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Student Research Report

UBC Academic District Energy System: Thermal Energy Storage

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UBC Academic District Energy System:

Thermal Energy Storage

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SEEDS Summer Project

The University of British Columbia

Executive Summary

This report aims to investigate thermal storage alternatives for the University of British Columbia (UBC) to explore in its journey to carbon neutrality by 2050. The thermal storage system will ideally reduce peak thermal energy requirements from the UBC district heating system during start-ups in the cold months of the year, thereby flattening overall energy usage. District heating systems have evolved over the years resulting in four distinct generations of systems; UBC is categorized as second generation as it is operating at above 100°C, though the infrastructure is set up to operate as a third generation system. Multiple categories of thermal energy storage (TES) were researched: storage as sensible, latent or thermo-chemical heat; long-term and short-term storage; and centralized or distributed. The most viable option for UBC at this time is a sensible thermal energy storage system that uses large thermal storage tanks to store energy, thus relieving the strains on the current system during peak hours. The first step towards utilizing thermal energy storage in a cost effective manner is to shift the district heating system to operate at below 100°C, and to accommodate for the use of an atmospheric thermal storage system. Large capacity, atmospheric thermal storage tanks were used for other University District Heating Systems, and provides an opportunity to be charged by a future campus renewable energy source.

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1 Introduction

A district heating system is a network of insulated pipes that connect buildings within a neighbourhood or city to a centralised heating plant, or a number of distributed heat producing plants. This set up facilitates a flexible infrastructure that allows a range of renewable energy sources to be integrated into the system. As district heating evolves into the fourth generation, “more efficiency, more renewables and more flexibility lead to a better energy system” (Euroheat & Power, 2020). The conceptual illustration below shows the Brædstrup solar district heating plant in Denmark. This illustration shows short-term and long-term heat storage integration into a district heating system, and uses solar power and natural gas-fired CHP as heat sources. The University of British Columbia (UBC) can gain ideas from the Brædstrup system for incorporation of storage and renewable energy into their existing system; however, it should be noted that not all the components may be applicable for the UBC system. As a preliminary step, this report aims to investigate thermal storage alternatives which UBC should explore in its journey to carbon neutrality by 2050.

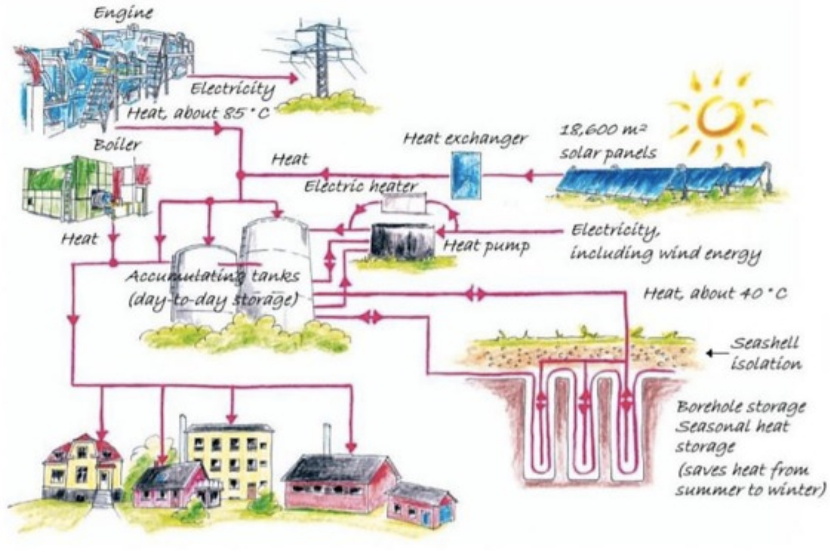


Figure 1 – Brædstrup solar district heating plant in Denmark
Source: Tian et al. (2019

1.1 UBC Academic District Energy System

Information on the UBC Academic District Energy System (ADES) was obtained from the UBC Energy & Water Services website. The CEC houses 3 x 15MW natural gas-fired high efficiency boilers. These boilers along with the Bioresearch Research Demonstration Facility (BRDF) provide heat into the hot water district energy system. The schematic below shows all of the energy sources that are connected to the ADES.

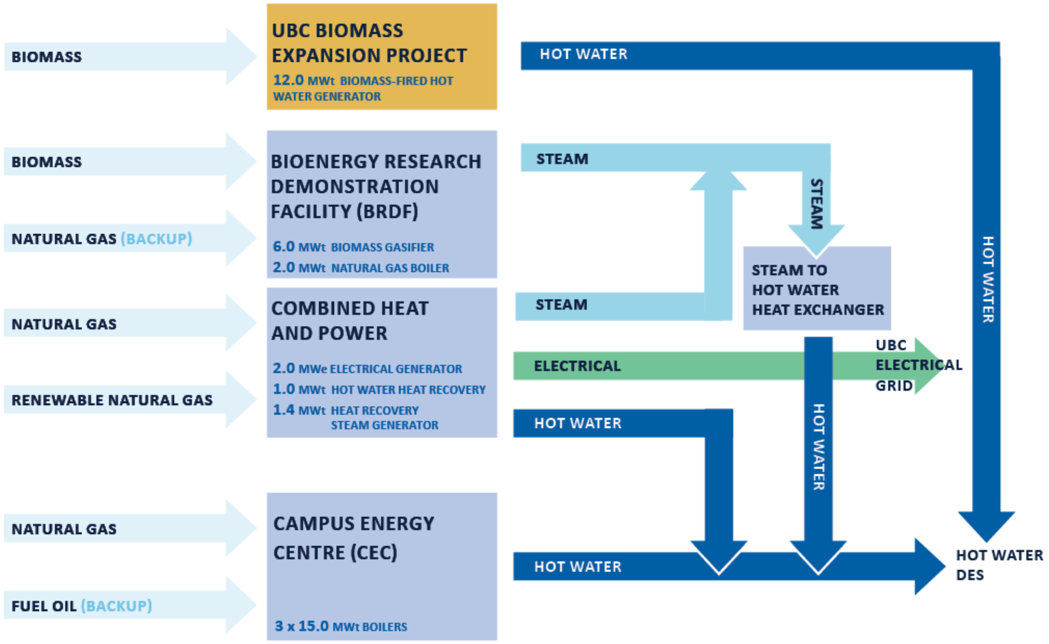


Figure 2 – Schematic of UBC's Academic District Energy System
Source: UBC Energy & Water Services (n.d.)

The BRDF went into operation in 2012, and has a capacity to generate 6 MW of Thermal Energy (Steam), and 2.4 MW Thermal Heat Recovery from the generation of electricity by operating in co-generation mode. This provides 30% of thermal energy for UBC's Academic District Energy System and 5% of campus electrical energy. Currently, an expansion project is underway to expand the existing BRDF with an additional 12 MWt (41 MMBtu/hr) of hot water boiler capacity. This expansion will allow the system to meet the projected growth in the upcoming years.

1.2 Target/Goals

The intention of this project is to bring UBC closer to the carbon neutral goal through the implementation of a thermal energy storage system. The thermal storage system will ideally reduce peak energy requirements during start-ups in the cold months of the year, thereby flattening overall energy usage. This will allow for reduced strain on the current system during winter's coldest days and reduce the need to run the natural gas boilers during shoulder seasons. To accommodate UBC's thermal demand growth through to 2030, the initial campus expansion plan included the installation of a 15MW gas-fired boiler. Installing a similar capacity thermal storage would avoid the need to install a 15MW gas-fired boiler to help achieve the zero emissions target. Additional details of UBC's thermal demands are provided and discussed in Section 3 Analysis.

As it stands, the most immediate goal is for short-term thermal storage versus longer-term seasonal storage. The first step in reaching the short-term goal would be to install the accumulating tanks for daily thermal storage. The components of the accumulating tanks can be integrated into UBC's current system as shown in Figure 1.

In order for UBC to reach its carbon neutral target, campus heating should continue to be a focus, using the summer 2020 project as a phase 1 assessment. Future phases could consider using a renewable energy form to charge the thermal storage specifically through passive solar heating. Long term, seasonal storage systems (such as pit or borehole storage) could be reassessed in the future. Other future considerations for achieving net zero emissions include conversion of existing gas-fired boilers to electric, or the addition of heat pumps (using wind or tidal as an energy source) into the system.

2 Literature Review

2.1 Evolution of District Heating

District heating systems have been around for a long time. Development of heating systems has been categorized in terms of "generations", indicating a major change in the technology with each successive generation. Lund et al. (2014) identify four successive generations, leading up to envisioning and defining what the fourth generation should look like. The figure below is a visual illustration of their progression.

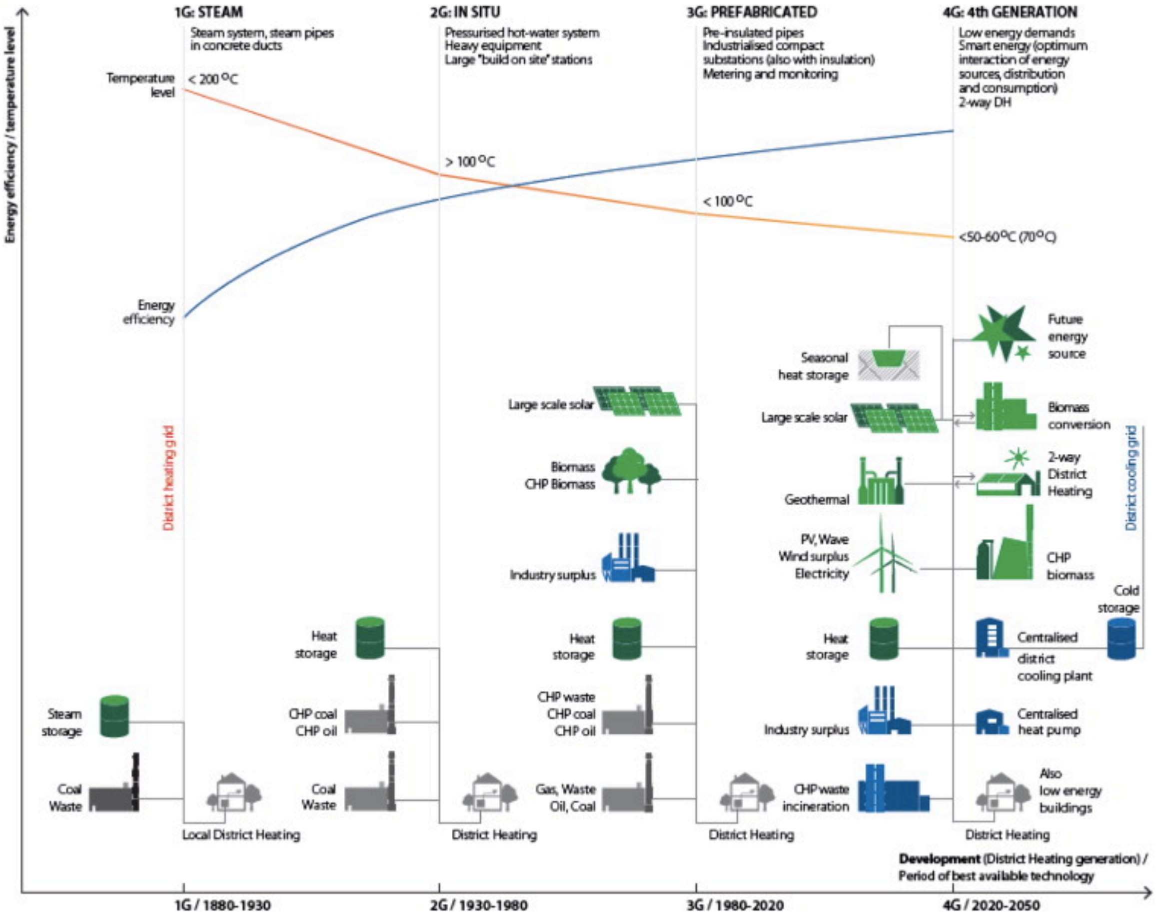


Figure 3 – Generations of District Heating
Source: Lund et al (2014)

The first generation started in the 1880s in America and was widely used until the 1930s. Steam was generated in power plants and distributed via steam pipes to the end users. “Typical components were steam pipes in concrete ducts, steam traps, and compensators” (Lund et al., 2014, p.2). This system was introduced to replace individual boilers in apartment buildings; however, there were reliability and safety issues of this system due to the hot pressurized steam in the pipes. These steam systems have mostly been converted to newer generations, with the exception of old New York (Manhattan), and Paris, where steam is still used as the main heat carrier.

The second generation took over in the 1930s and used pressurized hot water at over 100 °C to supply heat. “Typical components were water pipes in concrete ducts, large tube-and-shell heat exchangers, and material-intensive, large, and heavy valves” (Lund et al., 2014, p.2). The Soviets used this generation to build the district heating systems within the former USSR and it is still widely used in Russia and Eastern Europe. The second generation was a more efficient system by utilizing hot water and combined heat and power (CHP) generation.

The third generation was introduced in the 1970s and uses circulating water at less than 100 °C to supply heat. This approach was adopted in the big expansion of heating systems in the Nordic countries as a response to the oil crises of the 1970s, where heat distribution achieved wide public acceptance because it also led to an improvement in urban air quality by removing single-building oil-fired heating systems. Many of the district heating manufacturers are Scandinavian, and so the third generation is sometimes referred to as “Scandinavian district heating technology”. “Typical components are prefabricated, pre-insulated pipes directly buried into the ground, compact substations using plate stainless steel heat exchangers, and material lean components” (Lund et al., 2014, p.2). This generation is the most commonly installed system worldwide (in China, Korea, USA and Canada), and the older systems in Central and Eastern Europe are now being replaced with third generation systems. In general, these first three generations focused on optimizing the system to run at increasingly higher efficiency, while reducing construction and installation costs.

The fourth generation shifts the focus to developing a system with high flexibility to accommodate the incorporation of renewable energy into the system. Lund et al. (2014) state that "an important frame-work condition for the need for further development of district heating infrastructures and technologies is the change in primary motivation in various societies, namely to transform into a future sustainable energy system" (p.2), and outline the following five challenges for the new system to overcome (p.3):

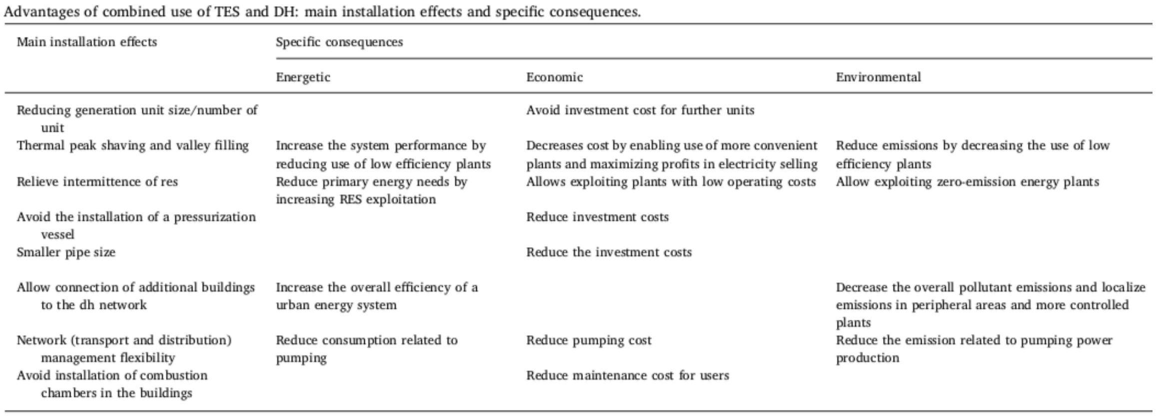
1. Ability to supply low-temperature district heating for space heating and domestic hot water (DHW) to existing buildings, energy-renovated existing buildings and new low-energy buildings.
2. Ability to distribute heat in networks with low grid losses
3. Ability to recycle heat from low-temperature sources and integrate renewable heat sources such as solar and geothermal heat.
4. Ability to be an integrated part of smart energy systems (i.e. integrated smart electricity, gas, fluid and thermal grids) including being an integrated part of 4th Generation District Cooling systems.
5. Ability to ensure suitable planning, cost and motivation structures in relation to the operation as well as to strategic investments related to the transformation into future sustainable energy systems

The fourth generation operates at less than 70 °C to supply heat, and focuses on incorporating renewable heat sources such as biomass power plants, geothermal, solar and wind energy.

2.2 Thermal Energy Storage

When thermal energy storage (TES) systems are integrated into district heating (DH) systems, they help manage the fluctuations in supply and demand, thereby increasing the flexibility and performance of the entire system (Guelpa & Verda, 2019). The following table provides details of these advantages.

Table 1 – Advantages of adding TES into a district heating system
Source: Guelpa & Verda (2019)



Advantages of combined use of TES and DH: main installation effects and specific consequences.

Main installation effects	Specific consequences		
	Energetic	Economic	Environmental
Reducing generation unit size/number of unit		Avoid investment cost for further units	
Thermal peak shaving and valley filling	Increase the system performance by reducing use of low efficiency plants	Decreases cost by enabling use of more convenient plants and maximizing profits in electricity selling	Reduce emissions by decreasing the use of low efficiency plants
Relieve intermittence of res	Reduce primary energy needs by increasing RES exploitation	Allows exploiting plants with low operating costs	Allow exploiting zero-emission energy plants
Avoid the installation of a pressurization vessel		Reduce investment costs	
Smaller pipe size		Reduce the investment costs	
Allow connection of additional buildings to the dh network	Increase the overall efficiency of a urban energy system		Decrease the overall pollutant emissions and localize emissions in peripheral areas and more controlled plants
Network (transport and distribution) management flexibility	Reduce consumption related to pumping	Reduce pumping cost	Reduce the emission related to pumping power production
Avoid installation of combustion chambers in the buildings		Reduce maintenance cost for users	

Guelpa & Verda (2019) have offered the following possible classifications of TES in district heating systems:

1. Physical phenomenon (sensible, latent, and chemical storage)
2. Storage duration (short term and long term/seasonal)
3. Distributed and localized

The figure below is a visual representation of these categories.

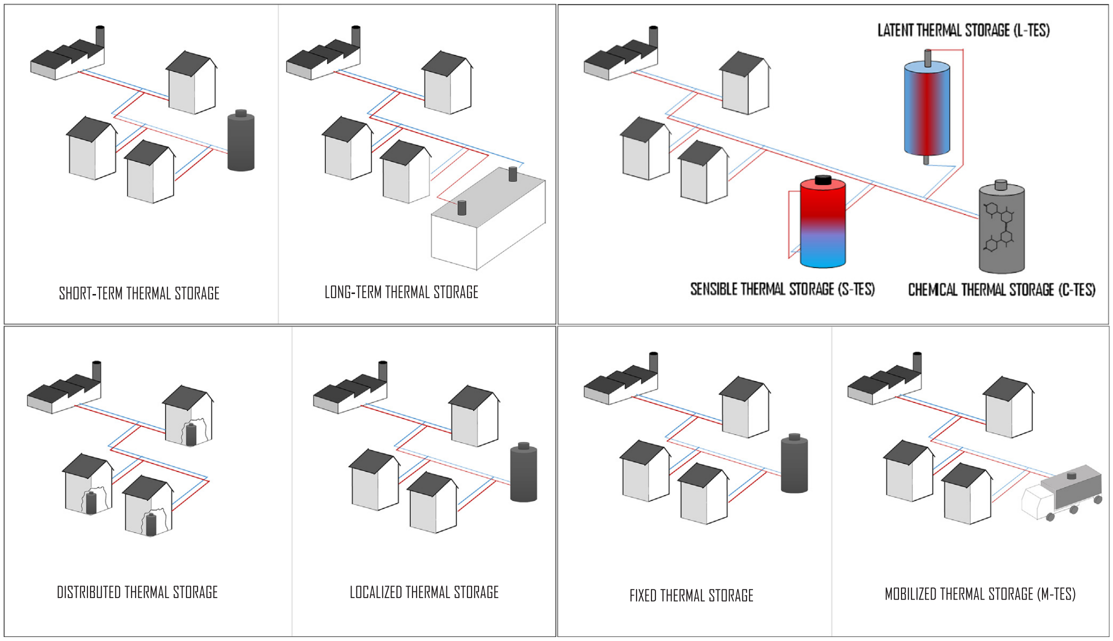


Figure 4 – Classifications for TES connected to district heating systems
Source: Guelpa & Verda (2019)

2.2.1 Physical phenomenon

There are three main types of storage technologies, sensible, latent and chemical, described in Figure 5 below.

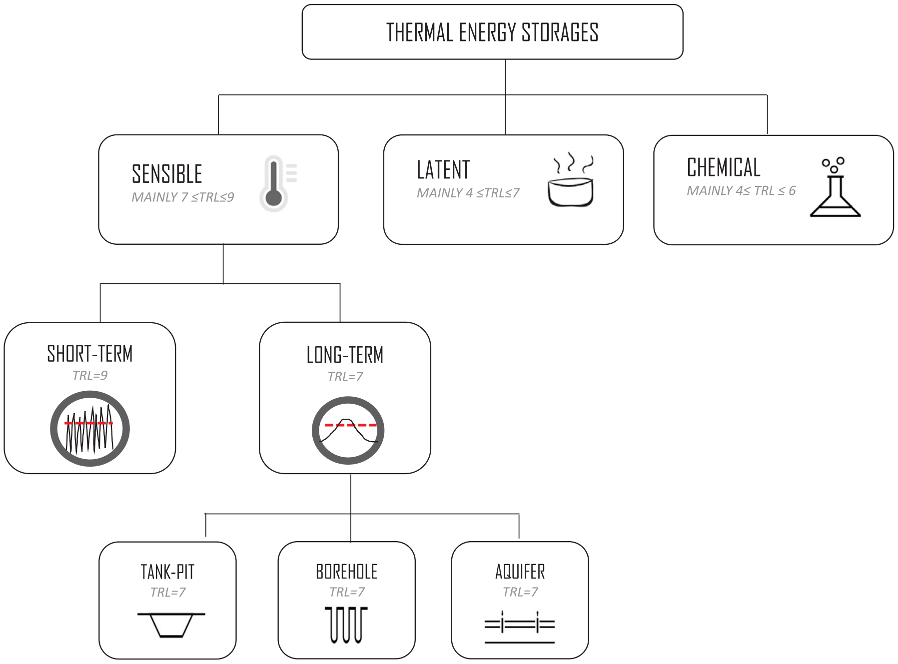


Figure 5 – Physical Phenomenon of Energy Storage
Source: Guelpa & Verda (2019)

Sensible heat storage uses the temperature increase of the storage medium to store heat. Tables 2 and 3 list the various types of materials used in sensible heat storage systems.

Table 2 – List of selected solid-liquid materials for sensible heat storage
Source: Sarbu et al. (2018)

Medium	Fluid Type	Temperature Range (°C)	Density (kg/m^3)	Specific Heat (J/(kg·K))
Sand	-	20	1555	800
Rock	-	20	2560	879
Brick	-	20	1600	840
Concrete	-	20	2240	880
Granite	-	20	2640	820
Aluminium	-	20	2707	896
Cast iron	-	20	7900	837
Water	-	0–100	1000	4190
Calorie HT43	Oil	12–260	867	2200
Engine oil	Oil	≤160	888	1880
Ethanol	Organic liquid	≤78	790	2400
Propane	Organic liquid	≤97	800	2500
Butane	Organic liquid	≤118	809	2400
Isotunaol	Organic liquid	≤100	808	3000
Isopentanol	Organic liquid	≤148	831	2200
Octane	Organic liquid	≤126	704	2400

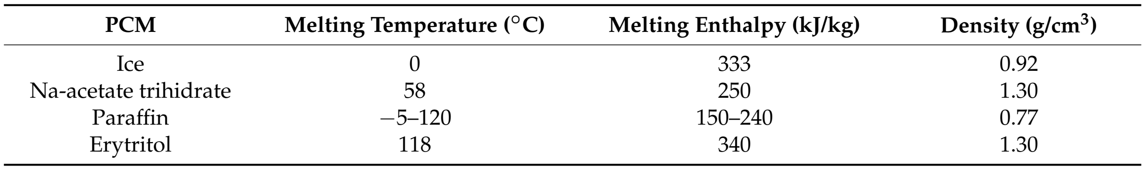
Table 3 – Solid-state sensible heat storage materials
Source: Sarbu et al. (2018)

Storage Materials	Working Temperature (°C)	Density (kg/m^3)	Thermal Conductivity (W/(m·K))	Specific Heat (kJ/(kg·°C))
Sand-rock minerals	200–300	1700	1.0	1.30
Reinforced concrete	200–400	2200	1.5	0.85
Cast iron	200–400	7200	37.0	0.56
NaCl	200–500	2160	7.0	0.85
Cast steel	200–700	7800	40.0	0.60
Silica fire bricks	200–700	1820	1.5	1.00
Magnesia fire bricks	200–1200	3000	5.0	1.15

The appropriate material selection is based on metrics such as cost, physical characteristics, availability and social impact. Sensible heat storage is most commonly used in district heating systems, the majority of which use water as the storage material. In sensible heat systems, an insulation material must be used to reduce thermal losses and based on operating temperatures; pressurization may be required to prevent evaporation. A major drawback with a sensible storage system is the low storage density, which impacts temperature variability and volume requirements. Nevertheless, sensible heat storage is a widely adopted and robust technology that benefits from low installation cost, ease of installation and high reliability (Guelpa & Verda, 2019).

Latent heat storage consists of a heat storage medium that is heated and cooled within a containment vessel. A heat transfer fluid is required which delivers thermal energy to the medium through a heat exchanger (Guelpa & Verda, 2019). Latent heat storage is commonly referred to as a phase change storage system. Table 4 below displays common phase change materials (PCM) used for latent heat storage. Purpose, temperature, enthalpy, density and cost are all considerations when selecting an appropriate PCM.

Table 4 – PCM properties
Source: Sarbu et al. (2018)



PCM	Melting Temperature (°C)	Melting Enthalpy (kJ/kg)	Density (g/cm^3)
Ice	0	333	0.92
Na-acetate trihidrate	58	250	1.30
Paraffin	−5–120	150–240	0.77
Erytritol	118	340	1.30

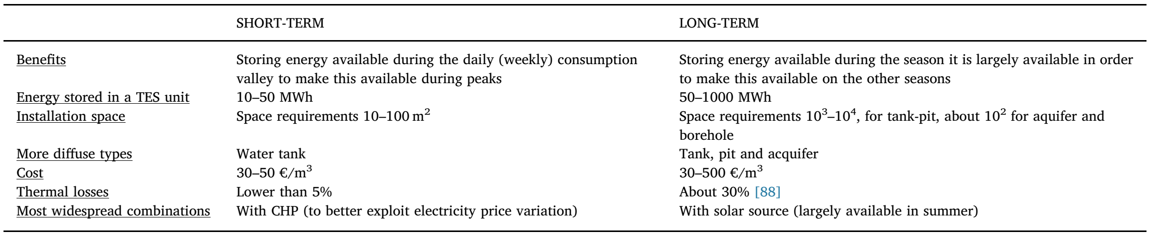
The advantage of this type of technology is that it has a much higher energy density than sensible heat storage systems, so that the volume required is significantly less. Additional advantages include thermal efficiency due to reduced thermal losses. Some universities in warmer geographies are beginning to implement phase change material systems, like ice reservoirs, for campus cooling. The implementation of this type of thermal storage for cooling has provided annual savings in operation at campuses such as Florida Gulf Coast University and Chabot-Las Positas, a community college in California (Calmac, 2020). However, latent heat storage is less commonly tied to district heating systems and presents a much higher cost alternative, roughly four times as expensive as a TES water tank alternative (Guelpa & Verda, 2019).

Chemical storage can be grouped into two categories, chemical reversible reactions and absorption and adsorption. The former category involves endothermic reactions that occur when excess heat is available, storing products at ambient temperature and then releasing energy through a reverse reaction. The latter category uses the bonding of a gas to the surface of a solid for absorption, rather than creating a new material for adsorption. Of the three types of storage, chemical storage has arguably the highest energy density and the least thermal losses. Many materials have been trialled in connection with district heating systems and have been deemed unfit as the necessary temperatures cannot be reached. Materials such as zeolite have proven to be adequate in short term TES systems tied to district heating. A study in Munich, showed that the return on investment of the technology was roughly 7–8 years, but varies tremendously based on in-peak and off-peak energy prices (Guelpa & Verda, 2019).

2.2.2 Storage Duration

All three thermal energy storage types discussed in the previous section can be used for short and long-term storage. Short-term storage refers to technology with the capacity to store heat for hours or days. Short-term storage typically is in the form of tank storage (e.g. insulated, weather-protected steel tanks). Long-term or seasonal storage will span over months and requires a larger storage volume. Pit, borehole, or aquifer thermal energy storage may be suitable applications (Nielsen & Sørensen, 2016). Seasonal storage allows for thermal energy to be stored during summer and shoulder seasons when thermal energy demand is low or negligible. The stored energy can then be accessed during times of peak demand in colder shoulder months and the winter. Table 5 below, describes the benefits, amount of energy stored, storage technologies, cost, thermal losses and potential system combinations (Guelpa & Verda, 2019).

Table 5 – Main characteristics of short-term and long-term localized TESs
Source: Guelpa & Verda (2019)



	SHORT-TERM	LONG-TERM
Benefits	Storing energy available during the daily (weekly) consumption valley to make this available during peaks	Storing energy available during the season it is largely available in order to make this available on the other seasons
Energy stored in a TES unit	10–50 MWh	50–1000 MWh
Installation space	Space requirements 10–100 m^2	Space requirements 10^3–10^4, for tank-pit, about 10^2 for aquifer and borehole
More diffuse types	Water tank	Tank, pit and acquifer
Cost	30–50 €/m^3	30–500 €/m^3
Thermal losses	Lower than 5%	About 30% [88]
Most widespread combinations	With CHP (to better exploit electricity price variation)	With solar source (largely available in summer)

The decision to implement short-term versus long-term TES is based largely on the application. It is more typical for short-term storage to be used when daily demand and production vary significantly. Conversely, seasonal or long-term storage is optimal when availability varies seasonally. When considering TES installation in a DH system, space constraints are a key concern. Short-term storage typically utilizes a footprint of approximately 50 -100 m^2. For long-term storage systems, it is common to require areas between 10,000 and 100,000 m^2, with exceptions for borehole and aquifer systems that require less land surface. Long-term storage technologies tend to have more expensive infrastructure and experience higher thermal losses, than the short-term duration alternatives (Guelpa & Verda, 2019).

Tank and pit technologies are large vessels, made of welded steel or concrete, that hold heated or chilled water as a heat store. The tanks can be placed above ground or below ground in a pit. While tank and pit technology can be used for both short-term and long-term storage, it is most commonly used for short-term storage in DH systems.

There are two categories of tank TES systems. Atmospheric TES and Pressurized TES. Atmospheric TES is used with DH systems running below 100°C and with temperature gaps not exceeding 30 to 40°C. As shown in Figure 6 below, a pressurized DH system does not require alteration when using a pressurized TES vessel. Due to the pressure difference between the tank and pipeline, a system running at atmospheric pressure and lower temperatures must be fitted with an appropriate pump and valve system along with an expansion tank, referred to as a pressurized vessel in Figure 6. This is the preferred technology when the storage system is designed to run for only a limited number of hours before thermal recharging (Guelpa & Verda, 2019).

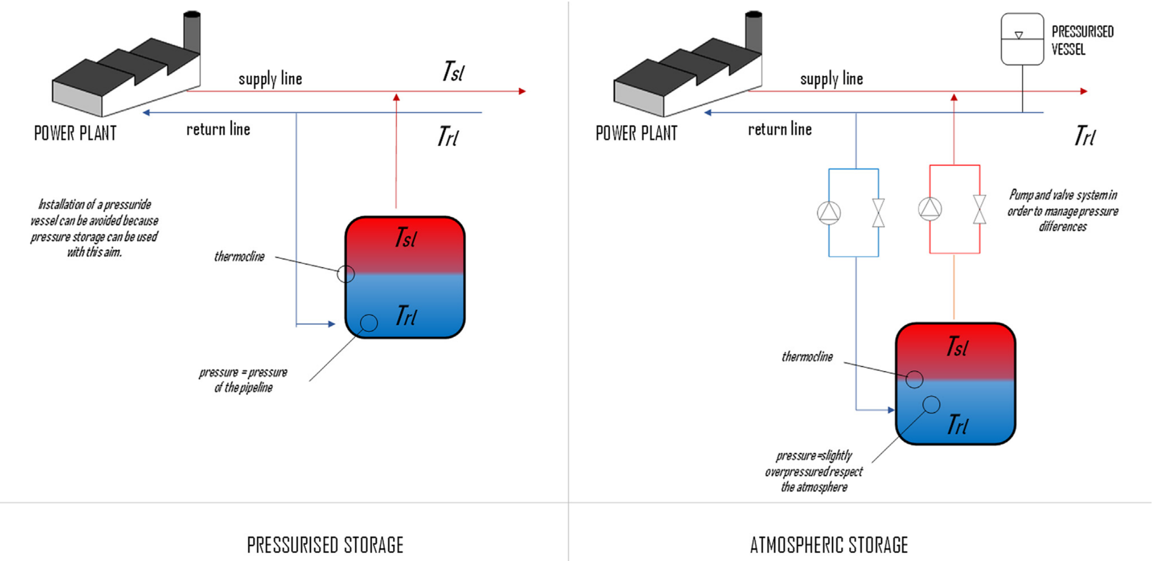


Figure 6 – Storage System Configurations
Source: Guelpa & Verda (2019)

Pressurized TES systems are predominantly used in conjunction with high temperature district heating systems as water temperatures in excess of 100°C must be pressurized to avoid boiling. The storage tank will generally operate at the same temperatures and pressures of the DH system and can act as a pressurization vessel (Guelpa & Verda, 2019)

Aquifer TES is a common long-term storage method used in areas with geological rock systems containing groundwater. The groundwater can be extracted and re-injected after heating, to be stored for later use, but the groundwater mass flow rate should be kept as low as possible (Guelpa & Verda, 2019). Capacity of aquifer systems ranges from 100 kW to 30 MW. The payback period of this type of system is generally between 2 and 10 years but depends on the application and the local hydrogeology. The economics of this TES design are intriguing, but the challenge is in the system parameters. The geology of the desired location must contain two rock beds one above and one below the aquifer, to serve as a container. From discussions with Julie Pett of EWS, it is understood that UBC is not in an area where the hydrogeology favours aquifer TES.

Borehole TES is a longer-term storage mechanism that utilizes the heat capacity of the soil to store heat. The system is installed in an open field where u-pipe boreholes are drilled into the ground at a depth of 30 to 200 m. Additional surface insulation is required to reduce thermal losses. Significant planning is required, as this technology requires high heat capacity, thermal conductivity, and ground that is drillable with low or, ideally, zero groundwater flow. Determining the number of boreholes, the spacing between boreholes, their depth, and additional engineering details are key in the technology's success. The overall area required is much larger than that of tank TES. It is common for this system to take years to reach peak thermal storage, as the system water must be used to gradually heat the earth. Even at peak operation, the system still suffers from a low thermal conductivity and therefore slow response. Size and cost barriers must be overcome to use this technology (Guelpa & Verda, 2019).

There are Canadian success stories when implementing borehole technology as a thermal storage system. A notable example is the Drake Landing Solar Community (DLSC) project, which uses solar thermal energy and seasonal storage to provide space heating to a 52-house community in Okotoks, AB. It took 3 years to fully charge the borehole storage so that it can supply sufficient heating for the winter season. It is recommended that UBC omit this technology from further consideration due to the duration of time required to reach the desired storage temperature, the scale and geology mismatch. Additional details are provided in Appendix 8.1 Case Study – Drake Landing Solar Community.

Short-term TES systems often use latent heat storage with an appropriate phase change material, as discussed in the previous section. It should be noted that this technology is more readily used for district cooling systems using ice storage as the cost is low and latent heat is high. The use of paraffin wax as a PCM for DH systems is a less common choice for short-term storage. Latent heat systems can be appropriately implemented as heating for greenhouses. Long term latent thermal storage is complex and presents no benefit over TES using water (Guelpa & Verda, 2019).

Chemical storage may play a more significant future role in short-term TES systems; however, in order to reach and maintain desired temperatures, the technology must be researched further. In addition, chemical storage may not be financially viable due to the quantity of chemical material required (Guelpa & Verda, 2019).

2.2.3 Distributed and localized

One of two approaches can be taken when determining the implementation of a TES system: distributed or localized. A distributed system includes building level storage, with TES tanks placed at each building. This can present a space concern for those buildings where free space is scarce. Heat can be stored and used by the building where the storage is located, thus reducing transportation and distribution. Leveraging building level storage reduces the source power required during times of high demand. This approach has the disadvantage that it is more costly for the total heat storage capacity compared to centralized storage (Jebamalai et al., 2020).

Centralized storage is more typical. The large reservoir volume reduces heat loss due to the lower surface to volume ratio. Additionally, centralized storage presents a more cost-effective approach as the cost per gallon stored decreases as the stored volume increases. Typically, centralized storage systems are located within 100 meters of the source and there must be adequate space available for a large central tank (Jebamalai et al., 2020).

Overall, building level storage is better suited for daily storage and centralized for seasonal storage (Jebamalai et al., 2020). However, a combined system, using both building level as daily storage and centralized for seasonal, may prove to be the most cost effective network.

3 Analysis

3.1 UBC DES Information

As previously mentioned in Section 1.2, the future UBC DES will have possible inputs supplied by multiple heat sources: 45MW from the Campus Energy Centre and up to 20.4MW from the Biomass Plant, when operating in cogen mode. The DES follows an "N-1" operating strategy, which means that it is desirable to always have one boiler as an emergency spare. Table 6 below shows the current thermal supply into the UBC DES.

Table 6 – UBC Thermal Energy Supply

Supply Source	**N-1 boiler Max Capacity**	**N-1 boiler Normal Operation**
	(MW)	(MW)
Biomass Cogen	2.4	2.2
Biomass Gasifier	6	5.4
Biomass Expansion	12	10.8
Campus Energy Centre	30	Balance of requirement
Total	**50.4**	

UBC has based their university growth forecast on a 2% annual growth. From this basis, the following peak thermal demands were estimated for the upcoming years.

Table 7 – UBC Peak Thermal Demand Forecast

Year	**Peak Thermal Demand (MW)**
2020	49.9
2025	55.1
2030	60.9
2035	67.2
2040	74.2
2045	81.9
2050	90.5

UBC EWS has requested a thermal storage capacity that would provide flexibility in the system to accommodate growth up to the year 2030. Initial storage considerations were to be designed based on UBC DES operating conditions as shown in Table 8, below.

Table 8 – UBC DES Operating Conditions

Temperature	**Winter**	**Summer**
Supply Temperature	115°C	70°C
Typical Return Temperature	75°C	55°C
System Design Pressure	1600 kPag	
Typical Operating Pressure Range	800-1000 kPag	

However, vendor feedback stipulated that atmospheric tank storage cannot accommodate temperatures above 100°C (Guy Frankenfurt, DN Tanks 2020). Based on the feedback, it is recommended that the UBC DH winter supply temperature be lowered so that atmospheric storage may be considered.

As defined previously, third generation DH consists of pre-fabricated, pre-insulated pipes, compact heat exchangers, and operates at below 100°C (Lund et al., 2015). UBC has already invested in third generation infrastructure as part of the steam-to-hot water upgrade, now all that is required is to lower operating temperatures to 95°C or below for a complete transition to a third generation system.

3.2 Future Usage Forecast and Capacity Investigation

UBC Energy & Water Services provided a spreadsheet of data compiled based on the 2020 fiscal year demand and the data was extrapolated to forecast until 2050 based on a 2% growth (UBC EWS, 2020). Based on the projected timeline that it will take to implement the thermal storage, the 2030 projections were used for analysis.

Using the heat source capacities listed in Table 6, four scenarios were created. The first scenario includes those days where maximum hourly demand is less than 18.4 MW where the BRDF capacity alone can be used to satisfy campus demand. The second scenario consists of those days with maximum hourly demand above 18.4 MW and below 32.2 MW, where at least one hour of the day has demand that exceeds BRDF capacity and requires one CEC boiler to be run. The third scenario identifies days having maximum hourly demand above 32.2 MW and below 46 MW, requiring the BRDF and two CEC boilers to be run. Finally, scenario 4 includes those days where maximum hourly demand exceeds 46 MW and requires all 3 boilers to be run. Table 9 below categorizes the various scenarios that the UBC DES can run with the addition of a TES.

Table 9 – Potential Operating Conditions with TES Installed

Supply Source	**n-1 boiler Max Capacity (MW)**	**Scenario 1 Demand <18.4 MW**	**Scenario 2 Demand 18.4 to 32.2 MW**	**Scenario 3 Demand 32.2 to 46 MW**	**Scenario 4 Demand >46 MW**
Biomass Cogen	2.4	✓	✓	✓	✓
Biomass Gasifier	6	✓	✓	✓	✓
Biomass Expansion	12	✓	✓	✓	✓
Campus Energy Centre (3 x 15MW)	30	-	1 boiler	2 boilers	3 boilers (exceeds N-1)
TES addition		TES not required	capacity to charge TES	capacity to charge TES	at times, not enough capacity to charge TES
No of days in each scenario		**130**	**98**	**119**	**19**

An example for the classification method is as follows:

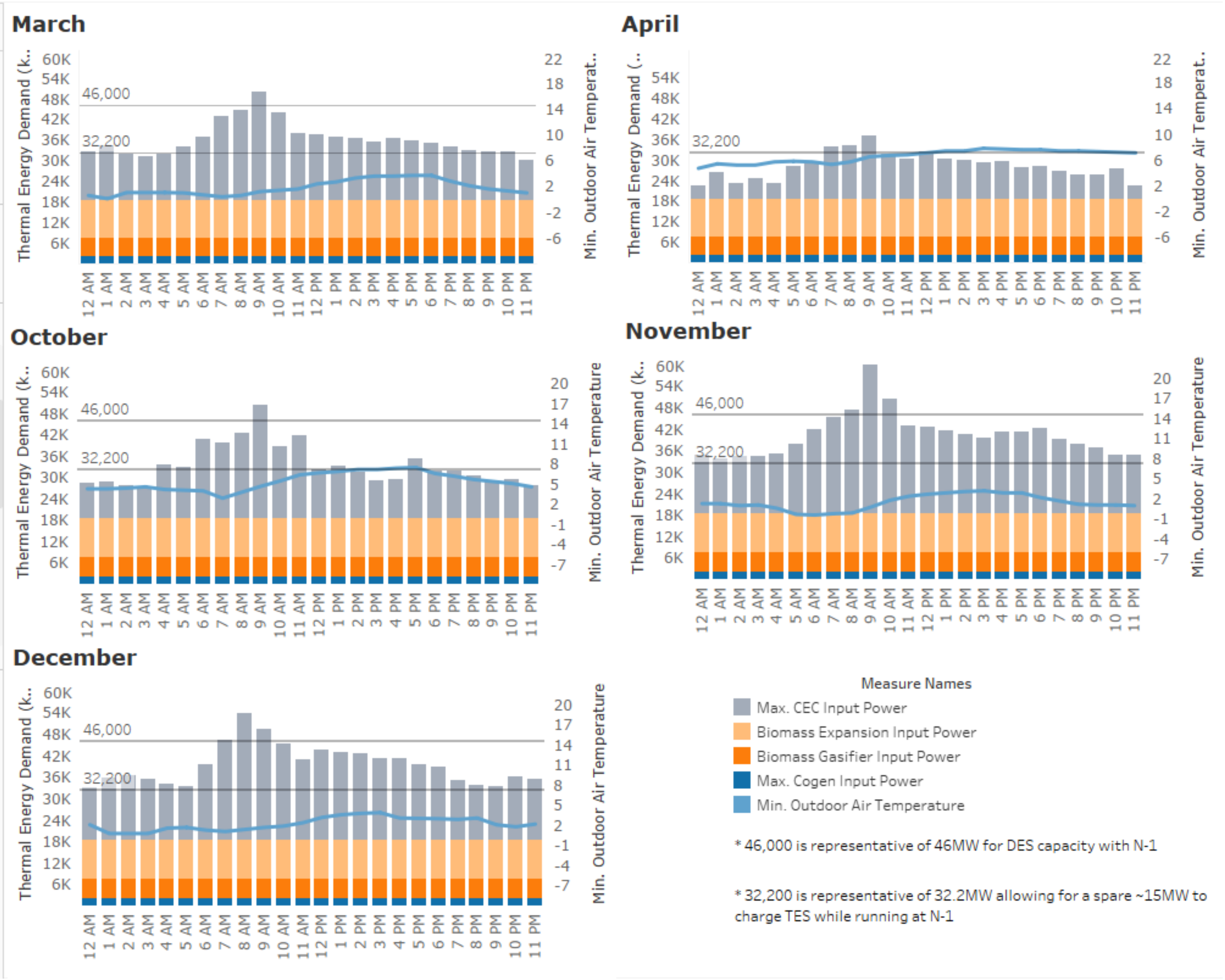
A day was placed into a given category if there was a single hour in the day where maximum demand fell into a category, i.e. below 18.4 MW, between 18.4 and 32.2 MW, between 32.2 and 46 MW and above 46 MW. For example, maximum hourly demand on February 1st 2030 is estimated to be 32.5 MW, so that there is at least one hour when demand is above 32.2 and below 46 MW and the day is therefore categorized into scenario 3.

Using this system of categorization, an estimated number of days in which the TES will be leveraged was gathered. The TES is most valuable on days in scenarios 2 and 3 when the peak demand exceeds the maximum output from the BRDF but there are periods during the day when there is available supply to charge the TES. In total, 217 days out of the year fall into these two categories. For the days that fall into scenario 4, a more in depth assessment is needed into hourly demand, the number of consecutive cold days, the storage duration and heat loss, to better predict the viability of the TES system.

The UBC system is operated so that supply meets short-term demand. The campus plans to utilize the BRDF output as the primary thermal energy source, and only fire the natural gas boilers from the CEC when needed. The charts in Figure 7 below display the estimated demand during the day for each month of the shoulder seasons; i.e. those months where thermal energy is required frequently, but outdoor air temperatures are not as low as during the depth of winter. The charts shown are indicative of the coldest day of each month when the thermal demand is the highest, representing the worst-case scenario in each month as a basis for sizing the heat storage.

In the shoulder months, it is currently common for the CEC to run at least one gas-fired boiler if not two, and at some hours even all three. The days in these months primarily fall into scenarios 2 or 3. They specifically benefit from thermal storage through charging during hours when demand is low to flatten the peak output when demand is high. As previously noted, the BRDF and its expansion can typically operate to deliver approximately 16.2 MW of heat with an additional 2.2 MW coming from the Biomass Cogen Plant to account for 18.4 MW of total thermal energy. When demand exceeds this figure, the CEC can fire one boiler for an output of roughly 32.2 MW (using ~92% of boiler max capacity), two boilers for an output of 46 MW and in extreme weather, all three for a total output of about 59.8 MW as a conservative estimate.

The constant lines in the charts below show the times when the demand reaches 32 MW and 46 MW. The area below these lines shows the hours when operating in this way generates a surplus heat output that could be used to charge the TES in preparation for a cold day or peak demand hours. In this way, the additional storage would allow the N-1 protocol to remain in place even on "worst-case" days when demand is high.


March

April

October

November

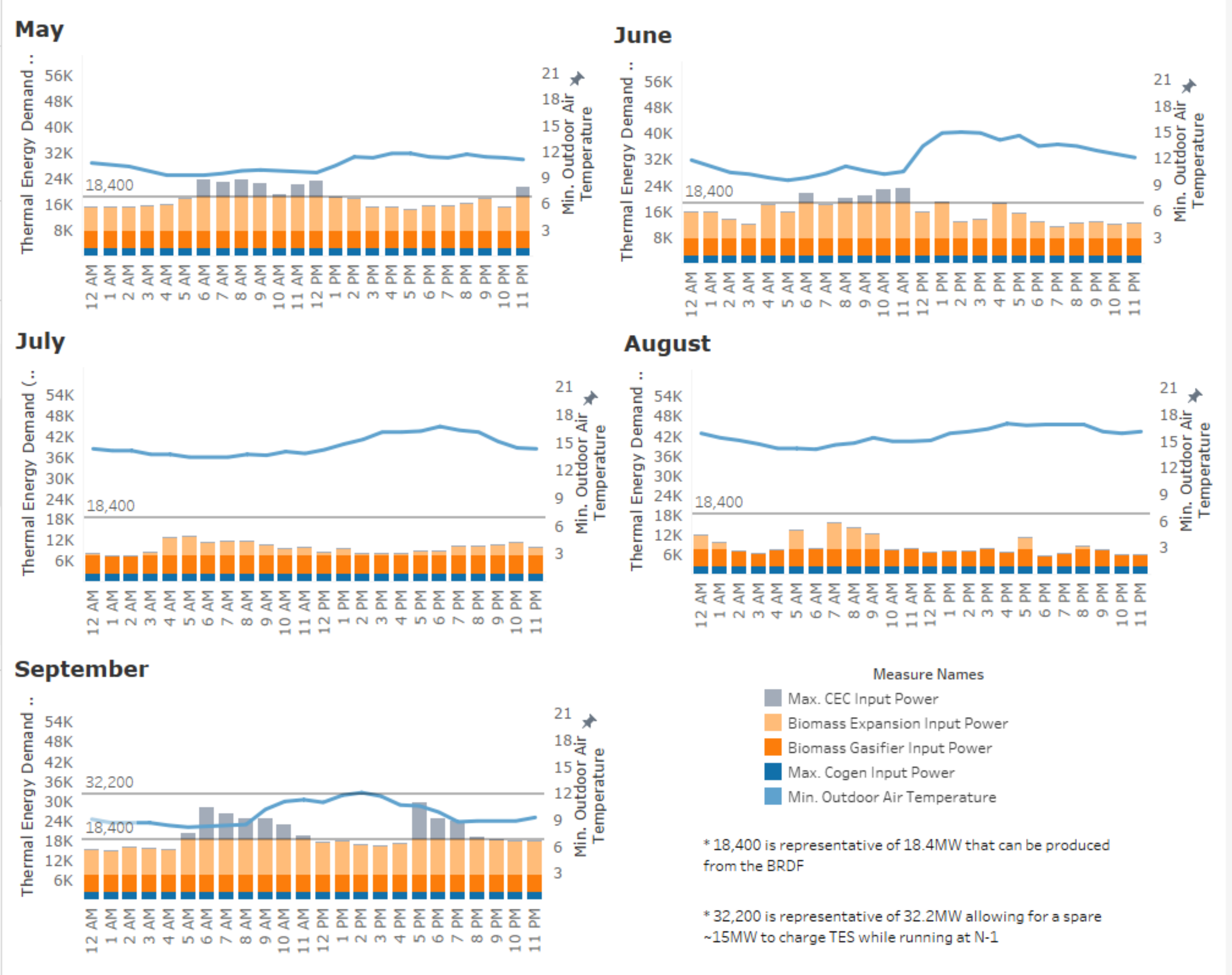
December

* 46,000 is representative of 46MW for DES capacity with N-1

* 32,200 is representative of 32.2MW allowing for a spare ~15MW to charge TES while running at N-1

Figure 7 – Maximum demand from each month of the shoulder seasons

Demand profiles for the warmer summer months, including May, are shown in Figure 8 below for May through September. The majority of the days in these months fall into the first scenario and require little thermal energy in comparison to shoulder months. This campus demand can typically be supplied from the BRDF alone. The coldest day and maximum thermal energy demand is shown in the charts, but such days are really exceptional in these months. On these days, the BRDF in combination with thermal storage may be desirable.



* 18,400 is representative of 18.4MW that can be produced from the BRDF

* 32,200 is representative of 32.2MW allowing for a spare ~15MW to charge TES while running at N-1

Figure 8 – Maximum demand from each month of the summer season, including May

The final two months in question are typically the coldest in the year, January and February. Demand profiles for the most extreme cold days of those months are shown in Figure 9 below; they represent the greatest demand on the campus energy system and greatest strain on the generation capacity. Days such as the ones displayed in Figure 9 are exemplary of the fourth scenario. If the N-1 protocol is to be retained, campus growth and anticipated days such as the ones shown demonstrate the need for an additional natural gas boiler. However, the graphs are indicative of the most extreme cases, not the typical day. On average days during these months, the TES would still be beneficial, as some of the capacity strain would be alleviated by charging the system during times of lower demand to support the times of peak demand.

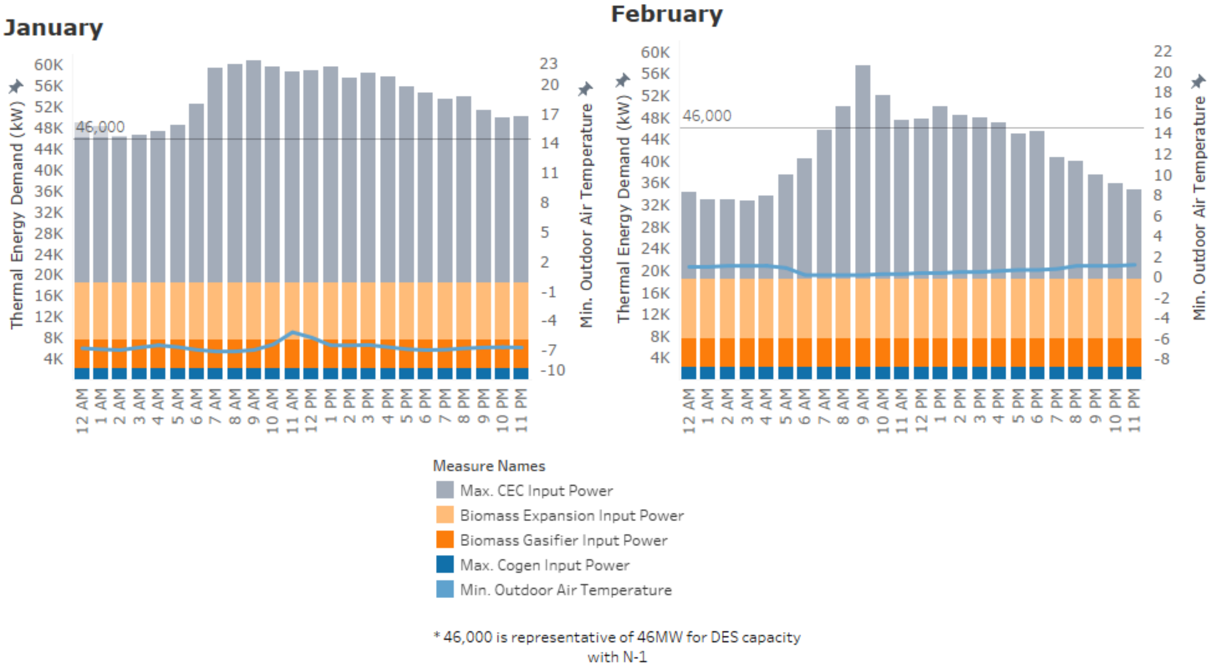


Figure 9 – Maximum demand for the coldest months of the year

In summary, there are 130 days when campus demand falls below 18.4 MW, when the BRDF alone can handle demand and as a result the energy source is “green.” There are 98 days when demand is such that the BRDF and one CEC boiler must be run to meet the demand. On these days, the TES system charged by energy from the single boiler not needed for campus demand or a second boiler could be used for TES charging and the N-1 protocol will be maintained. There are 219 days in which two boilers are necessary for one or several hours in the day. By charging the TES during the hours of lower demand, the TES system can then be leveraged during hours of peak demand to reduce the need to run the boilers as much during those hours. Finally, there are 19 days that are the coldest of the year when demand is so high that it is necessary to run all three boilers. On these days, there are fewer hours available to charge the TES system but the added charge allows for a safety net of added thermal energy that would act as an N-1 alternative.

From the analyzed data, it appears that approximately 18 MWh of thermal storage would allow the UBC DES system to charge and utilize the TES to address the largest spike shown in the month of November between 8-11am, while allowing the university to maintain the N-1 protocol. 18 MWh of storage was an estimation that was calculated from the charts shown above, by summing the hourly energy requirements over 46 MW on the coldest day in November, a shoulder season month. There are three hours where the energy demand exceeds the supply that the BRDF and two CEC boilers can produce, approximately 2 MWh + 12MWh + 4MWh. This TES capacity is adequate for most of the other shoulder season months and will reduce the need to run all three CEC boilers. This was used as a starting size to provide to the vendors to obtain budget quotes.

4 Discussion

4.1 Typical District Heat Storage Systems

Discussions with TES vendors in the course of this study confirmed the conclusion from the literature review, that district heating systems most commonly store thermal energy using a hot water storage tank. Hennessy et al. (2019) stated that "a centralised thermal storage tank installed next to a CHP is the most common TES configuration in DH. In fact, in Sweden and Denmark, where thermal grids are prevalent, nearly all CHP plants have short-term sensible storage tanks to cover peak demand periods."

Companies such as DN Tanks build large concrete tanks filled with thousands of cubic meters of water for the purpose of hot water storage. The insulation used depends on the temperature requirements and the allowable heat loss of the TES tank. The tanks of this size and material are atmospheric so the water temperature cannot exceed 100°C; more commonly, it is in the range 65 - 85°C. Because UBC's DH system is currently pressurized, operating at around 1000 kPag and can see temperature spikes up to 115°C, technologies like DN tanks are not viable as is. However, there are certain workarounds such as building in a decoupled system that uses a heat exchanger to separate the pressurised system from the atmospheric storage; see Section 2.

Universities around the world are beginning to implement thermal storage to reduce their footprints. Stanford has been an energy storage pioneer in North America through its implementation of three atmospheric thermal storage tanks, two for chilled water and one for hot water storage. The state of the art system is shown in Figure 10 below where the hot water storage tank can be identified by its red color. Other universities are expected to follow suit in the years to come as efforts to reduce GHG emissions becomes increasingly important (University, S. & Golden, M., 2019).

Figure 10 – Stanford energy facility with hot water storage in red
Source: University, S. & Golden, M. (2019, May 07)

4.2 Storage Options

Based on UBC's requirements, the most applicable type of TES is short-term storage as sensible heat. Three options were determined to be applicable for consideration for the UBC system:

1. Atmospheric tank - this option would require the system to be adjusted to run at lower temperature (less than 95°C) and lower pressure. It would be installed between the heat source (boilers) and the circulation pumps. This type of storage is most commonly used in district heating systems.

2. Atmospheric tank(s) with heat exchanger - the heat exchanger would allow the UBC DES to run at current pressure and temperature, but would lose thermal storage efficiency (heat loss).
3. Pressurized vessels - this option allows the UBC DES to run at current pressure and temperature; however, pressurized vessels are typically more costly than atmospheric tanks.

Vendors specializing in TES and pressure vessel fabrication were contacted to obtain information on the types of storage that they can provide. The brochures and budget quotes obtained are attached in Appendix 8.3 for reference. The vendor contacts are provided below:

DN Tanks
Guy Frankenfield (Guy.Frankenfield@dntanks.com)
Energy Market Manager

410 East Trinity Blvd.
Grand Prairie, TX
75050
www.dntankstes.com

5Blue Process Equipment Inc.
Lucian Negreanu, P.Eng (lnegreanu@5blue.com)
Mechanical Engineering Manager

2303 - 8th Street
Nisku, AB
T9E 7Z3
www.5Blue.com

Mcdermott/CB&I Storage Solutions
Rafael Velasco (rvelasco@mcdermott.com)

700 – 6th Avenue SW
Suite 1920
Calgary, AB
T2P 0T8
www.mcdermott.com

4.2.1 Atmospheric Tank Option

The atmospheric tank alternative was assessed and two alternative quotes were provided by DN tanks. The tank size quoted was based on vendor discretion to provide the most economical option based on a preliminary request of approximately 18MWh.

For a 25 MWh concrete storage tank, the unit cost is approximately $38,000 per MWh of storage. A larger, 75 MWh, storage tank was quoted at about $20,000 per MWh of storage to provide a comparison of the decrease in unit price as the tank size increases. These capacities are based on a supply temperature of 95°C and return of 70°C, keeping temperatures below 100°C for the reasons set out in earlier sections of this report. This option requires UBC to make adjustments to the current operating conditions.

This option is the most common approach taken for DH system thermal storage. Progressive universities like Stanford have opted for this technology (University, S. & Golden, M., 2019). This is a long term, forward thinking approach that allows for future integration of other renewable energy sources, and allows for further GHG reductions or carbon neutrality. This alternative, however, will require detailed review of the existing DH system and probably some modifications to enable operation at temperatures below 100°C.

4.2.2 Atmospheric Tank with Heat Exchanger Option

This option allows UBC to maintain current operating temperatures, which exceed 100°C during the winter season. Because the atmospheric tanks require temperatures below 100°C to avoid vaporization, the pressurized stream must be decoupled using a heat exchanger to enable non-pressurized storage.

A budget quote was not requested for this option because it involves more in depth design engineering, likely with multiple vendors, and therefore requires more time than could be allocated within this project.

4.2.3 Pressure Vessel Option

A budget quote was provided at \$370,000 for one 270m3 vessel, plus shipping fee of \$72,000 from Alberta. The 3.7m diameter by 24m long (seam to seam) horizontal vessel was based on the largest vessel that would be practical to ship.

This option also allows UBC to maintain the current operating temperatures, exceeding 100°C during the winter season. As the capacity requirement increases, the footprint to install multiple vessels also increases. While this option does not require pre-investment to decrease the UBC DES temperature, it is a near-sighted solution. Operation at above 100°C limits the renewable energy sources that can provide heat at such a high temperature. To provide a cost comparison with the atmospheric tank option, the price per MW was calculated to be approximately \$35,000/MWh of storage.

4.3 Potential Locations

The figures below show the overall UBC DES and identify potential locations to locate the thermal energy storage. As recommended by the tank vendor, the tank(s) should be located within approximately 100 metres of the energy generating source, i.e. the BRDF and/or the CEC, to maximise efficiency and reduce heat loss.

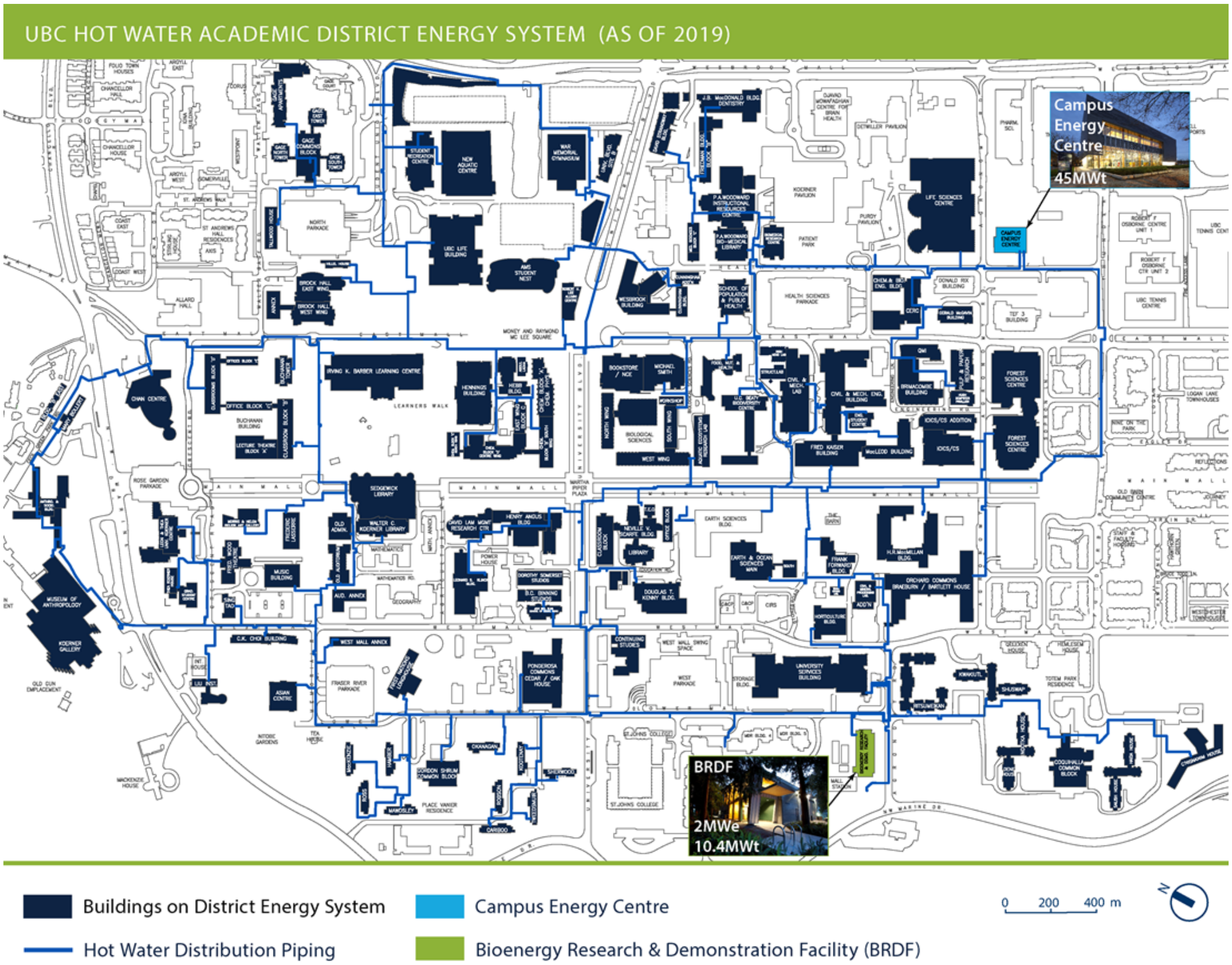


Figure 11 – UBC Academic District Energy System
Source: UBC EWS (n.d.)

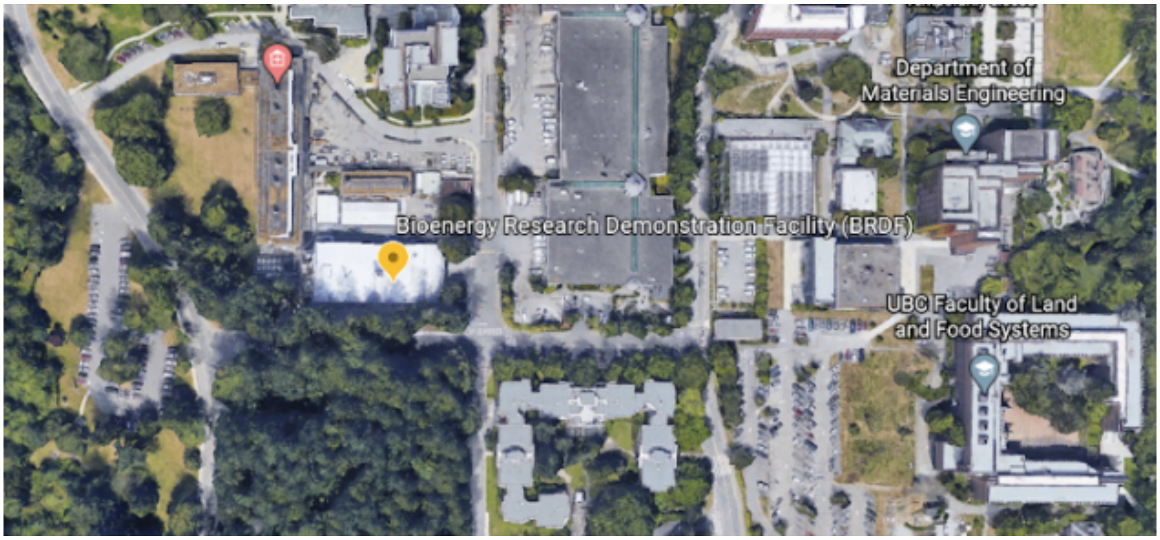


Figure 12 – BRDF and surrounding area
Source: Google Earth

Storage could potentially be installed in the parking lot behind the BRDF building, noted in Figure 12, or in the wooded area across the street. There is potential for an added storage tank beside the CEC assuming the field noted in Figure 13 is still an undeveloped area. It is worth noting that the Google Earth image in Figure 13 shows the CEC as under construction, indicating that these images are not current. Further possible locations need to be explored.

Figure 13 – Field beside CEC
Source: Google Earth

5 Future Considerations

The scope of this project was to assess thermal energy storage alternatives for UBC in the effort to bring UBC closer to a carbon-neutral future. As the assessment progressed, several additional considerations became apparent – obstacles to be overcome in upgrading UBC's heat distribution system to "third generation" practice. The most notable take-away from this work is the clear conclusion that UBC must reassess the operation of the district heating system, in particular the water temperatures which should be reduced from the current maximum, about 109°C, to below 95°C. This will allow for a reduction in system pressure. However, it may require an increase in water flow in the system, to convey sufficient heat, and this is likely to require replacement of some heat exchangers. Once the system is set to these operating conditions, more TES technologies will become suitable for use, safety will be significantly improved, and the costs of maintenance, insurance and certification should be reduced.

To aid in the continuation of the thermal storage journey, it is recommended that a phase two project be conducted to assess the component constraints driving the need for winter supply temperatures above 100°C. This is the first step necessary to upgrade the UBC district heating system from a generation 2 system to generation 3, enabling implementation of atmospheric TES. Evaluation of the capital expenditure to upgrade the necessary system components would be a beneficial component of this work.

To support the district heating system changes required for the TES implementation, further investigation should be done to quantify the GHG emissions from the current district heating system and the estimated 2030 system as a baseline. These figures should then be compared to the GHG emissions of the system with TES integration. It is recommended that the consideration of the district heating system emissions when TES is added in addition to a renewable energy source used to charge the storage. An assessment into the viable renewable energy sources for this purpose would be of significant benefit. The viability of each energy source for the university's geography should be assessed prior to implementation.

This assessment should be accompanied by an economic assessment that considers future carbon taxes, the addition of a natural gas boiler versus a TES system, and the potential energy generation savings as a result of the TES system. Eventually, the university should consider the same investigation for the conversion of existing gas-fired boilers to electric or the addition of heat pumps into the system. All of the above mentioned investments will aid in achieving net zero emissions future for the University of British Columbia.

Once the district heating system progresses to a third generation style system, UBC can confidently progress with adding thermal energy storage to the campus district heating system. More in depth assessment of the location for the TES tanks, or even further future seasonal storage, should be carried out. If UBC intends to add centralized or decentralized TES tanks, land use should be considered during campus planning.

6 Conclusion

As can be seen with the technology and systems discussed, district heating systems come in all shapes and sizes. DHC+ Technology Platform (2012) points out that "while employing similar operating principles, each network develops according to specific local circumstances and the historical developments of the technology in the region" (p.7). These are particularly good points to keep in mind when designing a new system, or upgrading an existing one: what works in one region may not be applicable in another. As district energy systems evolve to the fourth generation, they should provide a flexible infrastructure that allows a range of renewable energy sources to be integrated.

In order to reach the carbon neutral goal, it is recommended that UBC first analyse their current district heating system to understand how system temperatures and pressures can be reduced to atmospheric pressure. This advance towards third and fourth generation DH systems has become an industry standard. UBC has already invested in third generation infrastructure as part of the steam-to-hot water upgrade; now the university must take the next steps to lower operating temperatures to 95°C or below and complete the transition into the third generation. This action presents the most logical first step, followed by the implementation of an atmospheric TES tank. The addition of a TES system will alleviate the need to add an additional natural gas boiler, has the potential to reduce power generation expenditures, and ideally reduce the campus GHG emissions as exemplified by the Stanford campus. For that reason, it is necessary to scope the location for the potential tanks early on, prior to further campus development.

In the long term, UBC should continue to advance their system through the use of additional renewable energy sources. Converting the natural gas boilers, while a major capital expenditure currently, should remain a strong consideration for the future, considering future techno-economic analysis. As more universities continue towards carbon neutrality, UBC can leverage the best practices and know-how to better their DH system. Through further development and innovation, there is a real possibility that they can operate as a carbon neutral energy system.

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8 Appendices

8.1 Case Study – Drake Landing Solar Community

Information on the Drake Landing Solar Community (DLSC) project was obtained from the Drake Landing Solar Community website. Natural Resources Canada developed the DLSC project, which is located in Okotoks, AB and services 52 houses in the community. It utilizes a district system that collects and stores solar energy (heated water) underground during the summer months, and then distributes the energy during winter months for space heating.

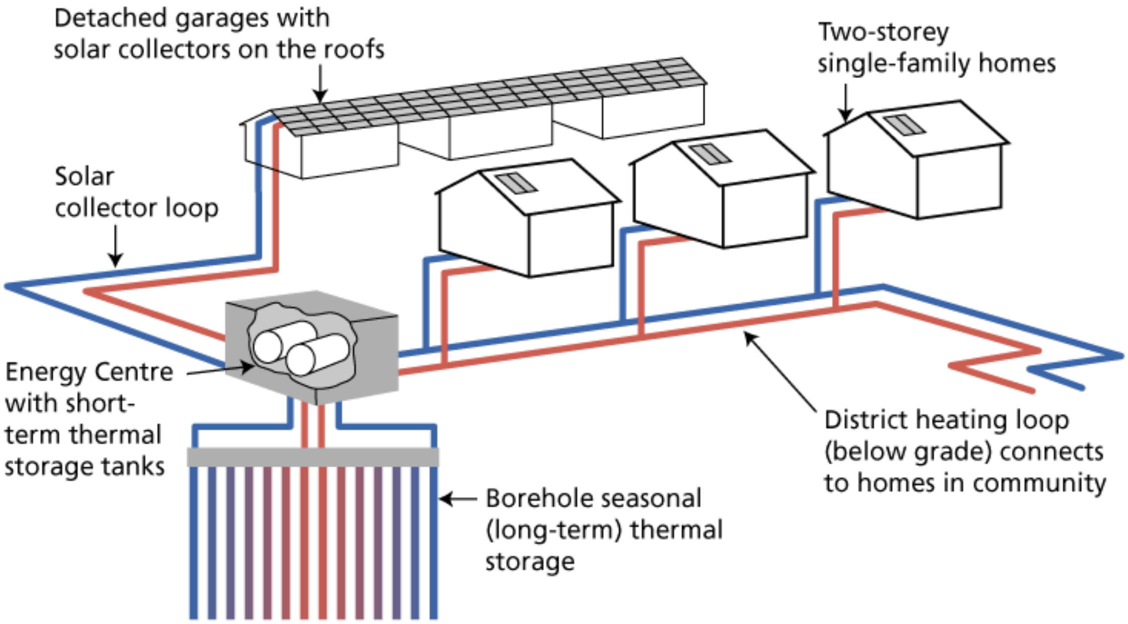


Figure 14 – Solar Seasonal Storage and District Loop
Source: Drake Landing Solar Community (n.d.)

In the summer time, solar energy is captured with 800 solar panels that are mounted on garage roofs throughout the community. The panels heat up a water/glycol solution, which then travels to the Energy Centre. At the Energy Centre, a heat exchanger transfers the heat from the solution to the short-term thermal storage tank, and then is returned back to the solar collector system. The heated water in the short-term storage tank is then injected into the borehole thermal storage (BTES) system, which will then heat the ground for seasonal energy storage. After exchanging heat with the ground, the water is circulated back to the short-term storage to repeat the cycle.

By the end of each summer, the ground temperature will reach up to 80°C. However, it is interesting to note that "it took approximately three years to fully charge the BTES field. In the first years of operation, the field operated at relatively low temperatures, and the recoverable energy was largely depleted before the end of the heating season" (DLSC, n.d.).

In the winter time, the heat from the BTES is retrieved to use for space heating in the homes. The heated water is cycled from the BTES to the short-term storage tank, and then circulated to the homes through the district heating loop. The figure below shows the aerial and side views of the BTES.

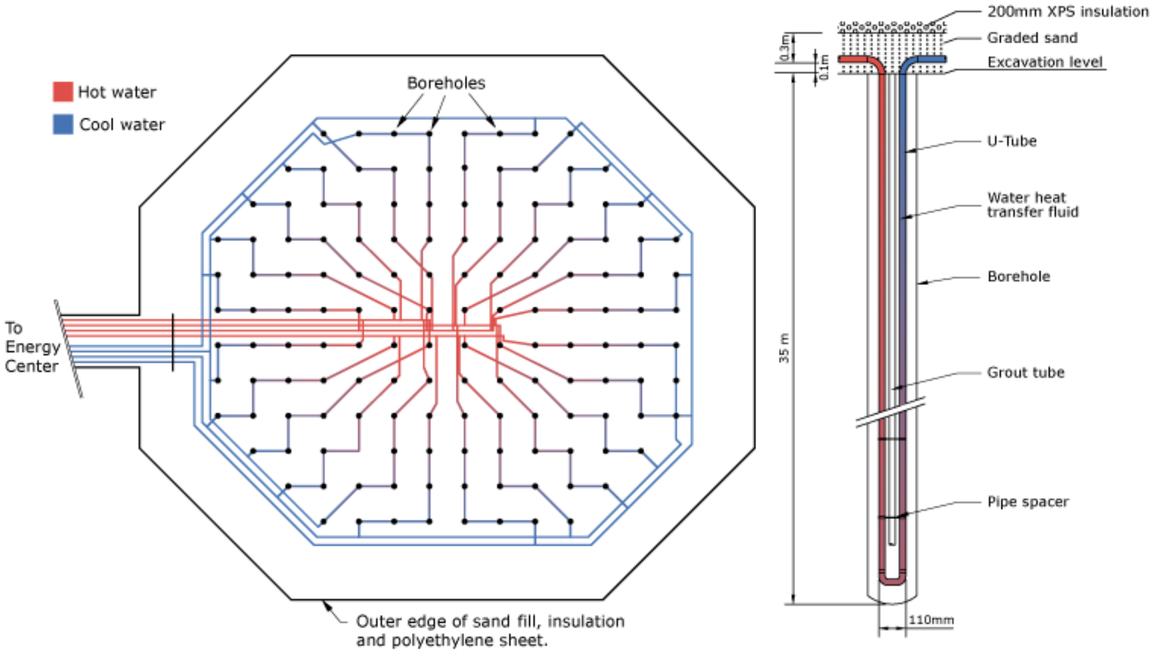
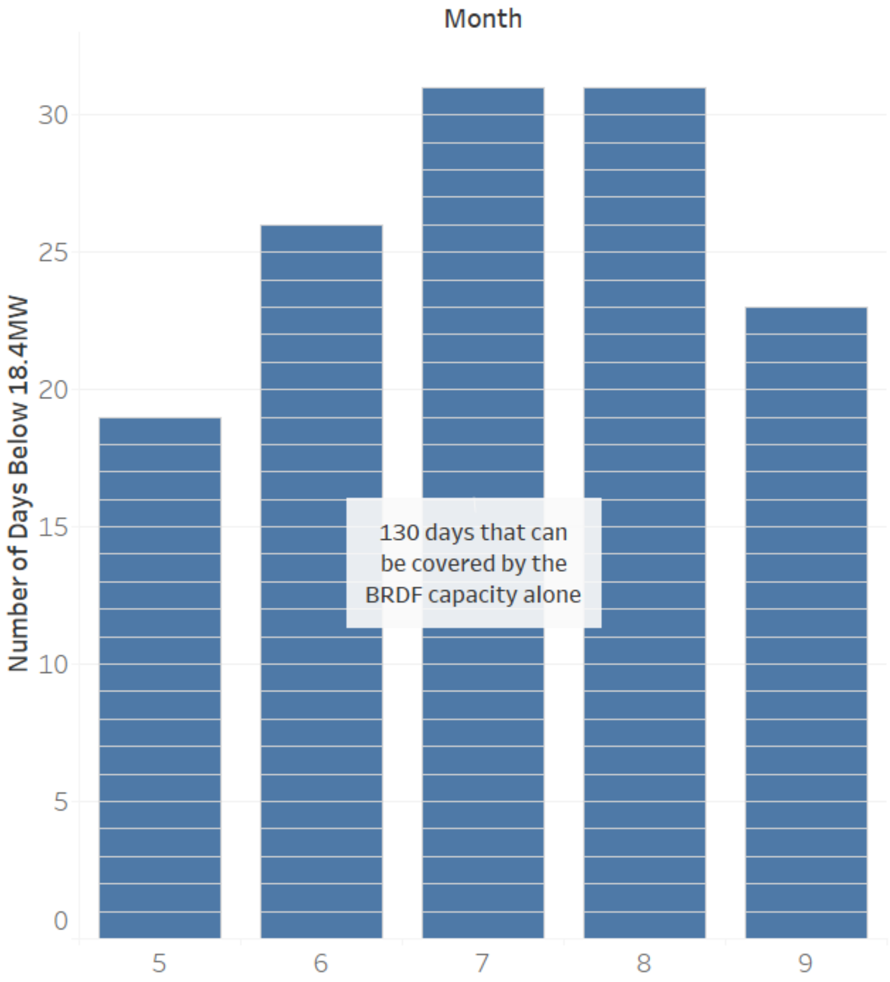
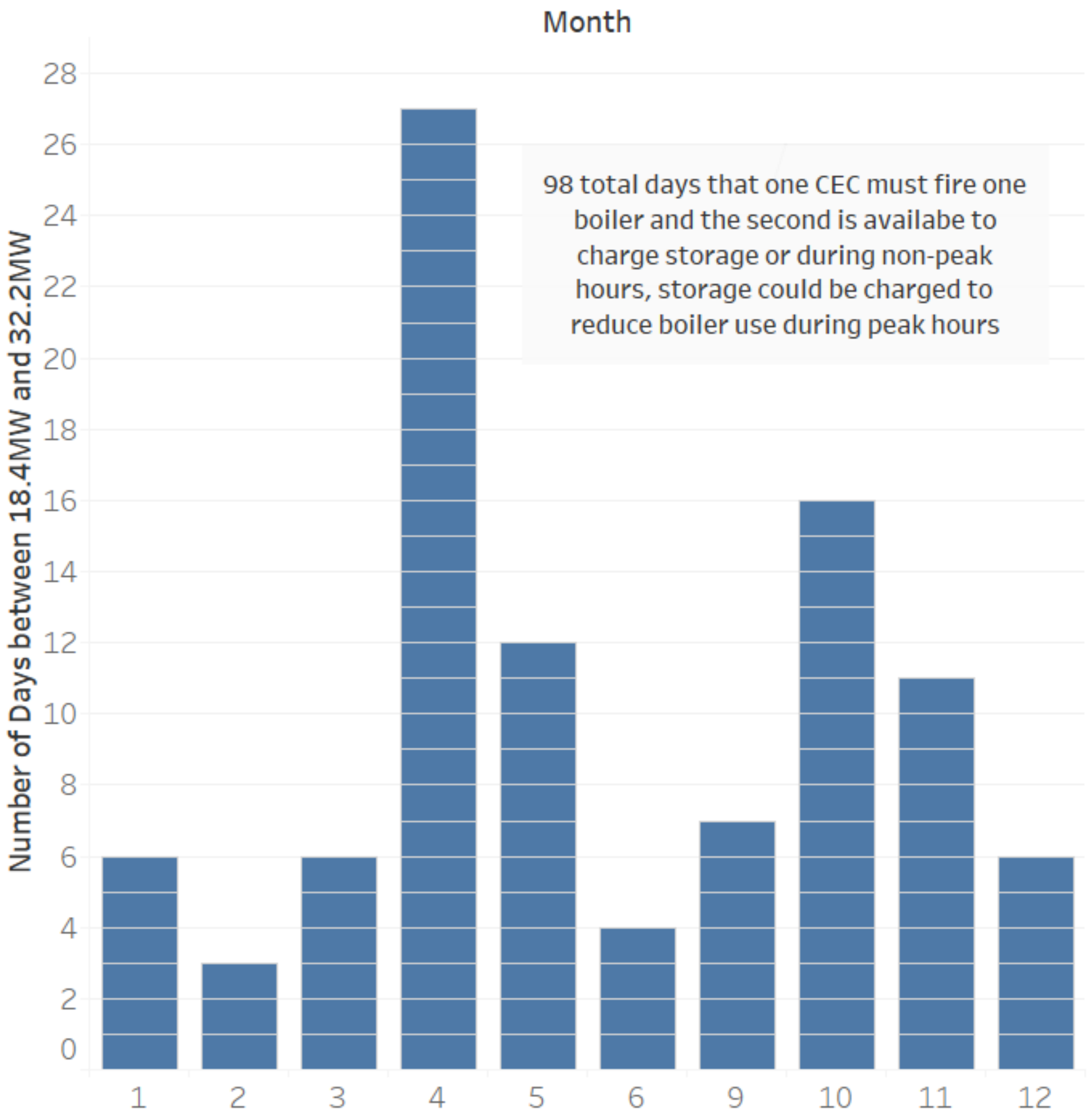
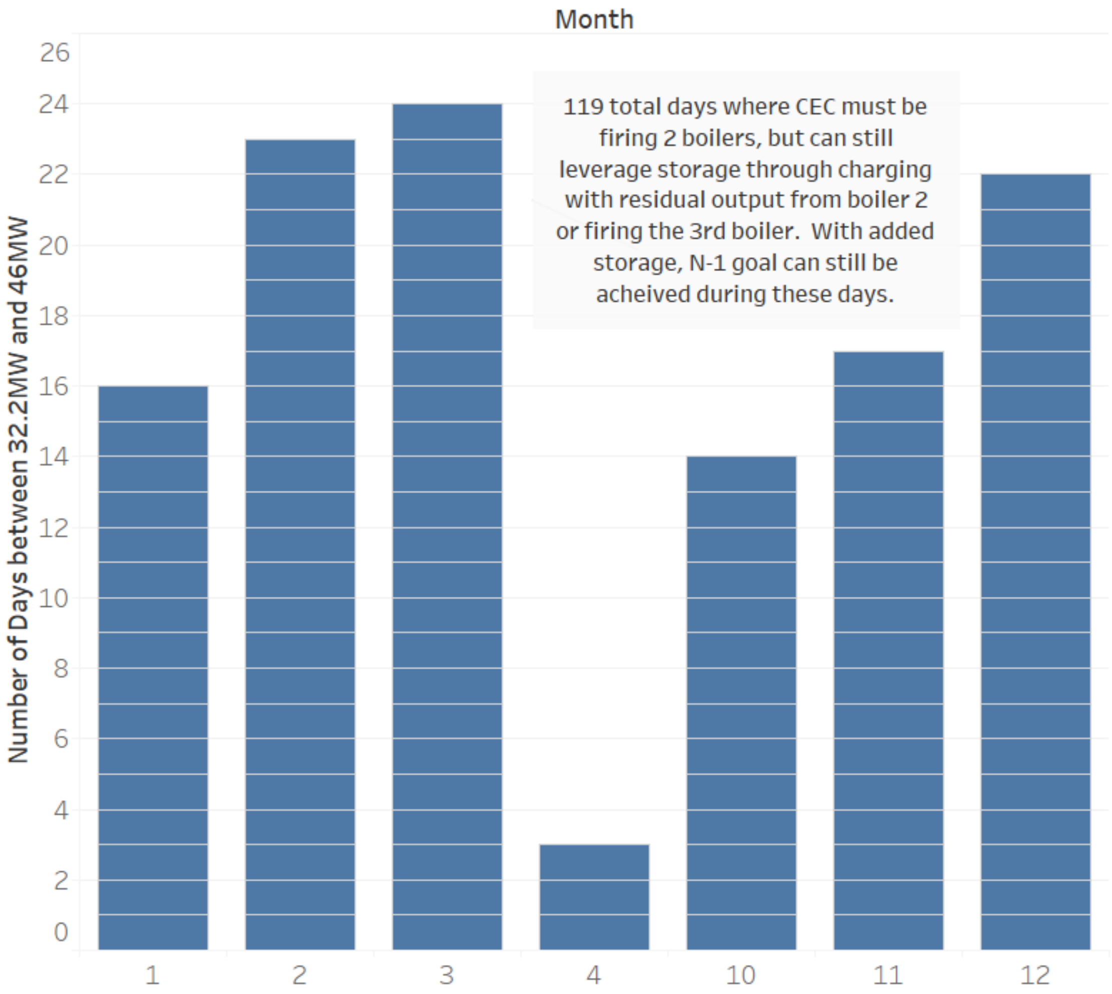


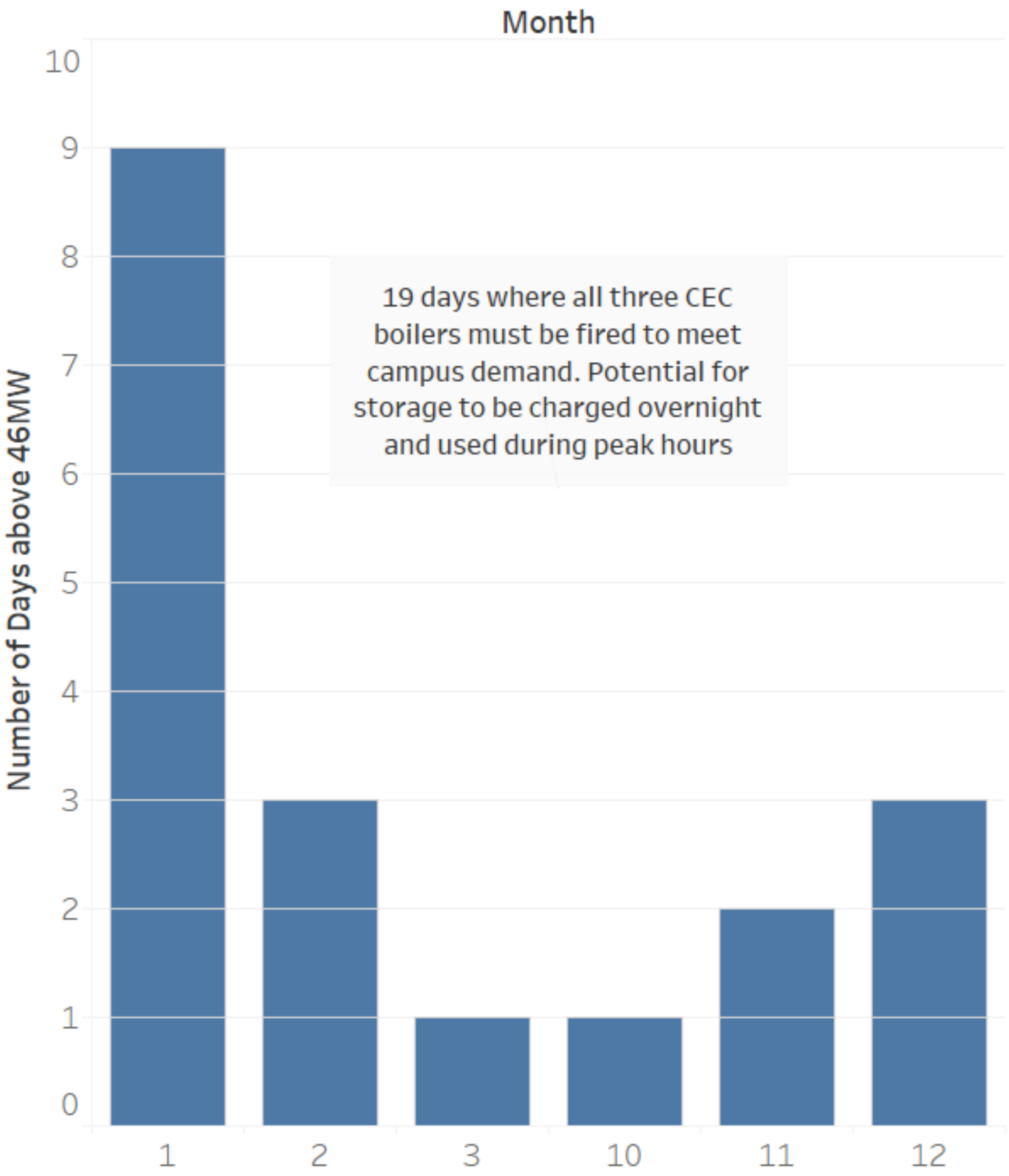
Figure 15 – BTES System
Source: Drake Landing Solar Community (n.d.)

8.2 Tableau Figures




Month
Number of Days between 18.4MW and 32.2MW
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
9
10
11
12
98 total days that one CEC must fire one boiler and the second is availabe to charge storage or during non-peak hours, storage could be charged to reduce boiler use during peak hours


Month
Number of Days between 32.2MW and 46MW
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
10
11
12
119 total days where CEC must be firing 2 boilers, but can still leverage storage through charging with residual output from boiler 2 or firing the 3rd boiler. With added storage, N-1 goal can still be acheived during these days.



19 days where all three CEC boilers must be fired to meet campus demand. Potential for storage to be charged overnight and used during peak hours

8.3 Vendor Information

Issued as separate PDF attachments for reference.