1 Purpose of the Guide

This measure is designed to provide maximum flexibility to users in order to simulate the basic design configurations and control schemes delineated in the ASHRAE Cool Thermal Storage Design Guide (2019) for ice storage technologies. This document provides general guidance for implementing the ASHRAE recommendations through this measure.

2 Measure Overview

2.1 General Description

The measure allows users attach ice thermal energy storage (ITS) to a chilled water loop and a chiller of their choice for the purpose of exploring load flexibility potential for a given building. Several hardware configuration and control strategy options are available to allow rapid modeling and parametric evaluation of various ITS possibilities. Schedule-based and Energy Management System (EMS) script-based controls are available at the user's discretion. A demand-response testing script is also available to assist in evaluating the resiliency/flexibility of a given ITS design and control pairing.

2.2 Measure Contents

The measure folder contains the following directories and files:

- add_ice_storage_tank/
    - docs/
        - Ice Measure Implementation Guide.pdf
    - resources/
        - OsLib_Schedules.rb
    - tests/
        - output/
        - add_ice_storage_tank_test.rb
        - ice_test_model.osm
    - LICENSE.md
    - measure.rb
    - measure.xml
    - README.md
    - README.md.erb

2.3 User Arguments

See README.md file for complete list of user arguments.

2.4 Model Pre-Requisites

This measure requires an OpenStudio model with an existing chilled water loop. The measure can be applied to any existing air-cooled, water-cooled, or adsorption chiller within the model.

2.5 Measure Limitations

The measure will not work with the following situations:

- Chilled water loops using heat pump models
- An ice storage tank placed in parallel with a single chiller. This situation usually occurs in retrofits where the return water mass flow rate is split between the chiller and the ice tank. This measure must be placed in series with at least one chiller. However, this limitation does not prevent the measure from being applied to loops with multiple chillers in parallel (see Section 3.4).

3 Hardware Configuration Options and Implications

It is convenient to think of configuration before control, but both are inherently coupled and appear in a mixed order within the user-input option list. The ITS will be placed in series with the user-selected chiller. It is not necessary to have multiple chillers.

3.1 Chiller Options

The measure allows users to resize their selected chiller using a sizing multiplier. This multiplier is applied to the chiller's nominal capacity. It is often both feasible and economically preferable to downsize a chiller coupled with ice storage. Typical values range from 0.4-0.7 but generally only apply to Partial Storage designs.

The chiller limiter option is discussed below in Section 4.3.

3.2 Ice Tank Options

The ice tank capacity, in ton-hours, must be set by the user and cannot be autosized. A thaw process indicator for either internal (InsideMelt) or external melt (OutsideMelt) is also available. Charge and discharge performance curves included within the ice model are based on an internal melt device. It is recommended to use the InsideMelt default option.

The ice tank object contains a built-in bypass which is controlled by the ice tank availability. If the ice is unavailable, the full mass flow rate bypass the tank. If the tank is in operation, EnergyPlus calculates the mass flow rate required to pass through the tank vs. bypass the tank in order to mix at the outlet to achieve the desired setpoint temperature. This is performed internally to the ThermalStorage:Ice:Detailed object in EnergyPlus.

Ice tank performance curves may not be modified within the measure's user arguments, but they may be adjusted through the OpenStudio GUI after the measure has been applied to the model.

3.3 Configuration Options

If the Partial Storage objective is selected, either the chiller or the ice tank may be placed as the upstream device. As the upstream device sees the highest return water temperatures, this selection will impact performance and energy calculations.

If the Full Storage objective is selected, the chiller is placed downstream of the ice tank regardless of user-selection for this argument. If a full storage control is desired, but it is imperative that the chiller be located upstream in the model, users should select the Partial Storage objective and refer to Section 4.2 for implementation guidance.

3.4 Multiple Chillers in Parallel

Users may select one of several chillers within their model to be used in series with the ice tank. However, because this measure adjusts both the selected chiller and its corresponding plant loop, users must verify plant loop operation after this measure is applied.

Due to the added complexity of multiple-chiller loops, it is unlikely that this measure will immediately produce the desired results if applied from the Measures tab. It should instead by applied using "Apply Measures Now," and inspected from the HVAC tab within the GUI.

3.5 Chiller and Loop Modifications

The chiller setpoint temperature for ice charging must be set by the user (in F). Values around 25F are normal. Users may set a new loop setpoint temperature and a new design temperature difference, or they may retain the existing values within their model.

Several changes are made without user input. The loop load distribution scheme is set to "SequentialLoad" and the common pipe simulation is set to "TwoWayCommonPipe." The chiller and loop minimum temperatures are adjusted to accommodate ice charging. The working fluid is changed from water to 25% ethylene glycol, if necessary.

The performance curves for the chiller are evaluated at the lower ice-making temperatures; both warnings and information messages are produced if curve extrapolation is required.

4 Implementing Control Strategies

4.1 Full Storage

Full Storage may be achieved through four different paths, described in the two subsections below.

4.1.1 The Full Storage Option

By selecting the Full Storage objective, the ice tank will be placed upstream of the chiller and full storage will be implemented during the ice discharge time window specified by the user. The upstream option and the intermediate temperature setpoint arguments are ignored.

4.1.2 Full Storage via Partial Storage

Full Storage can be achieved under all the Partial Storage configurations but requires additional user inputs.

If Partial Storage, Storage Upstream is configured, full storage is achieved by setting the intermediate setpoint equal to the loop setpoint temperature.

If Partial Storage, Chiller Upstream is configured, full storage is achieved by setting the intermediate setpoint temperature to any value greater than the expected highest return water temperature value.

Another option for a Partial Storage, Chiller Upstream configuration, is to set the chiller limiter to 0. This enforces a 0 degree temperature difference across the chiller evaporator during ice discharge.

4.2 Partial Storage

Many options for partial storage are possible, and are primarily actuated through temperature setpoints, schedules, and EMS scripting.

4.2.1 Load Leveling

To achieve load leveling, it is necessary to downsize the chiller using the sizing multiplier and adjust the ice charge and discharge windows to provide a nearly uniform load on the chiller over the diurnal cycle. This is most easily achieved with a Partial Storage, Chiller Upstream configuration. Set the intermediate setpoint equal to the loop setpoint. Any loads unmet by the chiller will be met by the ice, if state-of-charge permits.

4.2.2 Demand Limiting

The measure allows two paths to achieve demand limiting operation. The first uses setpoint schedules. Select a Partial Storage, Chiller Upstream configuration and set the intermediate setpoint temperature to a value above the loop setpoint temperature, but below the expected return water temperature. The chiller will meet a variable load but will be limited to some fraction of the design load. The ice will meet the remaining (nearly uniform) load throughout the day.

The other option is to use a Partial Storage, Chiller Upstream configuration, but also implement a chiller limiter. This will employ EMS scripting to maintain a uniform cooling load over the chiller at some reduced capacity value. The remaining load, which will now vary with return water temperature, will be met by the ice.

4.3 Remarks on the Chiller Limiter

The chiller limiter has only been tested with the Partial Storage, Chiller Upstream configuration, as this is the typical use case.

The chiller limiter approximates a demand limiter, but applies to chiller cooling capacity, not chiller electrical power. Thus, even when using the limiter, chiller power will vary over the course of the day due to variation in COP with ambient conditions.

The chiller limiter overrides all other temperature setpoint controls. Thus, if the limiter is applied, but the ice tank is depleted, the loop setpoint temperature may not be met. If a chiller limit is used, inspect the results of high cooling days to determine if the loop temperature setpoint is unmet. An output variable called Limit Counter reports the number of simulation (zone) timesteps in which the limiter was applied throughout the entire run period.

It is possible to combine a chiller limiter with a chiller setpoint temperature schedule, applied via the intermediate temperature setpoint.

5 Testing Demand Response Events

5.1 Purpose of the DR Tester

The demand response (DR) tester allows users to examine the flexibility potential of a specific ITS design and control strategy. This tester overlays on top of the existing control strategy and is useful for exploring impacts of short/no-notice DR events. Users may select a specific date, time, and duration during for the DR event.

5.2 Exploring Load Add Events

In the event of excess renewables, it may be desirable to switch chiller-ITS operation into a load-add mode of operation. During the DR event, the chiller will attempt to make ice to charge the ice tank, while also meeting loads. If the chiller has been purposefully undersized as part of a partial storage strategy, it is likely that the chiller will not be able to make ice. Instead, merely a decreased rate of ice depletion may be observed.

5.3 Exploring Load Shed Events

Load shed events may be examined where the chiller is permitted to assist if the ice is depleted, or where the chiller is prevented from turning-on, regardless of ice tank state of charge. In the latter case, building comfort impacts may be explored and weighed against potential cost savings associated with a DR event.

At the completion of a DR event, routine control is immediately returned. Thus, the DR tester also allows examination of rebound effects, even if they are delayed several hours.

6 References

ASHRAE Design Guide for Cool Thermal Storage, 2nd Ed., 2019

ASHRAE Handbook: HVAC Systems and Equipment, Ch 50: Thermal Storage

EnergyPlus v9.1 Engineering Reference

EnergyPlus v9.1 Input/Output Reference