready). Using simulated results, load duration curves, peak day load profiles and annual electricity consumption are presented. It is found that in a mild climate a CCASHP is a good approach for energy savings and reducing peaks. In colder climates, a combination of storage and heat pump is required to reach both goals.

Introduction

Canada's housing stock contains over 11 million low-rise detached, semi and row-attached dwellings (Natural Resources Canada, 2018). Sixty-six percent of those dwellings are heated with combustion systems (gas/oil/wood/propane/coal) or a hybrid of combustion and electricity. Five percent are heated with heat pumps, and 29% are heated with electric resistance systems only (Natural Resources Canada, 2018). In recent years, the federal, and provincial and territorial governments have developed a set of goals to reduce greenhouse gas emissions (Environment and Climate Change Canada, 2016). To accomplish this, a set of aspirational goals were developed for space heating (SH) and DHW equipment (Energy and Mines Ministers' Conference, 2018). These goals state that "… all space heating technologies for sale in Canada meet an energy performance of more than 100%" by 2035 (Energy and Mines Ministers' Conference, 2018). The energy performance discussed in the government's documents is akin to a performance factor calculated by dividing the heat energy delivered to the space by the energy used. A similar goal is stated for domestic hot water (DHW) heating. Traditional combustion and electric resistance systems can't meet these goals, as they can't operate at an efficiency greater than 100%. Although various technologies are available, currently, the easiest way to reach these goals is to replace some of the combustion and electric resistance heating systems with electrically driven heat pumps, which can deliver coefficients of performance greater than 1.

If Canada is to meet this goal, a push towards electrification of heating systems is required. This will undoubtedly cause problems for the electrical grid during periods of peak demand. The aim of this project is to evaluate few simple space heating and DHW technologies to see which of them can help reduce the annual energy demand, while also help mitigate the increased peak on the electrical grid.

Tamasauskas et al (2015) and Candanedo et al (2015) have studied the energy and peak impacts of various heat pump systems (air-air, air-water, and ground-source) with and without water storage, for space heating only. Their work was focused on a NZER home in Toronto and Vancouver, two relatively mild climates. Both papers found that the addition of storage reduced the heating peak power. Additionally, Candanedo et al (2015) found that model predictive controls can further reduce peak power consumption. In Belgium, Masy et al (2015) studied the effects of air-to-water heat pumps with radiators and floor heating, and high thermal mass in the building. Using the thermal mass as storage, and model predictive controls, they found that they could reduce the cost of heating by shifting some of the peak hours demand to off-peak periods.

This paper is inspired by the previous work by Tamasauskas et al (2015) and Candanedo et al (2015) but addresses some limitations of those works. This paper looks at older housing archetypes, as well as expands the analysis to a colder climate, and evaluates two different storage mediums. A simplified modelling approach was employed for this analysis. The aim was to find combinations of archetypes, climates and mechanical systems that can reduce energy demand and peak demand compared with a baseline of resistance electric space heating and DHW. Once identified, these combinations can be further explored in the future with a more refined model.

Methodology

This section discusses the archetypes, climates, mechanical systems, and the modelling methodology used.

Archetype

Three archetypes were evaluated: a Pre-1980 archetype, a Post-1980 archetype, and a NZER archetype. Those archetypes were estimated to be representative of their vintage. A methodology used for selecting archetypes

related to the one used for this study is described by Asaee et al. (2019).

Climates

Three climates, in three different National Energy Code for Buildings (NECB) (Codes Canada, 2017) climate zones, were evaluated: Vancouver (zone 4), Toronto (zone 5), and Winnipeg (zone 7A). For this work, the weather year with the coldest hour in the past 30 years for each location was chosen. This ensures that the systems can perform at peak conditions for a 1 in 30 year event without placing additional burden on the grid. Canadian Weather and Engineering Datasets (CWEEDS) were used for this purpose. (Environment and Climate Change Canada, 2019)

Mechanical Systems

All SH systems except the Resistance Heating (baseline) system were modelled as forced air distribution systems.

Resistance Heating (baseline) The baseline system was an all-electric resistance heating system with DHW tank and baseboard heating. The space heating system was 100% efficient, and there was a small heat loss in the DHW tank.

CCASHP with resistance DHW tank. The second system was a typical CCASHP with an auxiliary electric resistance heater and an electric resistance heated DHW tank. The CCASHP was sized to for the house heating load at -8.3°C for the Pre-1980 and Post-1980 archetypes. For the NZER house, the CCASHP was sized for the entire load, except for Winnipeg, where the cutoff temperature of the CCASHP was higher than the absolute minimum ambient temperature. In this case the CCASHP was sized to provide the entire heating load at the cutoff temperature. The CCASHP was sized for the full load for the NZER archetype, because it is possible to size a reasonable heat pump at full load with that archetype. For the other archetypes, the heat pump would need to be very large (due to the large heating load and low capacity at cold temperatures) and costly.

Brick with resistance DHW. The third system was a brick storage system for space heating. The brick storage volume was set to 1 m^3 for all cases. This volume is consistent with currently available brick storage units. An electric resistance heater is used to charge the bricks to a maximum temperature of 730°C. An outdoor temperature reset controller is used to control the setpoint temperature of the brick storage. The resistance heater in the brick storage is sized based on a portion of the average heat demand on the peak day (by trial and error, approx. 70% of peak heating load was found to be a good starting point). The controller ensures that if the DHW tank requires heat, the brick storage heater will modulate down by the same amount so that the total (SH + DHW) power requirement is never higher than the brick heater rated power (unless the DHW power requirement is higher on its own, then the SH heater is deactivated, and storage only is used). This strategy ensures flattening of peaks and constrains the peak power consumption to a value much lower than the sum of the DHW and SH loads without storage and integrated controls. A typical DHW tank with resistance heating was used for DHW heating.

Brick with ASHP and resistance DHW. Same as previous system with an additional ASHP in parallel with the brick storage. The ASHP provides as much of the thermal load as possible at every time step. The total power requirement (HP + DHW + Brick electric resistance heater) is not allowed to exceed the brick storage electric resistance heater rated power (unless the DHW requirements are higher than the storage resistance size). A typical ASHP was selected instead of a CCASHP for cost and practical reasons. If a more complex system is installed (heat pump and storage), using a less expensive heat pump is a more cost-effective approach. Also, since the storage system is expected to be used during colder periods, the heat pump does not need the same performance at cold temperatures as a stand-alone CCASHP. The ASHP is sized for full heating load at -8.3°C.

Water Tank. This system consists of a single 1 m^3 tank heated with resistance heaters. This provides heat for both the space heating and the DHW. The tank setpoint temperature is 80°C, for the heating season, and 60°C for the rest of the year.

Water Tank with Air-to-Water Heat Pump. This system is similar to the previous one. However, the main source of heat for the tank is a variable speed air-to-water heat pump (A2W HP). The A2W HP sizing was the same for all archetypes. Although this is not cost-optimal in a real situation, the turndown ratio of the heat pump was high enough (4.2 for typical conditions) to provide a wide range of capacities without cycling. An electric resistance backup is provided to heat the 1 m^3 tank. For the DHW loads, the mains water picks up heat through a heat exchanger in the 1 m^3 tank during water draws before ending in a small, DHW tank, where it is heated to 55°C. The 1 m^3 tank setpoint is calculated with an outdoor temperature reset controller. The A2W HP is only able to provide the 55°C temperature with air temperatures down to -15°C. The outdoor air temperature reset controller allows for the A2W heat pump to operate when less thermal storage is required due to lower heating loads (and lower tank temperatures). When more thermal storage is required (which results in higher required tank temperatures, up to 80°C), the electric resistance heater supplies the entire thermal load to the tank.

Modelling

This paper presents initial results in a project to evaluate the usefulness and feasibility of storage systems for Canadian housing in an electrification of heating systems context. The aim of this current work is to identify potential areas for further exploration. A simple modelling approach was used for this analysis. This subsection briefly discusses the modelling approach.

For every combination of archetype and climate, a HOT2000 simulation calculated monthly heating demand (NRCan, 2020). A methodology developed previously was used to estimate hourly heating loads from those monthly outputs and hourly weather files (Brideau, 2020). The hourly heating loads were then used to analyse the mechanical systems (further discussed below). The hourly DHW loads are based on a normalized 24-hour flow schedule from the National Building Code of Canada (National Research Council of Canada, 2015) and the same mains water temperature model as the one used in HOT2000. The total amount of hot water per day for each archetype was set to 190 L per day.

Microsoft Excel was used to write simple hourly models for each mechanical system.

The 1 m^3 storage (water or brick) was described with a single node energy balance (over the one-hour time step), as shown in Equation 1.

$$E_{stored,t+1} = E_{stored,t} + E_{aux,t} + E_{HP,t} - E_{SH,t} - E_{DHW,t} - E_{loss,t} \quad (1)$$

Where E is energy stored or transfered over one hour (J), subscript t is time t, *stored* is the energy stored in the tank, *aux* is any electrical resistance auxilary heat to the storage, *HP* is heat pump heat to the storage, *SH* is heat taken from the storage to heat the house, *DHW* is heat taken from the storage to heat domestic hot water, and *loss* is storage loss through conduction to surrounding environment. Many of these equal zero at any time, or for some systems. For example, only the *Water Tank with Air-to-Water Heat Pump* uses a heat pump to heat the large tank, and uses the large tank to preheat DHW.

Storage losses are calculated based on storage wall conductivity and area, with the room air temperature set at a constant 22°C. Losses to the house contribute to the heating of the house if there is a SH requirement at that timestep. If there is no heating requirement, the storage still loses heat, but it has no impact on the house. This is one of the downsides of this high level methodology as there is no way to iterate between the mechanical system solution and the house solution.

If we assume that the stored energy in the storage is 0 J at 0°C (arbitrary point of reference), then we can calculate the storage temperature $T_{s,t}$ (°C) at every time step based solely on $E_{stored,t}$, $C_{p,s}$ (specific heat of storage material, $J \cdot kg^{-1} \cdot K^{-1}$), and m_s (mass of storage material, kg) with Equation 2.

$$T_{s,t} = \frac{E_{stored,t}}{m_s C_{p,s}} \quad (2)$$

Domestic hot water tanks were simply assumed to have a constant 30W loss (good assumption for most medium to large sized residential tanks), and water draws were added to that loss at the time step they were required. The electrical demand was assumed to be the loss plus the water draw demand for each time step. For one system, *Water Tank with Air-to-Water Heat Pump*, the water draw demand was the left-over requirements following the preheat in the large tank.

Heat pumps were modelled using performance maps. The performance maps from the following heat pumps were used (manufacturer data):

- A2W HP: Mitsubishi PUHZ-HW140V/YHA2
- ASHP: Goodman GSZ140361K*/ ARUF37C14**+TXV
- CCASHP: Daikin DZ20VC0361B* /CA*F3743*6D*+MBVC1600**-1A*+TXV.

All heat pumps heating capacities and power consumptions were normalized, then scaled up or down to mimic sizing of the heat pumps. Heat pumps of the same brand and series but of different sizes usually have similar performance curve shapes, so scaling is appropriate for this work. Heat pump sizing was discussed in the Methodology Section. Derating of heat pumps for cycling was ignored.

Fan energy was assumed to enter the air flow stream and contribute to heating of the air. Pump energy was ignored for this study.

Any heat exchangers in this study had an effectiveness of 1 (i.e., perfect heat exchanger).

The many assumptions and simplifications made in this study are likely not adequate to inform a detailed design. However, the aim of this study was to compare a few systems and how they could reduce annual energy and peak power consumption. For this task, these assumptions and simplifications are likely adequate. A more sophisticated model can be used in the future to refine the results of the systems of interest.

Metric for Comparing Performance of Systems

The aim of this work was to identify systems that might be suitable for energy reduction and peak reduction. To compare each combination, a performance score that combines both criteria was created. This performance score is:

$$S = \Delta E \cdot \Delta P / (E_{baseline} \cdot P_{baseline}) \quad (3)$$

where ΔE is the annual energy savings (GJ), ΔP is the peak power reduction (kW), $E_{baseline}$ is the baseline annual energy consumption (for respective city/archetype combination), and $P_{baseline}$ is the baseline peak power (for respective city/archetype combination). Results for this performance score are discussed in a later section.

Results

Hourly simulation results (annual runs) were used to compare annual energy savings and peak power consumption.

Annual Energy Savings

Annual energy savings compared with the baseline case of a fully electric resistance system, are shown in Figure 1. For reference, Table 1 shows the annual energy consumption of the baseline system (electric resistance heating).

Mechanical systems utilizing heat pumps help reduce annual energy demand, while storage systems without heat pumps utilize slightly more energy due to tank losses.

For homes with high energy demands (Pre 1980s) the *CCASHP + DHW* tank and the *Brick w ASHP* systems provide the most energy savings. In archetypes with high energy demands, the *Water Tank with A2W HP* is unable to perform as efficiently due to the competing requirements between:

1. the low tank temperature setpoint required for the heat pump to operate at high COP (and provide energy savings), and
2. the high tank temperature setpoint required to meet high energy demand.

Table 1. Annual energy use (GJ) for baseline case system (electric resistance SH and DHW) by archetype and city

	NZE-Ready	Post 1980	Pre 1980
Toronto	16.3	46.8	92.3
Vancouver	12.0	32.3	64.1
Winnipeg	26.1	72.9	140.7

For low load homes (NZER), the *Water Tank w A2W HP* system reduced the energy consumption more than the other systems. This is due to the ability to maintain a lower tank setpoint temperature for more of the heating season, allowing the heat pump to operate. Also, since the space heat demand is low, the DHW load is much more important in the low load homes. The *Water Tank w A2W HP* system utilizes the heat pump for water heating, reducing the DHW energy consumption. The highest energy reduction for the NZER archetype is in Vancouver, with a 4.9 GJ reduction, which is a 41% reduction compared with the baseline.

Although the space heating load is highest in Winnipeg, a significant portion of this load happens at ambient temperatures below the various heat pump cut-off temperatures, or at temperatures with lower Coefficient of Performance (COP). This results in higher energy reduction in Toronto than Winnipeg for systems with heat pumps. Of all the combinations, the largest annual energy savings occur in the Pre 1980 archetype in Toronto, with the *CCASHP + DHW tank*. That case results in 43.7 GJ energy savings, or a 47% reduction compared with the baseline.

The *Brick w ASHP* systems result in some savings for Pre and Post 1980 archetypes, but not for the NZER archetype. For the NZER archetype, the important losses in the Brick storage combined with the low heating demand result in no energy savings (and even additional energy consumption). The losses from the brick storage could also result in space overheating in low load homes. For example, at full capacity (730°C storage temperature, with 70 mm insulation) the brick storage loses approximately 2 kW to the surrounding space. This is enough to meet most, or all, of a NZER home's space heating demand. Temperature reset controls and higher storage insulation levels can mitigate this risk. Overheating was impossible to directly evaluate in this study but would be a very important consideration in homes with high temperature storage systems.

Peak Power Reduction

For the purposes of this paper, peak power is defined as the hour of the year with the highest DHW and SH related electrical power consumption. Peak power day is defined as the day that contains the peak power hour. Peak power reduction compared to the baseline system is an important metric if electrification of SH and DHW systems are to become mainstream in Canada. Reducing peak power consumption might allow for smaller sizing of various grid components, and reduced power requirements from often more expensive and polluting peaking power plants.

Reduction in peak power for each system, archetype, and city compared with the baseline system is showed in Figure 2. The peak power requirements for the baseline system (electric resistance heating) are shown in Table 2.

Table 2. Annual peak power (kW) for baseline case system (electric resistance SH and DHW) by archetype and city

	NZE-Ready	Post 1980	Pre 1980
Toronto	4.1	7.3	12.6
Vancouver	3.0	5.9	10.0
Winnipeg	5.6	10.7	18.6

The *CCASHP + Tank* system shows no peak power reduction in Winnipeg. This is due to the very cold ambient temperatures. During much of the winter, the ambient temperature is below the CCASHP cut-off temperature, and space heat is supplied with an electric resistance heater backup. In Toronto, only a fraction of the space heat is provided by the CCASHP at peak conditions. As mentioned in the Methodology Section, the CCASHP was sized for loads at -8.3°C due to large sizes required for full load sizing. It is possible to size for full load, and there might be other CCASHPs with better low temperature performance, better suited for that purpose. In Vancouver, the CCASHP provided a large reduction in peak power. For that case, the CCASHP was sized for the entire load, as Vancouver has a relatively mild climate, and it would not be unrealistic to do so.

In the colder two climates (Toronto and Winnipeg) the Brick storage systems (with and without ASHP) provided the highest peak reduction for the Pre and Post 1980 archetypes. In Toronto and Vancouver, the Water Tank systems (with or without A2W HP) provide the greatest reduction in peak power consumption for NZER archetypes. This is due to the relatively lower SH demand, compared to the DHW demand. A portion of the DHW demand peak in this case can be met with the large water storage tank. In this study the Brick storage systems are not equiped with water heat

Table 3. Performance scores, for combinations of archetypes, cities, and systems. Highlighted are the best performance scores for city/archetype combinations. High score is better

		Archetypes		
City	**System**	**NZE-Ready**	**Post 1980**	**Pre 1980**
Toronto	Brick w ASHP	0.000	**0.082**	**0.137**
	CCASHP + DHW Tank	0.010	0.023	0.019
	Water Tank w A2W HP	**0.164**	0.042	0.036
Vancouver	Brick w ASHP	0.000	0.078	0.174
	CCASHP + DHW Tank	0.007	**0.125**	**0.205**
	Water Tank w A2W HP	**0.298**	**0.122**	0.078
Winnipeg	Brick w ASHP	0.000	**0.023**	**0.042**
	CCASHP + DHW Tank	0.000	0.000	0.000
	Water Tank w A2W HP	**0.072**	**0.024**	0.015

exchangers to heat DHW, therefore there is no peak reduction possible for the DHW load for those systems.

There are commercially available systems that include hydronic heat exchangers in brick storage. They haven't been evaluated here, but it would likely help reduce DHW peaks.

For Winnipeg, the colder climate means that even the NZER home has a significant peak space heating load (4 kW) and while the Water Tank systems deliver an advantage for the DHW load, the brick systems can provide additional storage for SH load, and both systems end up providing similar results in terms of peak power reduction.

The addition of a heat pump to storage systems does not drastically impact the peak electrical consumption in any climate. This is due to the fact that peak consumption occurs at a time when outdoor air temperature is very low and either the heat pump performance is poor or the heat pump is not available at all. Additionally, the thermal storage already provides significant the peak reduction, and the addition of a heat pump only marginally improves this peak power reduction performance. In Vancouver, a CCASHP (with a typical resistance DHW tank) does provide a considerable reduction in peak demand without the need for additional storage.

Identification of Systems that Result in Reduced Peak Power and Annual Energy Consumption

Table 3 shows the performance score for each combination. Highlighted are the best performance score for each archetype and city combination. The list does not list systems without heat pumps as they do not reduce energy demand.One interesting lesson is that the brick system with ASHP may not work well in NZER archetypes. It is likely that finely tuned controls of the storage temperature would help in that matter, but at this point, there appear to be better options. To reduce peak and annual energy consumption, the best solution for NZER archetypes is the Water Tank w A2W HP, regardless of climate. This is likely due to the relatively large importance of the DHW loads for those archetypes, and the availability of a HP and storage for DHW.

As the SH load gets more important (because of climate, or archetype), the brick storage becomes better performing. For Vancouver however, a CCASHP with a simple resistance DHW tank is the best case for Post-1980s, and Pre-1980s archetypes. In that mild climate, the CCASHP can perform at high COPs, and doesn't have to rely on electrical resistive backup.

Sample Load Duration Curves and Peak Day Load Profiles

Figures Figure 3 through Figure 8 show load duration curves and 30 year peak day load profiles for Winnipeg Pre 1980 archetype (high load), Toronto Post 1980 archetype (mid load), and Vancouver NZER archetype (low load). The kW rating next to each legend title in the load duration curve figures is the peak power consumption for that system. The Winnipeg Pre 1980 results show that the high amount of available storage in the brick systems (due to high brick temperatures) can greatly reduce the peak power consumption. Additionally, Figure 4 shows that the DHW load is small compared with the space heating load, but that amplitude of the the variation of the DHW load is significant. Table 3 confirms that Brick with ASHP is the best option for Winnipeg Pre 1980 homes.

For the Toronto Post 1980 results, Figure 6 shows that the CCASHP was able to reduce the power requirement after 9AM. In this case, the ambient temperature went above the CCASHP cutoff temperature after 9AM, and the CCASHP was able to contribute to the space heating demand. The CCASHP still peaks to almost 7 kW, as opposed to the Brick w ASHP that maintains a flat demand of 4.3 kW for the

entire peak day. Table 3 confirms that Brick with ASHP is the best option for Toronto Post 1980 homes.

For Vancouver NZER, Figure 8 shows that the CCASHP is able to provide heat for the entire peak day due to the relatively mild ambient temperatures, but it has no impact on the significant DHW load. The brick storage systems also cannot reduce the power consumption during periods of high DHW demand. However, the water storage systems can because they are used to store heat for space heating and DHW. The load duration curves for the water storage systems are very flat compared with the other systems. Table 3 confirms that Water Tank w A2W HP is the best option for Vancouver NZER homes.

Conclusion

Four different combinations of sensible storage systems (water and brick) with and without heat pumps and a cold climate air source heat pump (CCASHP) were compared to a baseline of electric resistance heating. The aim was to find options that would reduce peak electrical power consumption and annual electrical energy demand for space heating and DHW.

Results showed that the CCASHP can produce significant reductions in electrical energy demand and peak power consumption in cases when the ambient air temperature remains mild.

For Vancouver, with the Pre and Post 1980 archetypes, the CCASHP + DHW tank is likely the best option in terms of simplicity and performance. For the NZER, a Water Tank with A2W HP would perform much better, as it could reduce the significant DHW load.

For Toronto and Winnipeg, the Brick with ASHP would perform well for the Pre and Post 1980 archetypes, and the Water Tank with A2W HP would perform best for the NZER archetype.

This study involved many simplifications and assumptions. Next steps will involve detailed simulation in a sub-hourly simulation tool. The modelling assumptions and the controls will be refined. Furthermore, a few additional mechanical systems (including heat pump DHW, and hydronic loop with brick storage) will be modelled. Lastly, an economic analysis and a greenhouse gas emissions analysis will be performed.

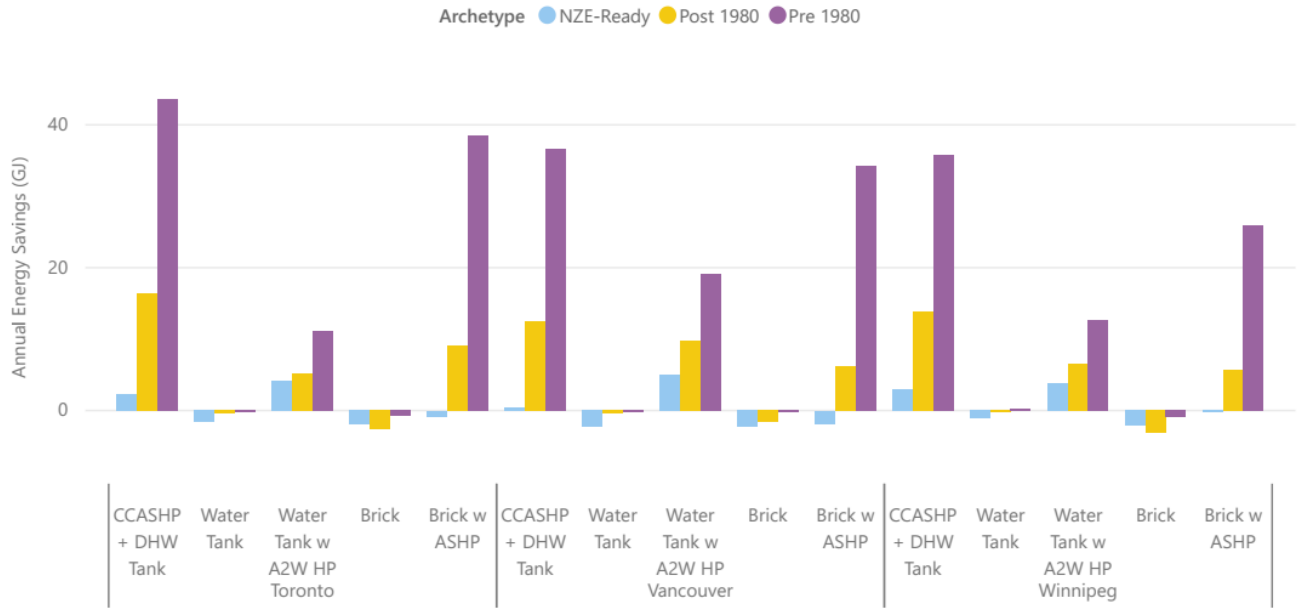

Figure 1. Annual energy savings by archetype, system, and city

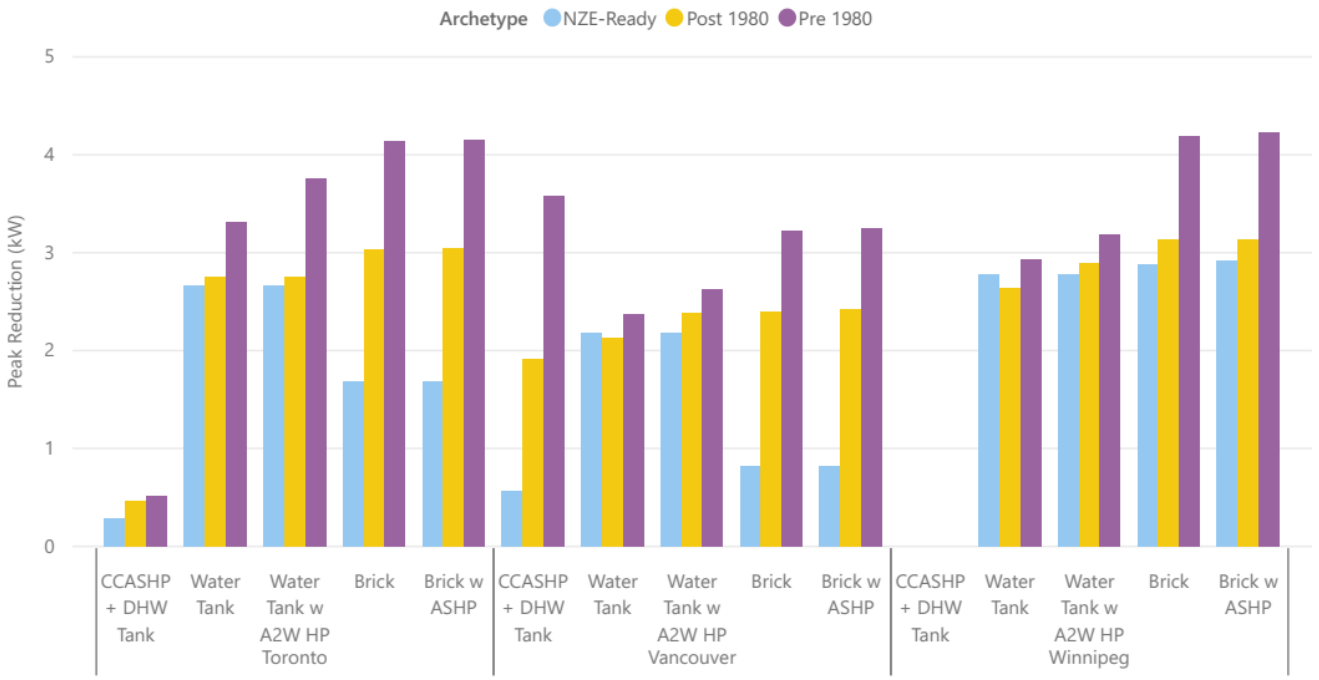

Figure 2. Electrical peak reduction by archetype, system, and city

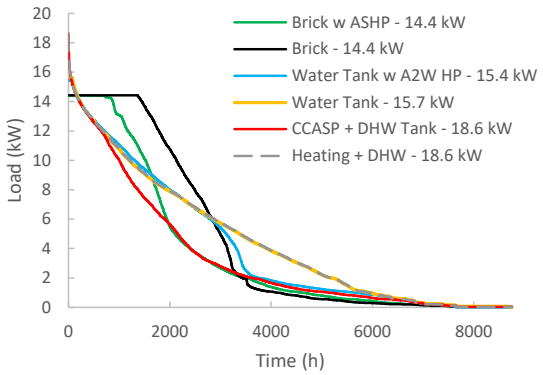

Figure 3. Load duration curve: Winnipeg, Pre 1980 archetype

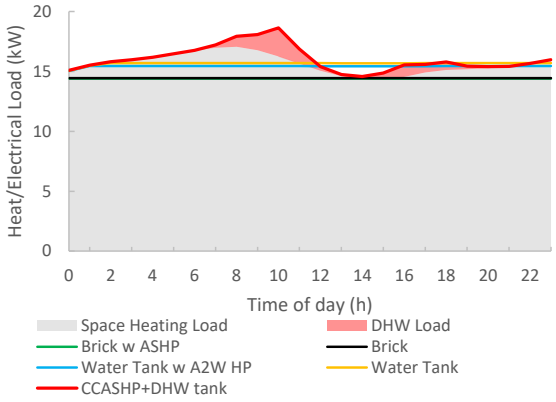

Figure 4. Peak day load profile for various systems: Winnipeg, Pre 1980 archetype

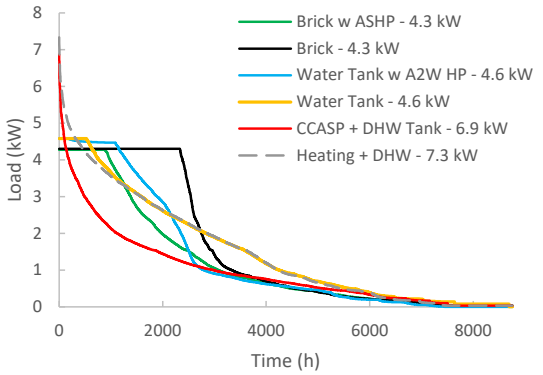

Figure 5. Load duration curve: Toronto, Post 1980 archetype

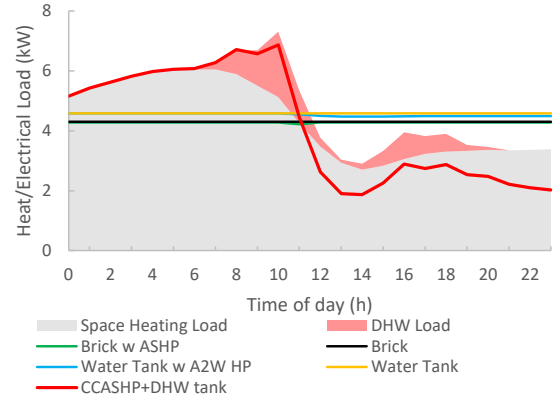

Figure 6. Peak day load profile for various systems: Toronto, Post 1980 archetype

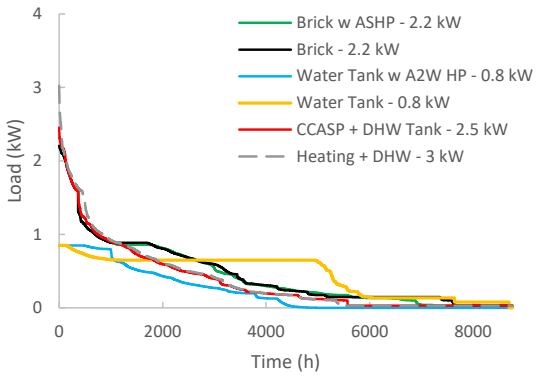

Figure 7. Load duration curve: Vancouver, NZER archetype

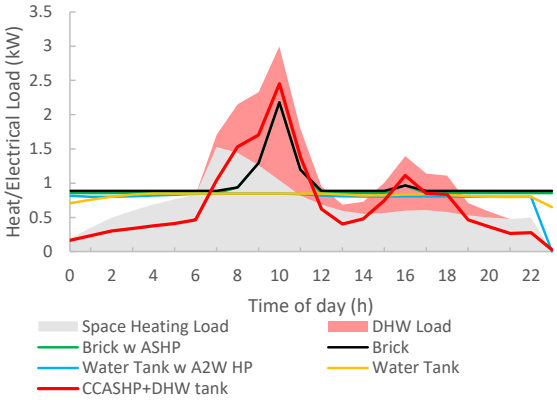

Figure 8. Peak day load profile for various systems: Vancouver, NZER archetype

References

Asaee, S. R., Ferguson, A., & Wills, A. (2019). Application of a Housing Technology Assessment Simulation Platform in Regulation R&D. *International Building Performance Simulation Association Conference.* Rome, Italy.

Brideau, S. (2020). Estimating Hourly Heating and Cooling Loads from Monthly Results. *ASHRAE Virtual Conference.*

Candanedo, J., Dehkordi, V. R., & Tamasauskas, J. (2015). Impact of Heat Pumps and Predictive Control on Residential Energy Use, Load and Grid Interaction: A Canadian Perspective. *Conference of International Building Performance Simulation Association.* Hyderabad, India.

Codes Canada. (2017). *National Energy Code of Canada for Buildings 2017.* National Research Council.

Energy and Mines Ministers' Conference. (2018). *Paving the Road to 2030 and Beyond: Market transformation road map for energy efficient equipment in the building sector.* Iqaluit: Natural Resources Canada.

Environment and Climate Change Canada. (2016). *Pan-Canadian Framework on Clean Growth and Climate Change.* Gatineau: Environment and Climate Change Canada.

Environment and Climate Change Canada. (2019). *Engineering Climate Datasets.* Retrieved from http://climate.weather.gc.ca/prods_servs/engineering_e.html

Masy, G., Georges, E., Verhelst, C., Lemort, V., & André, P. (2015). Smart grid energy flexible buildings through the use of heat pumps and building thermal mass as energy storage in the Belgian context. *Science and Technology for the Built Environment*, 800-811.

National Research Council of Canada. (2015). National Building Code of Canada. *Volume 2*. National Research Council of Canada.

Natural Resources Canada. (2018). *Comprehensive Energy Use Database.* Retrieved from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

NRCan. (2020, 12 1). *Tools for industry professionals*. Retrieved February 25, 2021, from https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-homes/professional-opportunities/tools-industry-professionals/20596

Tamasauskas, J., Candanedo, J., & Kegel, M. (2015). An Analysis of the Impact of Heat Pump Systems on Load Matching and Grid Interaction in the Canadian Context. *International Building Physics Conference.* Turin, Italy.