# Energy and Economic Analysis of an Ice-Storage System for an Office Building Using the Time of Use Tariffs for Toronto Hydro

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## Abstract

A baseline medium office building archetype model is used to assess the energy, peak reduction, and economic potential of an ice-storage system using time of use tariffs for Toronto Hydro. The results show that this mature technology can effectively reduce peak electricity during on-peak periods, and it has a small effect on the cooling related electricity consumption. However, it is also found that total electricity cost with ice storage deployed during on-peak periods is higher with the time of use tariffs than the base case with a tiered tariff. As a result, utilities such as Toronto Hydro need to better tailor their time of use tariff structures to enhance the financial performance of ice-storage systems so they can be more widely adopted as the electrification of buildings increases.

## Introduction

The electrification of the heating and cooling of the building stock is an essential part of the Government of Canada's plan to meet its targets for a net-zero-emissions economy. According to the National Energy Regulator (2023), in 2021 electricity represents about 38% of the total energy end-uses in the residential and commercial buildings sectors combined. Under the current measures scenario this is expected to grow to 46% by 2030 and to 50% by 2050. Under the global net-zero scenario these shares are projected to be 47% and 69%, respectively. Also, by 2030 under the global net-zero scenario buildings will account for about 57% of the total electricity consumption in Canada. Therefore, it is expected that buildings will contribute significantly to the peak electricity demand. Thermal storage technologies can help reduce the strain on the grid as electrification of buildings increases. This study deals with a mature technology for reducing cooling related electricity peak from on-peak to off-peak periods.

Conventional control strategies for ice-storage systems can be either full storage or partial storage (Henze et al. 2003). In full storage systems the ice-storage tank is sized to meet the total cooling load during the designated on-peak period while the chiller is off during this period. In partial storage systems we can have either chiller priority, storage priority, or constant-proportion control. In chiller priority mode the chiller runs continuously at reduced capacity and the storage is deployed to meet the remaining load. However, storage priority mode aims to use the storage system as much as possible during the on-peak period. In constant proportion the storage and the chiller meet a specific proportion of the load at all times.

Nassif et al. (2013) reports on the effect of an ice-storage system on the energy consumption, demand, and total energy cost for an existing office building in Florida. In that study an eQUEST model of the building predicts an increase of 11% in the energy consumption and a decrease of 32% in the annual energy cost with the use of a full storage ice system compared to base case that uses only a chiller. The Variable-Air Volume system in the building turns on at 7 a.m. and shuts off at 6 p.m. The on-peak period used is from 12 p.m. to 5 p.m. and the storage tank is charged from 10 p.m. until 7 p.m. The chiller setpoint is 7.22 °C during space cooling and -3.89 °C during the charging of the storage tank. The tariff structure used is US$0.06 per kWh for the base case and US$9.00 per kW for the base case with no ice storage. With storage the cost per kWh is US$0.08 and US$9.00 per kW during on-peak and US$0.05 per kWh during off-peak, respectively.

In another study Nassif et al. (2014) focuses on the optimization of the design of a chiller ice storage plant. They report that the use of ice storage can help reduce the size of the chiller by 20 to 25%. An optimization tool is developed to determine the optimum charging and discharging times, chiller size, and ice storage size for a given cooling load profile, utility tariff, and outdoor conditions. The chiller setpoint is -4 °C when charging the tank and 7 °C when meeting the space cooling load. An increase in the total energy consumption of 10% is reported with the use of ice-storage. The energy cost with the optimized system is 50% less using the same electricity tariff as in Nassif et al. 2013.

Henze et al. (2003) compare the relative performance of four operating strategies: constant proportion, partial storage with chiller priority, partial storage with storage

priority, and optimal control. They consider different types of ice storage systems and electric utility rate structures. Five building types are considered including a medium office and a large office. It is found that in many cases that storage priority was near optimal. The authors conclude that the success of an ice storage strategy is heavily dependent on good energy efficiency during the ice making process and on a favourable rate structure. Eight different tariffs are considered in this study and six them have both a cost per kWh and per kW. For most of the scenarios considered for the large office archetype, the increase in the cooling related energy consumption relative to the base varied from -3.0% to +8.0%.

In this study a medium office archetype model is used to predict the electricity peak, consumption, and cost using time of use and tiered tariffs from Toronto Hydro. The results will help assess whether the structure of these tariffs are sufficient to help increase the adoption of ice storage technology to effectively manage the effects of the anticipated increased electrification of the building stock.

## Reference Medium Office Building

The model used in this study is for the medium office archetype, shown in Figure 1, generated using the Building-Technology-Assessment Platform (BTAP), which is part of the open-source project 'openstudio-standards' hosted on GitHub. The model is compatible with the OpenStudio software version 3.6.1. The specifications in the performance path of the National Energy Code for Canada for Buildings (NECB) 2020 are used to generate the building model. The building has three storeys, a total conditioned floor area of 4982.2 $m^2$, and a fenestration to wall ratio of 40.0%. Each floor has four perimeter zones and one core zone, which are served by a Variable-Air Volume system and with baseboard heating. The cooling coils are hydronic and are connected to a chilled-water plant, which is connected to a water-cooled chiller linked to a cooling tower. Circulation pumps in the chilled-water and condenser loops are variable speed. The air systems have electric heating coils and the zones have electric baseboards.

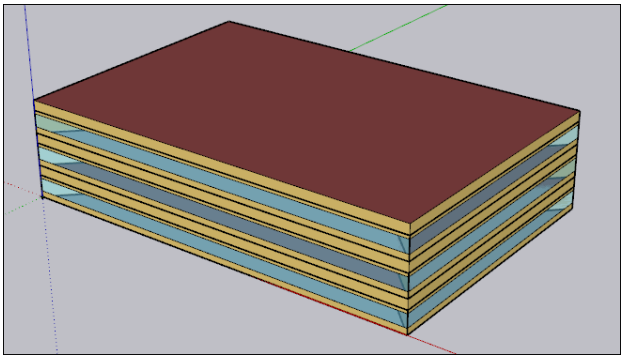

*Figure 1: Medium Office Archetype*

## Ice-Storage System

There are many different variations of the layout and operating characteristics of an ice storage system. Figure 2 shows the various components of the ice-storage system considered in this study. The chiller and the tank are placed in series. During off-peak hours the chiller is used to charge the storage tank. During this off-peak period there is no requirement for cooling in the building. During on-peak hours the chiller and/or the tank are used to meet the space cooling load based on a specific control strategy (full storage or partial storage). A 25% Ethylene Glycol solution is used as the working fluid. The chiller setpoint temperature is -4 °C during the charging phase of the ice-storage tank. The cold glycol solution is circulated inside pipes within the tank with ice forming on the outside of these pipes (inside-melt). The supply temperature to the building demand side is 7 °C. When full storage is used the setpoint temperature at the exit of the storage tank is set to 7 °C to meet the building cooling demand. In partial storage when the chiller is upstream of the tank the chiller setpoint can be set above 7 °C to divide the load between the chiller and the storage tank.

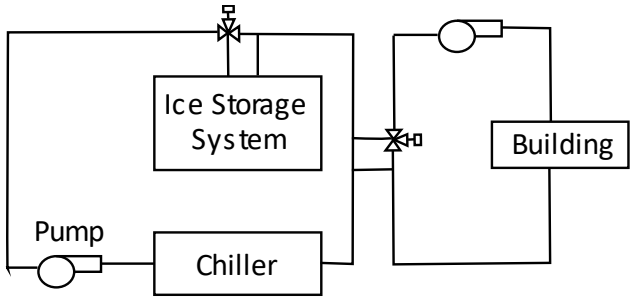


*Figure 2: Layout of ice-storage system*

## OpenStudio Measure for Ice-Storage

A measure named 'AddCentralIceStorage' to add ice-storage to an OpenStudio model is part of the Building Component Library (https://bcl.nrel.gov). The measure modifies the chilled-water loop of an existing model and adds an ice-storage tank such as the one in Figure 2 with the option of a chiller upstream or downstream of the tank. The EnergyPlus model 'ThermalStorage:Ice:Detailed' is used for the storage tank. The appropriate temperature setpoints and availability schedules for the chiller and the storage tank are set for either full or partial storage based on inputs for times of the day for charge start, charge end, discharge start, and discharge end. This measure doesn't include the option to size the storage tank based on summer design day cooling loads.

The 'AddCentralIceStorage' measure is adapted and included as part of BTAP as a separate Ruby method. After a sizing run the method is called and the cooling loads on the chiller are used to estimate the size of the storage tank needed and update the size of the chiller. Then the chilled-

water loop is modified to include a storage tank based on the inputs specific to the ice-storage system.

In order to properly estimate the electricity consumption of the chiller during the charging phase, it is important to account for the effect of the lower evaporator temperature on the COP and the capacity. This information is difficult to obtain directly from manufacturers. The Thermal Storage chapter of the ASHRAE HVAC Systems and Equipment Handbook (2020) recommends a value of 0.7 for the capacity correction curve during the charging phase, which is the same value used by Sehar et al. (2012). The Performance Path of the National Energy Code of Canada for Buildings 2020 specifies performance curves for capacity and Energy-Input Ratio for centrifugal, scroll, and rotary chillers. It is found that the curves for the rotary chiller can be extrapolated to a chiller setpoint temperature of -4 °C. At this setpoint temperature and a condenser inlet temperature of 29 °C, the capacity correction curve has a value 0.64 which is deemed acceptable. The NECB curves for the rotary chiller type are then used in the present study.

The reference NECB medium office model has a setpoint supply temperature for the condenser loop of 29 °C. In order to improve the performance of the chiller during the charging phase, the setpoint temperature for the condenser loop is allowed to float between 21 and 29 °C to take advantage of the lower ambient temperatures during off-peak periods.

## Toronto-Hydro Time of Use Tariffs

At the time of conducting the present study the details of the tariffs in effect during the summer of 2024 have not been published yet by Toronto Hydro. Tariff details in effect during the summer of 2023 is then used in the present study. Toronto Hydro offers two types of time of use tariffs for business customers: 'Time-of-Use Rate (TOU)' and 'Ultra-Low-Overnight (ULO)'. Table 1 contains information on the time of use periods and the associated electricity rates for the TOU tariff while Table 2 has this information for ULO tariff. The utility also has a 'Tiered' tariff with the first tier for electricity below 600 kWh/month at 8.7 c/kWh and the second above this limit at 10.3 c/kWh.

The tariffs also have customer charges which are a fixed amount per 30 days and are ignored in this analysis, because they are the same for the base case and the case with cold storage. There are also distribution charges that depend on the building class type, which depends on the maximum average monthly electricity demand. The medium office archetype belongs to the class 50-999 kW. In this case the total distribution charges add up to $9.9732 per kVA per 30 days, and the transmission charges add up to $6.7618 per peak kW per 30 days. If we use a power factor of 0.8, then the total demand charge would be $19.23 per peak kW. For comparison Hao et al. (2022) report demand charges for California utilities of US$19.13 for Pacific Gas and Electric and US$19.61 for Southern California Edison.

*Table 1: Toronto Hydro Time-of-Use (TOU) Electricity Tariff*

| Period | Weekday | Weekend |
|---|---|---|
| 7:00 AM-11:00 AM | Mid-Peak (10.2 c/kWh) | Off-Peak (7.4 c/kWh) |
| 11:00 AM-5:00 PM | On-Peak (15.1 c/kWh) | |
| 5:00 PM-7:00 PM | Mid-Peak (10.2 c/kWh) | |
| 7:00 PM-7:00 AM | Off-Peak (7.4 c/kWh) | |

*Table 2: Toronto Hydro Ultra-Low Overnight (ULO) Electricity Tariff*

| Period | Weekday | Weekend |
|---|---|---|
| 7:00 AM-4:00 PM | Mid-Peak (10.2 c/kWh) | Off-Peak (7.4 c/kWh) |
| 4:00 PM-9:00 PM | On-Peak (24 c/kWh) | |
| 9:00 PM-11:00 PM | Mid-Peak (10.2 c/kWh) | |
| 11:00 PM-7:00 AM | Ultra-Low-Overnight (2.4 c/kWh) | Ultra-Low-Overnight (2.4 c/kWh) |

## Sizing of Storage Tank and Chiller

The base case NECB 2020 medium office archetype uses a chilled-water plant to serve cooling coils in the air handling units. At the end of a sizing run within BTAP the time step cooling loads on the chiller during the summer design day are known. Then given a discharge period and whether the design strategy is full or partial storage, the total cooling energy that needs to be displaced to off-peak hours can be determined. This energy is the required size of the storage tank. For full storage an additional sizing factor of 10% is applied.

The total cooling energy to be displaced to off-peak hours is used to estimate a chiller capacity that can deliver this amount of energy during the charging period. This process accounts for the effect of the chiller setpoint temperature and condenser inlet temperature on the capacity of the chiller. In addition, the chiller still has to meet any cooling load outside of the charge and discharge periods. The final size of the chiller is then set to the maximum capacity needed to meet the demand for charging of the ice storage tank and the cooling loads of the building. An additional sizing factor of 10% is applied as stipulated by NECB 2020.

## Results and Discussion

Results are generated for the base case, full storage and partial storage scenarios using time of use information for the TOU and ULO tariffs of Toronto Hydro. An EnergyPlus

Weather file based on a Canadian Weather for Energy Calculations (CWEC) file for Toronto Pearson Airport is used. The simulation period is from May 1st to September 30th. It is decided in this study to focus first on the shifting of cooling loads from on-off periods to off-peak periods, because the time of use tariffs from Toronto Hydro offer the largest cost differential in the cost of a kWh between these two periods.

In the case of full storage, the tanks are sized to meet the full cooling demand during the on-peak period as specified in Table 1 and Table 2. The tank is charged off-peak from 9:00 PM to 5:00 AM for the TOU tariff, and from 11:00 PM to 5:00 AM for the ULO tariff. In the partial storage cases the chiller is placed upstream of the storage. During the discharge period the chiller setpoint temperature is 8.75 °C and 10.5 °C for the 25% and 50% partial storage cases, respectively. The storage tank then cools the liquid to the 7 °C needed for the building.

**Summer Design Day Chiller Electricity Demand and Storage Tank Ice Fraction**

Figure 3 shows the chiller electricity demand for the base case and for full storage (F-TOU and F-ULO) on the cooling design day for Toronto. The chiller starts to precool the building at 5:00 AM to reach the target cooling setpoint for the zones of 24 °C at 6:00 AM. The call for cooling in the building stops at 9:00 PM. This is why the charging of the tank occurs during off-peak periods outside of the time period 5:00 AM-9:00 PM. The electricity demand during charging of the chiller for the ULO tariff is smaller due to the smaller size of the tank needed in this case. Figure 4 shows the variation of the ice fraction in the storage tank during the design day for both tariffs. The charging of the tank starts at 9:00 PM for the TOU tariff and at 11:00 PM for the ULO tariff, but both tanks are fully charged at about the same time close to 4:00 AM.

Figure 5 shows the variation of the chiller electricity consumption for 25% partial storage on the summer design day. This control strategy is similar to imposing a limit on the capacity of the chiller. The chiller size in this case is comparable to the full storage case. Therefore, it takes only about 3 hours for TOU and 2 hours for ULO to fully charge the tanks as shown in Figure 6.

The results in Figure 3 and Figure 5 show that there is a very limited peak shaving for the full design day due to the large electricity demand still occurring during the mid-peak periods.

**Electricity Consumption**

Table 3 contains the results for electricity consumption for end-uses affected by the use of the ice-storage tank. Both full storage (F-TOU and F-ULO) and partial storage (P-TOU and P-ULO) scenarios are shown in the table. The total electricity consumption for scenarios with ice storage are

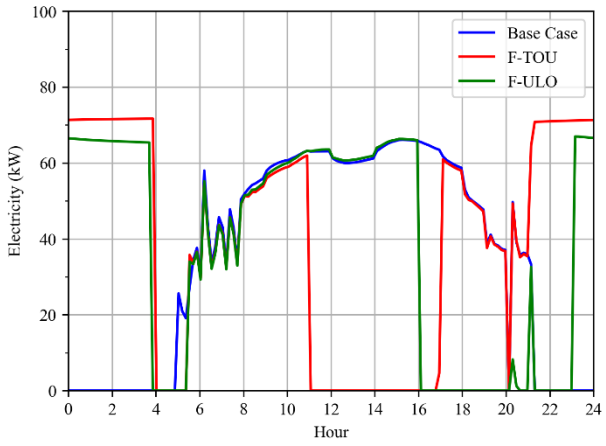


*Figure 3: Chiller Electricity Demand for Base Case and Full Storage on Summer Design Day*

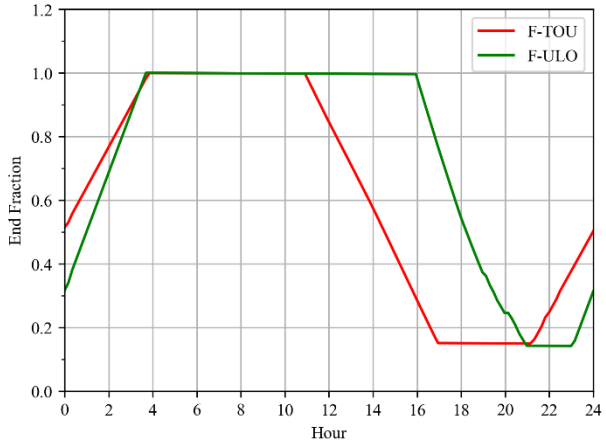


*Figure 4: Full Storage Ice Fraction During the Summer Design Day*

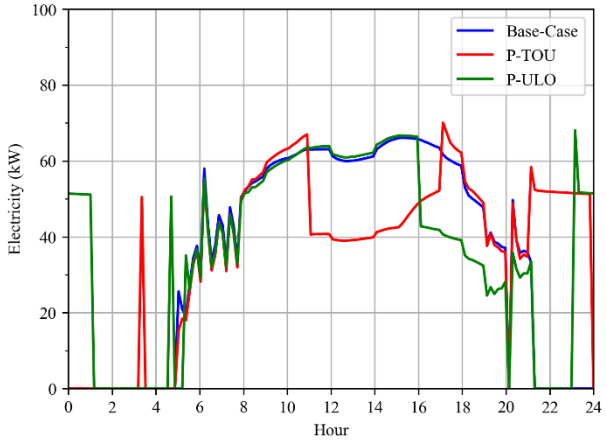


*Figure 5: Chiller Electricity Demand for Base Case and 25% Partial Storage on Summer Design Day*

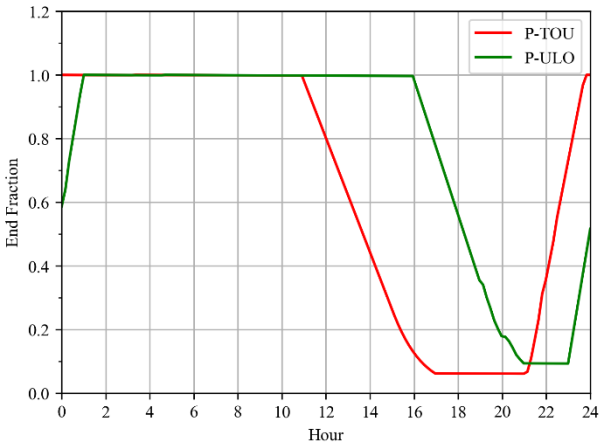


*Figure 6: End fraction for 25% Partial Storage During the Summer Design Day*

*Table 3: Equipment Electricity Consumption*

| Case | Chiller (GJ) | Pumps (GJ) | Heat Rej. (GJ) | Total (GJ) | PI (%) |
|---|---|---|---|---|---|
| Base Case | 207.1 | 55.7 | 11.0 | 273.7 | |
| F-TOU | 211.4 | 53.7 | 17.8 | 282.9 | 3.3 |
| P-TOU-25 | 203.7 | 56.3 | 16.9 | 276.9 | 1.2 |
| P-TOU-50 | 207.3 | 58.0 | 18.4 | 283.7 | 3.6 |
| F-ULO | 195.3 | 51.2 | 17.8 | 264.3 | -3.4 |
| P-ULO-25 | 198.3 | 55.5 | 18.2 | 272.0 | -0.6 |
| P-ULO-50 | 196.8 | 53.9 | 18.1 | 268.9 | -1.4 |

very comparable to the base case as confirmed by the low percentage increase PI values in the table. There is a consistent increase in the heat rejection equipment electricity consumption for the ice storage cases because of the lower condenser loop supply temperature setpoint in these cases. These results confirm that ice-storage doesn't necessarily save energy. Nassif et al. (2013 and 2014) reports an increase in total energy of about 10% with the use of ice storage. It is not clear though that if in these studies the condenser loop setpoint temperature is lowered to take advantage of the lower dry-bulb temperatures at night. The results are also in line with the relative increase in energy consumption reported by Henze et al. (2003) that varied from -3.0% to +8.0%.

**Chiller and Tank Sizes**

Table 4 shows the sizes of the chiller and storage tank needed for the various scenarios. It is found that the required chiller capacities are very close for all the cases considered. The storage tank is sized to meet all or part of the cooling demand during on-peak periods. A properly sized chiller is still needed for all other hours of the day when the storage tank is not deployed. The on-peak period for the ULO tariff results in smaller tank sizes in all cases compared to the TOU tariff. This is expected since the ULO tariff has a shorter on-peak period (5 vs 6 hours) and the period occurs later in the afternoon when the cooling loads are smaller.

*Table 4: Sizes of Chiller and Storage Tank*

| Case | Chiller Capacity (kW) | Tank Size (GJ) | PR |
|---|---|---|---|
| Base Case | 353.8 | NA | NA |
| F-TOU | 367.0 | 7.22 | 50.9 |
| P-TOU-25 | 340.6 | 1.82 | 93.2 |
| P-TOU-50 | 340.5 | 3.64 | 84.5 |
| F-ULO | 358.9 | 4.54 | 49.7 |
| P-ULO-25 | 358.9 | 1.52 | 86.4 |
| P-ULO-50 | 358.9 | 3.07 | 68.9 |

One way we can compare the relative performance of the ice storage systems for the various scenarios is to compare their ratios of cooling energy provided by the tank to the tank size. A higher ratio indicates that the tank is more fully deployed leading to better return on investment. This ratio PR for performance ratio is also shown in Table 4. As expected, the full storage scenario has the lowest PR values, because of excess tank capacity for most of the cooling season. The highest ratios are for the smallest tanks sizes based on 25% of the design loop temperature difference of 7 °C. It is also found that tariff ULO leads to lower values for PR probably because of the higher variability in the cooling loads during its on-peak period, which happens later in the afternoon from 4:00 PM-9:00 PM.

**Economic Analysis**

The time step total electricity consumption of the building predicted by the models is used to determine the total cost of electricity per floor area shown in Table 5 for the period from May 1st to September 30th. The table shows both the cost for the electricity consumed (kWh) and the demand charges for the 30-day peak (kW). The base case is assumed to be using the Tiered tariff from Toronto Hydro, which doesn't incentivise shifting electricity consumption to off-peak hours. The total cost of electricity is always higher than the base case when ice storage is used to shift on-peak electricity from on-peak to-off peak periods with either TOU or ULO tariffs. Also, the cost of electricity for partial storage is higher given the high cost per kWh for using more electricity during on-peak periods in the time of use tariffs. These results indicate that the savings in electricity cost from using ice storage cannot offset the higher cost of electricity during peak-periods with the time of use tariffs for non-cooling related electricity consumption.

The results in Table 5 show that there are almost no savings in the cost related to demand charges with ice-storage. This is because the shifting of cooling electricity consumption is only limited to the on-peak period, which has little impact on the magnitude of the maximum monthly electricity demand for this building archetype.

Therefore, an investment in an ice-storage system based on the current TOU and ULO tariffs structures to shift electricity only from on-peak to off-peak cannot be justified for the modelled archetype when compared to using a Tiered tariff with no storage. Additional incentives will be needed in the Toronto Hydro time of use tariffs to improve the financial benefit of deploying ice-storage.

In addition to the structure of the utility tariff, there are several operational factors that would decrease the energy efficiency and in turn the economic benefit of an ice storage system. First there is the reduction of the COP of the chiller with the lower evaporator temperature needed for ice making. Second there is the electricity consumption of circulation pumps that still need to operate during on-peak periods. Then there are heat gains to the tank and its auxiliary electricity consumption during charging and discharging phases. All of these effects need to be minimized to maximize the benefits from using an ice storage system.

*Table 5: Building Total Electricity Consumption and Cost for Ice Storage System*

| Case | Elec. (kWh/m$^2$) | kWh Cost ($/m$^2$) | kW Cost ($/m$^2$) | Total Cost ($/m$^2$) |
|---|---|---|---|---|
| Tiered | 48.5 | 4.99 | 3.97 | 8.96 |
| F-TOU | 49.0 | 5.24 | 3.86 | 9.10 |
| P-TOU-25 | 48.7 | 5.48 | 3.94 | 9.42 |
| P-TOU-50 | 49.1 | 5.35 | 3.95 | 9.30 |
| F-ULO | 48.0 | 5.43 | 3.97 | 9.40 |
| P-ULO-25 | 48.4 | 5.86 | 3.97 | 9.83 |
| P-ULO-50 | 48.3 | 5.51 | 3.97 | 9.49 |

**Effect of Limiting Demand Charges to On-Peak Periods**

Figure 7 shows the total electricity demand during the first week in July for the base case and full storage with the TOU tariff on-peak period. The figure shows the chiller turning on on the weekend to prevent internal zones from overheating, and to remove the heat gains from the surrounding to the tank. As stated previously ice storage has a limited impact on the monthly peak demand, but a significant impact on the peak during the on-peak periods. The figure also shows that the chiller electricity demand represents less than 50% of the total electricity demand during the on-peak periods. The high fraction in this case of non-cooling related electricity consumption during on-peak periods has a significant negative effect on the economic benefit of an ice-storage system as confirmed by the costs in Table 5. Extending the use of ice storage to the mid-peak periods can help improve the economic benefit of storage. It would also allow for a much larger decrease in peak demand. These same findings would also apply to the ULO tariff.

In Table 6 the total monthly peak demand reduction is shown for the different scenarios for the on-peak periods from May to September relative to the base case. The table also shows the savings in the cost of electricity if the demand charge of Toronto Hydro were applied only to the monthly maximum demand during on-peak periods. The cost of electricity savings are all positive except for the 25% partial storage.

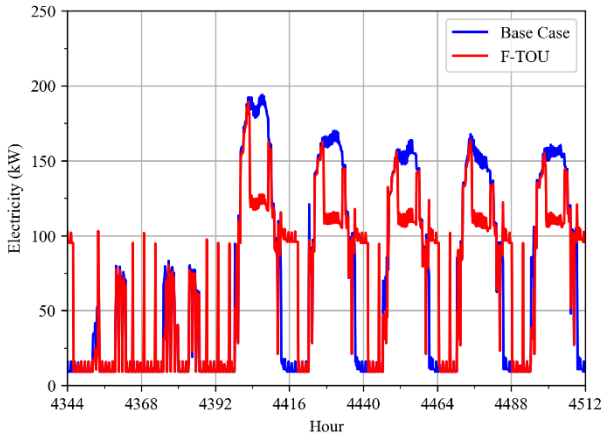


*Figure 7: Total Building Electrical Demand for Base Case and Full Storage During the First Week of July*

*Table 6: Sum of Monthly Peak Demand Reductions Relative to Base Case and Payback Years*

| Case | Total Peak Reduction (kW) | Elec. Savings ($/m$^2$) | Simple Pay Back (Years) |
|---|---|---|---|
| F-TOU | 366.9 | 1.16 | 17.9 |
| F-TOU-25 | 104.1 | -0.09 | --- |
| F-TOU-50 | 159.2 | 0.25 | 41.9 |
| F-ULO | 359.7 | 0.95 | 13.7 |
| P-ULO-25 | 115.3 | -0.42 | --- |
| P-ULO-50 | 183.8 | 0.19 | 46.5 |

Hao et al. (2022) report an estimate for the cost of an internal-melt ice storage tank of US$126/ton-hour. Using the same inflation rate of 7% used by Hao et al. and a currency exchange of 1.35, the cost for an ice tank is estimated to be $14,376/GJ in 2023. In the case of using ice storage only during on-peak periods, the capital cost difference with the base case is due to the cost of the ice tank since the chiller size remains almost the same as reported in Table 4. The electricity cost savings fromTable 6, the size of the required storage tank from Table 4, and the previous estimate of the cost of storage tank are then used to estimate a simple payback period in years, shown in Table 6, for the cases with positive electricity cost savings. In the case of both time of use tariffs, the payback years are much more attractive for a larger storage capacity.

**Effect of Using Ice Storage in Mid-Peak Periods**

This study so far focused on the impact of using ice storage during on-peak periods to shift electricity to off-peak periods. As stated previously there is potential for larger cost savings if we also extend the use of storage to the mid-peak periods as well. This strategy is tested with the TOU tariff using full storage. The tank is sized to meet the full cooling load from 7:00 AM-7:00 PM and it is charged from 9:00 PM-5:00 AM. The charging period is again chosen to coincide with the off-peak period and with no cooling demand from the building. The following results are obtained in this case:

- Tank Size: 13.28 GJ
- Chiller Size: 675.6 kW
- Electricity Consumption: 45.2 kWh/m$^2$
- Electricity Cost: \$8.40/m$^2$

Part of the reduction in electricity consumption is due to the higher chiller COP of 5.18 instead of 4.7 in the previous case F-TOU. The chiller COP is set based on prescriptive requirements of NECB 2020, which assign a COP based on the equipment capacity. The cost of electricity in this case is lower than the base case value of \$8.96/m$^2$ in Table 5. The estimated payback for only the capital cost of storage is 68.4 years in this case. This high payback is due in large part to the excess storage capacity during periods with low cooling demand. A detailed analysis of all storage scenarios applied to both on-peak and mid-peak periods will be considered in a future study. It is expected that better economic performance will be possible with partial storage deployed during on-peak and mid-peak periods.

## Conclusions

A model for a medium office archetype is used to predict the energy, demand, and economic performance of an ice-storage system to shift on-peak electricity consumption to off-peak. The analysis is based on a tiered tariff and two time of use tariffs from Toronto Hydro during the summer of 2023. Based on the results generated in this study, we can make the following conclusions:

1. The results confirm findings in the literature that the main advantage of an ice-storage system is to shift the use of electricity from on-peak to off-peak periods and it is not necessarily to reduce the overall electricity consumption.
2. The ratio of the cooling energy (GJ) provided by the storage tank to the size of the tank (GJ) is higher for partial storage than full storage. This ratio is also higher for the TOU tariff than the ULO tariff of Toronto Hydro.
3. The current Toronto Hydro Time-Of-Use and Ultra-Low-Overnight tariffs might not offer enough of an incentive to justify an investment in an ice-storage system relative to a Tiered tariff to shift only on-peak cooling electricity to off-peak.
4. The economic performance of ice storage to shift on-peak to off-peak improves significantly when the time of use tariffs are altered to consider maximum monthly demand during only on-peak periods. In this case the payback years for the full storage cases become attractive.
5. In order to maximize the potential of success of an ice-storage system it is very important to use lower condenser loop setpoint temperatures to offset the effect of the lower chiller COP during ice making. In addition, heat gains to the tank and its auxiliary electricity consumption need to be minimized.
6. Electricity consumption by circulation pumps to deliver chilled liquid to the cooling coils during on-peak periods cannot be shifted completely to off-peak hours. Therefore, the proper design of the pumping system to minimize the pumping energy required is a very important factor in the success of an ice storage system.
7. The high cost of electricity offered by the time of use tariffs to shift consumption from on-peak to off-peak would also increase the cost of non-cooling related electricity consumption that cannot be moved to off-peak periods. Whenever possible, every effort needs be made to lower this electricity use through the adoption of energy efficient equipment and also shifting this consumption to off-peak periods.
8. Results for a full ice storage system to shift on-peak and mid-peak cooling electricity with the TOU tariff indicate that full storage would not be a cost-effective option in this case.

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