

eQUEST: Modeling of Thermal Energy Storage System

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Contents

1. Objective	3
2. The problem	3
3. System without Thermal storage.....	4
4. System with Thermal storage.....	11
5. Comparison	16

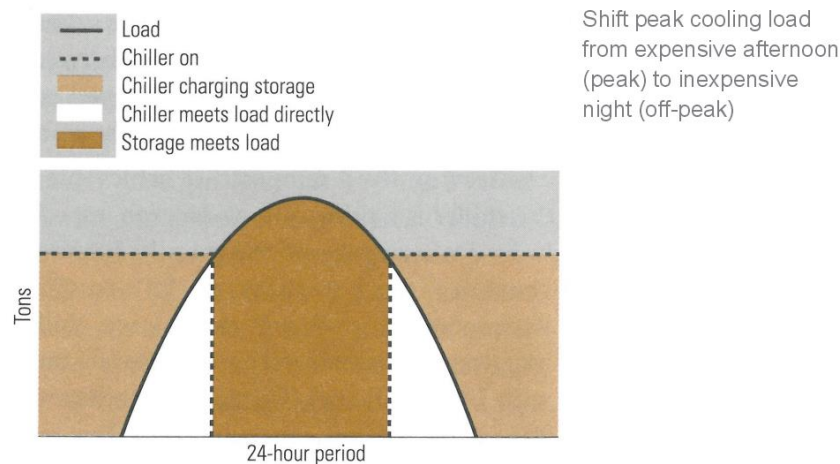
1. Objective

To learn how to model Thermal Energy Storage (TES) in eQUEST.

What is thermal energy storage?

Thermal energy storage includes a number of technologies that store thermal energy in energy storage tanks for later use. These applications include the production of ice, chilled water, or eutectic solution at night which is then used to cool the building during the day. The ice thermal storage (ITS) is one of thermal energy storage technology that is widely used in many countries to reduce electrical power or energy costs by moving the cost of cooling buildings from expensive "on-peak" periods to cheaper "off-peak" periods. The Thermal Energy Storage will be charged at night and the day cooling load will be met by discharging this thermal energy storage and running the chiller.

Typical Thermal Energy Storage load shifting is explained in the graph below:



Source: ASHRAE Design Guide for Cool Thermal Storage

2. The problem

In this tutorial we will create a building and add a thermal storage system to the building and add its controls. In the end we analyze the results to evaluate the performance of thermal energy storage.

Specifications of the model:

- Built up Area = 50,000 Sqft
- Conditioned Area = 50,000 Sqft
- Number of floors = 5
- Occupancy type = Daytime (9 AM to 6 PM)
- Lighting power density = 1 W/sqft
- Equipment power density = 0.4 W/Sqft

eQUEST: Modeling of Thermal energy storage system

- Occupancy = 100 Sqft/person
- Fresh air = 15 cfm/person
- Number of Chillers: 2
- Chiller Type = Electric reciprocating Hermetic
- Chiller size = Auto

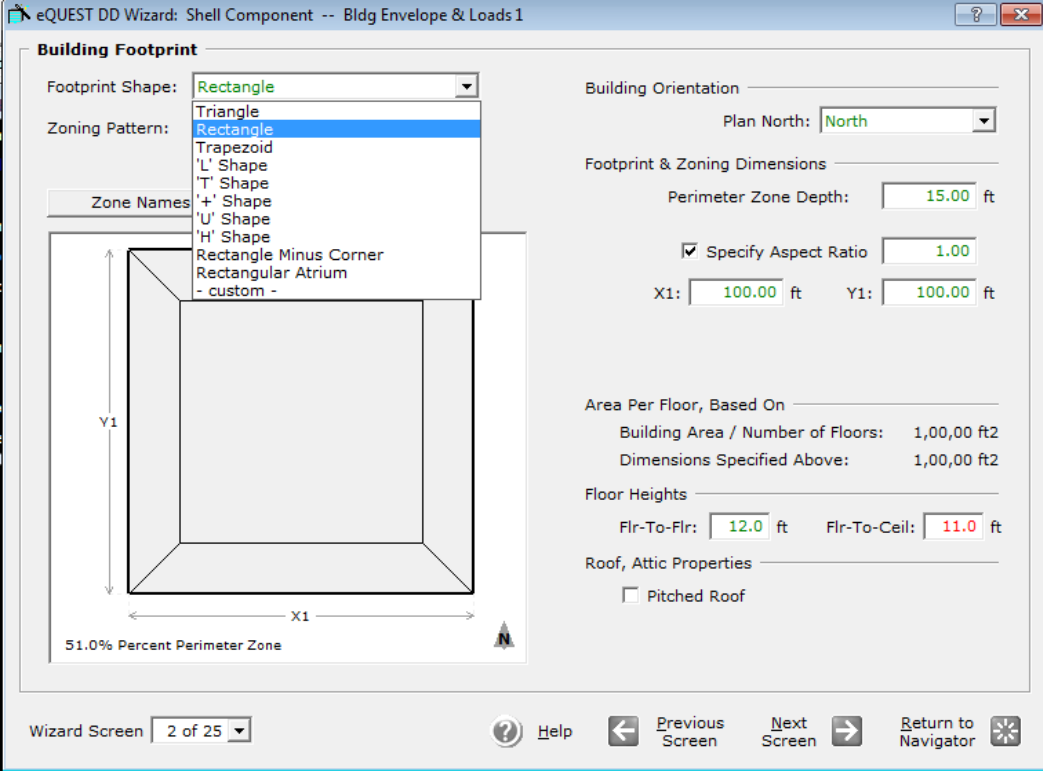
3. Modeling System without Thermal storage

Open eQUEST and model default square with core perimeter having 50,000 Sqft area in 5 floors.

The screenshot shows the 'eQUEST DD Wizard: Shell Component -- Bldg Envelope & Loads 1' window. The 'General Shell Information' tab is active. The 'Shell Name' field is 'Bldg Envelope & Loads 1'. The 'Building Type' dropdown is 'Office Bldg, Two Story'. The 'Specify Exact Site Coordinates' checkbox is unchecked. The 'Area and Floors' section shows 'Building Area' as '5,00,00 ft2', 'Number of Floors' as '5', 'Above Grade' as '5', and 'Below Grade' as '0'. The 'Use Floor Multipliers' checkbox is unchecked. The 'Other Data' section shows 'Shell Multiplier' as '1', 'Daylighting Controls' as 'No', 'Usage Details' as 'Hourly Enduse Profiles', and 'Prevent duplicate model components' checked. The 'Component Name Prefix' is 'EL1' and the 'Suffix' is empty. A note at the bottom of the section states '(# of Prefix + Suffix characters must be <= 4)'. The bottom of the window shows 'Wizard Screen 1 of 25', a 'Help' button, and navigation buttons for 'Previous Screen', 'Next Screen', and 'Return to Navigator'.

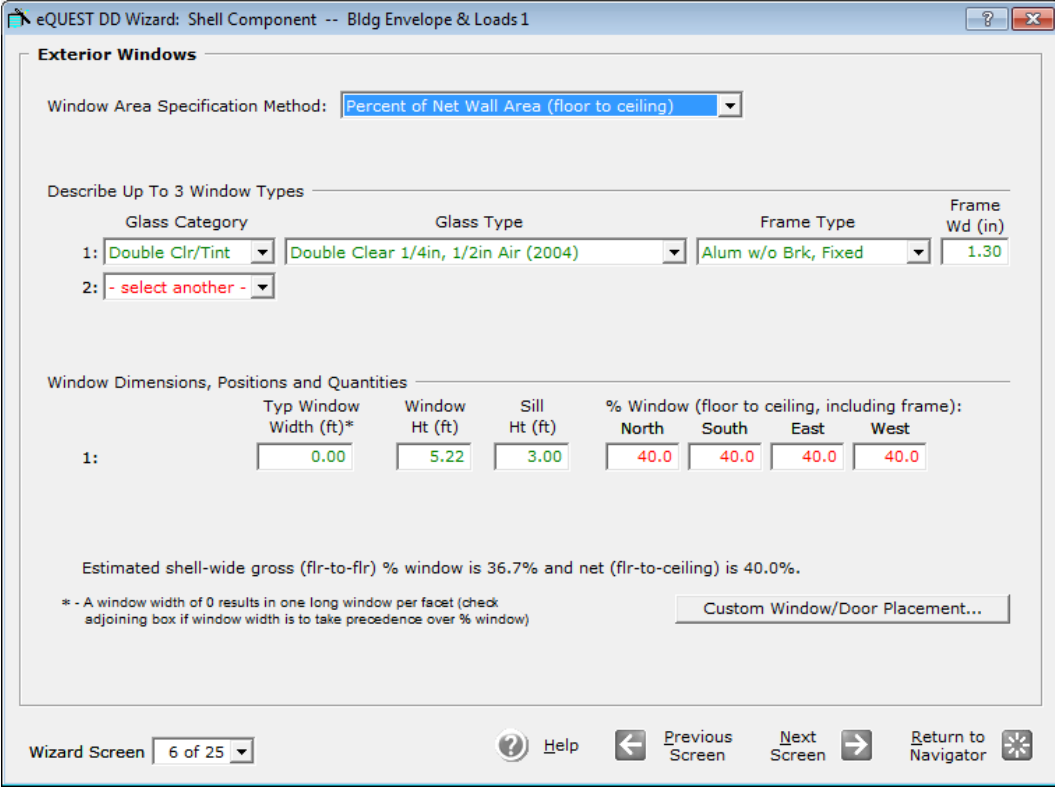
eQUEST: Modeling of Thermal energy storage system

Choose a rectangular foot print and let the floor to ceiling height be 11ft



The screenshot shows the 'Building Footprint' section of the eQUEST DD Wizard. The 'Footprint Shape' is set to 'Rectangle'. The 'Zoning Pattern' dropdown is open, showing options like 'Triangle', 'Rectangle', 'Trapezoid', etc. The 'Building Orientation' is set to 'North'. The 'Footprint & Zoning Dimensions' section shows 'Perimeter Zone Depth' as 15.00 ft, 'Specify Aspect Ratio' checked at 1.00, and 'X1' and 'Y1' both at 100.00 ft. The 'Area Per Floor, Based On' section shows 'Building Area / Number of Floors' and 'Dimensions Specified Above' both at 1,00,00 ft². The 'Floor Heights' section shows 'Flr-To-Flr' as 12.0 ft and 'Flr-To-Ceil' as 11.0 ft. The 'Roof, Attic Properties' section has 'Pitched Roof' unchecked. The 'Wizard Screen' is 2 of 25.

Change the window specification method to percent of net wall area (floor to ceiling) and specify only one window type with 40% window wall ratio on all four sides.



The screenshot shows the 'Exterior Windows' section of the eQUEST DD Wizard. The 'Window Area Specification Method' is set to 'Percent of Net Wall Area (floor to ceiling)'. The 'Describe Up To 3 Window Types' section shows one window type defined with 'Glass Category' as 'Double Clr/Tint', 'Glass Type' as 'Double Clear 1/4in, 1/2in Air (2004)', 'Frame Type' as 'Alum w/o Brk, Fixed', and 'Frame Wd (in)' as 1.30. The 'Window Dimensions, Positions and Quantities' section shows the following data for window type 1:

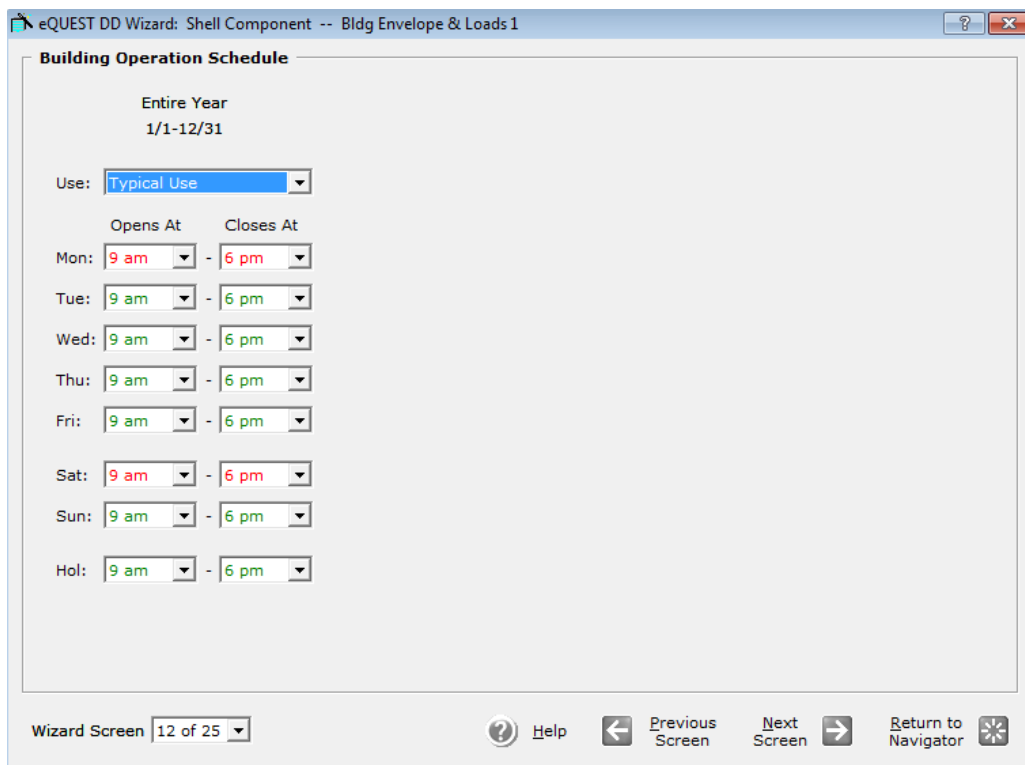
	Typ Window Width (ft)*	Window Ht (ft)	Sill Ht (ft)	% Window (floor to ceiling, including frame):			
				North	South	East	West
1:	0.00	5.22	3.00	40.0	40.0	40.0	40.0

Estimated shell-wide gross (flr-to-flr) % window is 36.7% and net (flr-to-ceiling) is 40.0%.
* - A window width of 0 results in one long window per facet (check adjoining box if window width is to take precedence over % window)

The 'Wizard Screen' is 6 of 25.

eQUEST: Modeling of Thermal energy storage system

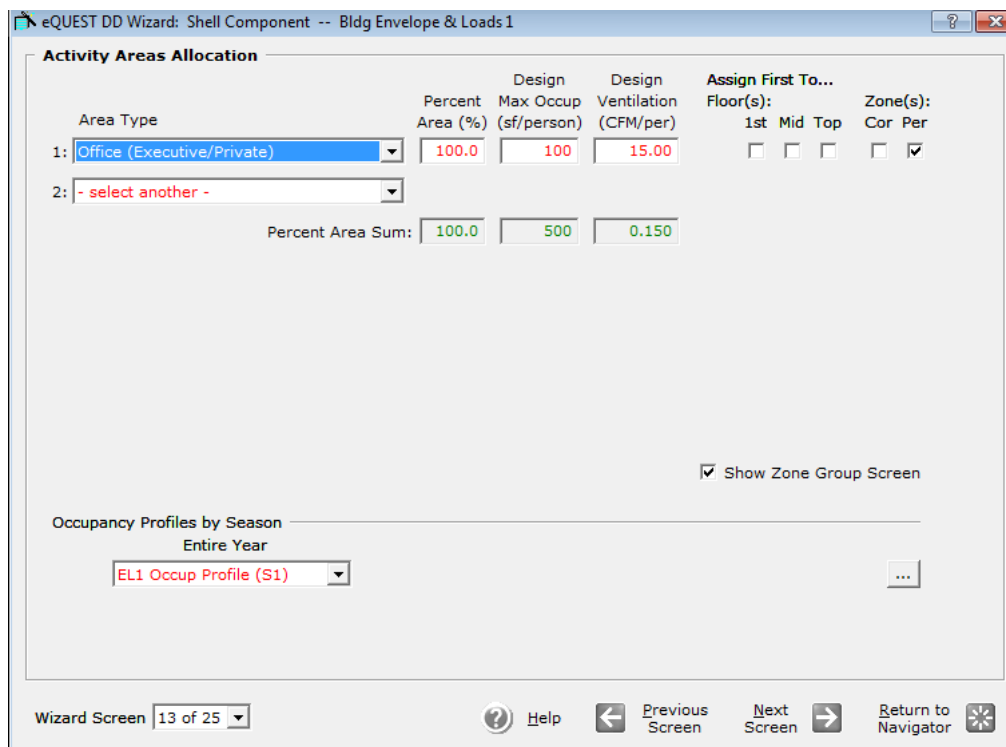
Define the schedule for the entire year as 9am to 6pm for all days of the year.



The screenshot shows the 'Building Operation Schedule' screen in the eQUEST DD Wizard. The 'Entire Year' is set to '1/1-12/31'. The 'Use' dropdown is set to 'Typical Use'. The 'Opens At' and 'Closes At' times are set to '9 am' and '6 pm' respectively for all days of the week (Mon, Tue, Wed, Thu, Fri, Sat, Sun, Hol). The 'Wizard Screen' indicator shows '12 of 25'.

Day	Opens At	Closes At
Mon	9 am	6 pm
Tue	9 am	6 pm
Wed	9 am	6 pm
Thu	9 am	6 pm
Fri	9 am	6 pm
Sat	9 am	6 pm
Sun	9 am	6 pm
Hol	9 am	6 pm

In Activity Area allocation screen, define the entire space as office area. For office area (Executive/private) changes the percent area to 100 and specify the design maximum occupancy to 100sf/person and the design ventilation to 15CFM/person. Change the rest of the area types to 'select another'.



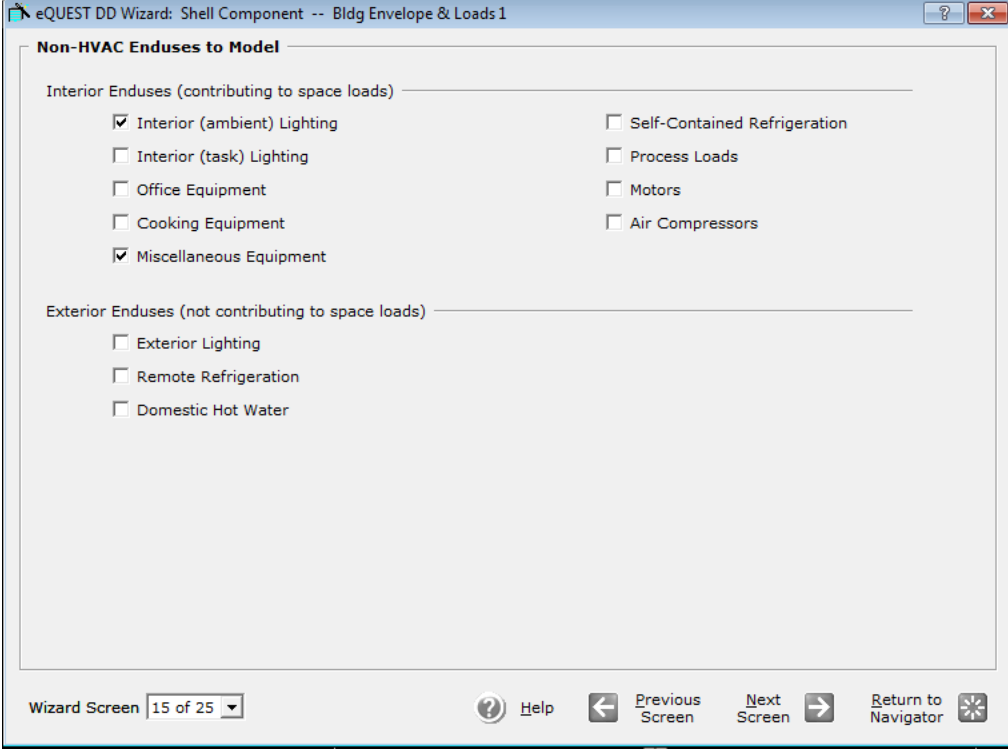
The screenshot shows the 'Activity Areas Allocation' screen in the eQUEST DD Wizard. The 'Area Type' dropdown is set to 'Office (Executive/Private)'. The 'Percent Area (%)' is set to '100.0', 'Design Max Occup' is set to '100', and 'Design Ventilation (CFM/per)' is set to '15.00'. The 'Assign First To...' section shows 'Floor(s):' with '1st', 'Mid', and 'Top' checkboxes, and 'Zone(s):' with 'Cor' and 'Per' checkboxes. The 'Percent Area Sum' is '100.0', 'Design Max Occup' is '500', and 'Design Ventilation' is '0.150'. The 'Occupancy Profiles by Season' section shows 'Entire Year' set to 'EL1 Occup Profile (S1)'. The 'Wizard Screen' indicator shows '13 of 25'.

Area Type	Percent Area (%)	Design Max Occup (sf/person)	Design Ventilation (CFM/per)
1: Office (Executive/Private)	100.0	100	15.00
2: - select another -			

Percent Area Sum: 100.0 Design Max Occup: 500 Design Ventilation: 0.150

eQUEST: Modeling of Thermal energy storage system

In non HVAC end uses, check the interior lighting and miscellaneous equipment and leave the rest of them unchecked.



Non-HVAC Enduses to Model

Interior Enduses (contributing to space loads)

- ☒ Interior (ambient) Lighting
- ☐ Interior (task) Lighting
- ☐ Office Equipment
- ☐ Cooking Equipment
- ☒ Miscellaneous Equipment
- ☐ Self-Contained Refrigeration
- ☐ Process Loads
- ☐ Motors
- ☐ Air Compressors

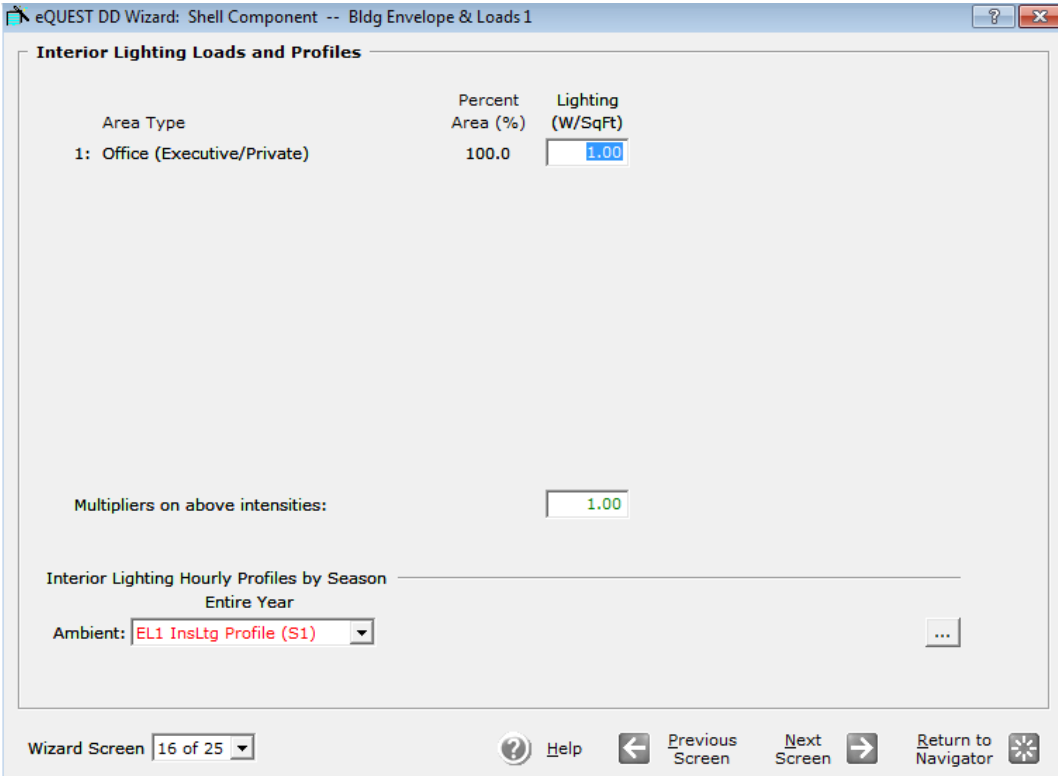
Exterior Enduses (not contributing to space loads)

- ☐ Exterior Lighting
- ☐ Remote Refrigeration
- ☐ Domestic Hot Water

Wizard Screen 15 of 25

Help Previous Screen Next Screen Return to Navigator

Define the LPD for the office area as 1 W/SqFt.



Interior Lighting Loads and Profiles

Area Type	Percent Area (%)	Lighting (W/SqFt)
1: Office (Executive/Private)	100.0	1.00

Multipliers on above intensities: 1.00

Interior Lighting Hourly Profiles by Season

Entire Year

Ambient: EL1 InsLtg Profile (S1)

Wizard Screen 16 of 25

Help Previous Screen Next Screen Return to Navigator

eQUEST: Modeling of Thermal energy storage system

Define the EPD for the office area as 0.4 W/SqFt.

eQUEST DD Wizard: Shell Component -- Bldg Envelope & Loads 1

Miscellaneous Loads and Profiles

Area Type	Percent Area (%)	----- Electric -----		---- Natural Gas ----	
		Load (W/SqFt)	Sensible Ht (frac)	Load (Btuh/SF)	Sensible Ht (frac)
1: Office (Executive/Private)	100.0	.4	1.00	0.00	1.00

Miscellaneous Equipment Hourly Profiles by Season

Entire Year

EL1 Misc Profile (S1)

Wizard Screen 20 of 25

Help Previous Screen Next Screen Return to Navigator

Change the Cooling Source to 'Chilled Water Coils' and Heating Source as 'No Heating'.

eQUEST DD Wizard: Air-Side System Type -- HVAC System 1

HVAC System Definition

System Type Name: HVAC System 1

Cooling Source: Chilled Water Coils

Heating Source: No Heating

System Type: Standard VAV (no reheat)

System per Area: System per Floor

Return Air Path: Ducted

Component Name Prefix: S1

Suffix:

(# Prefix+Suffix characters must be <= 4)

☒ Prevent duplicate model components

System Assignment to Thermal Zones

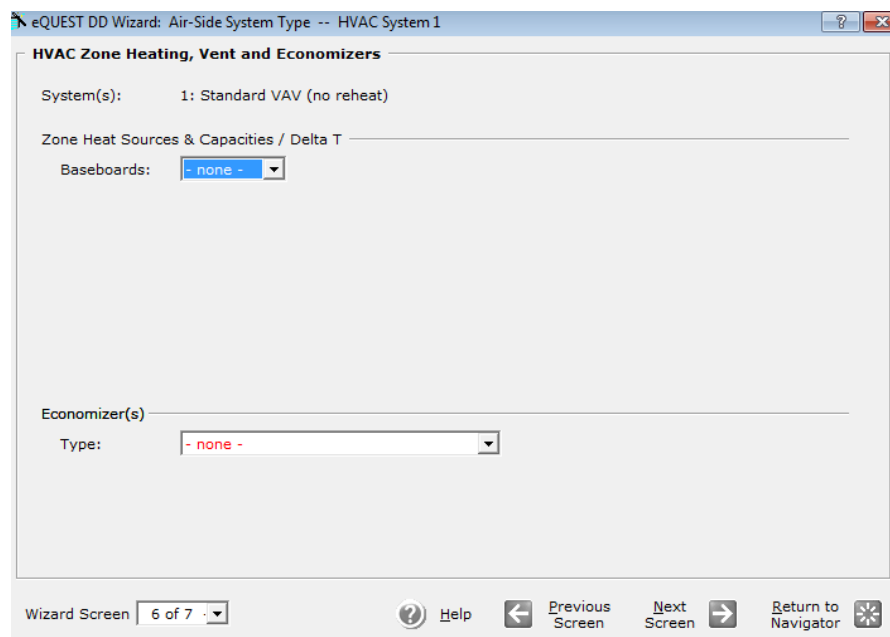
	Shell Component(s)	Description of Assigned Zones
1	Bldg Envelope & Loads 1	All Zones
2	- undefined -	

Wizard Screen 1 of 7

Help Previous Screen Next Screen Return to Navigator

eQUEST: Modeling of Thermal energy storage system

Mark the baseboard and economiser as 'none' in screen 6 of 7



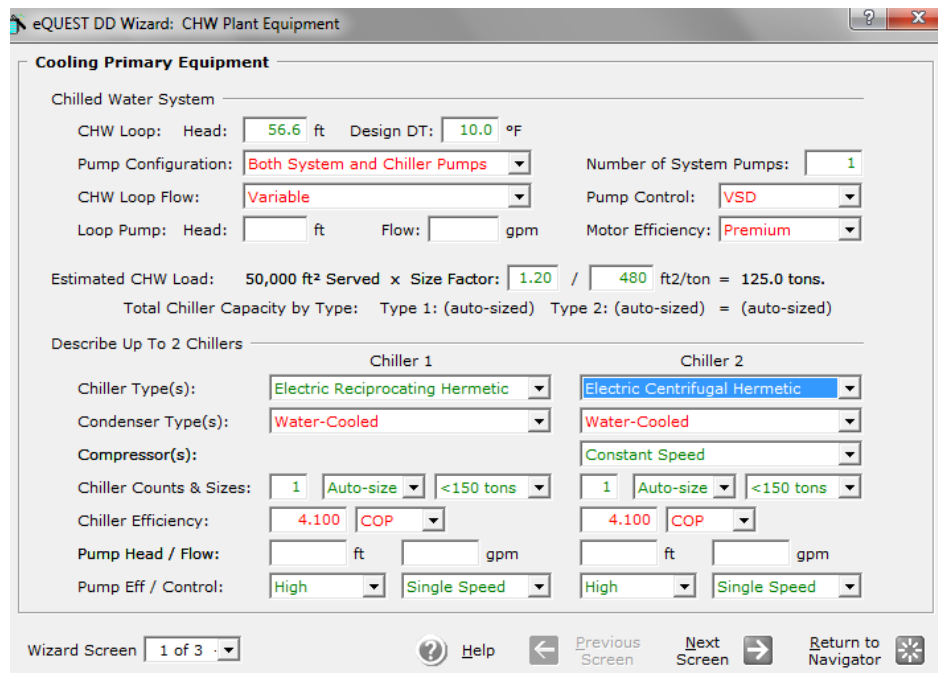
The screenshot shows the 'eQUEST DD Wizard: Air-Side System Type -- HVAC System 1' window. The title bar includes a help icon, a close icon, and the window name. The main content area is titled 'HVAC Zone Heating, Vent and Economizers'. It contains the following fields:

- System(s):** 1: Standard VAV (no reheat)
- Zone Heat Sources & Capacities / Delta T**
- Baseboards:** A dropdown menu set to '- none -'.
- Economizer(s)**
- Type:** A dropdown menu set to '- none -'.

At the bottom, there is a 'Wizard Screen' dropdown set to '6 of 7', a 'Help' button with a question mark icon, and navigation buttons: 'Previous Screen' (left arrow), 'Next Screen' (right arrow), and 'Return to Navigator' (star icon).

From the navigator select the CHW Plant Equipment and change the pump configuration to 'both system and chiller pumps' and CHW loop flow to Variable. Mark the pump control as 'VSD', motor efficiency to 'premium'.

Create two identical chillers and change both the chiller types to 'Electric reciprocating Hermetic'. Change the condenser type to 'Water cooled' and chiller Efficiency as 4.1 (COP) for both the chillers.



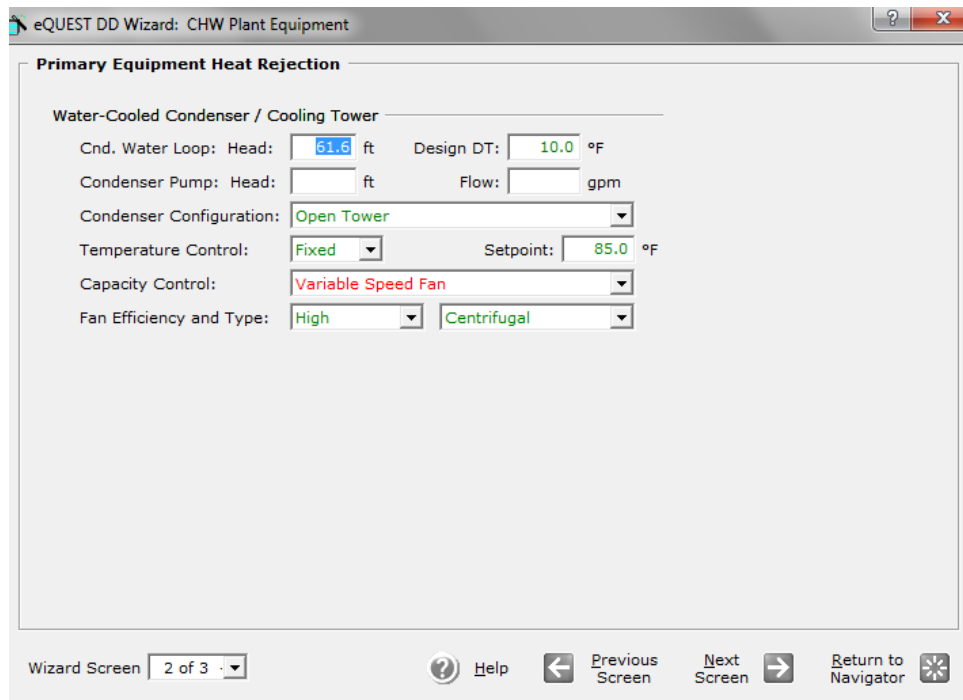
The screenshot shows the 'eQUEST DD Wizard: CHW Plant Equipment' window. The title bar includes a help icon, a close icon, and the window name. The main content area is titled 'Cooling Primary Equipment'. It contains the following fields:

- Chilled Water System**
- CHW Loop:** Head: 56.6 ft, Design DT: 10.0 °F
- Pump Configuration:** Both System and Chiller Pumps
- Number of System Pumps:** 1
- CHW Loop Flow:** Variable
- Pump Control:** VSD
- Loop Pump:** Head: [] ft, Flow: [] gpm
- Motor Efficiency:** Premium
- Estimated CHW Load:** 50,000 ft² Served x Size Factor: 1.20 / 480 ft²/ton = 125.0 tons.
- Total Chiller Capacity by Type:** Type 1: (auto-sized) Type 2: (auto-sized) = (auto-sized)
- Describe Up To 2 Chillers**
- Chiller 1**
- Chiller 2**
- Chiller Type(s):** Electric Reciprocating Hermetic (Chiller 1), Electric Centrifugal Hermetic (Chiller 2)
- Condenser Type(s):** Water-Cooled (Chiller 1), Water-Cooled (Chiller 2)
- Compressor(s):** Constant Speed (Chiller 2)
- Chiller Counts & Sizes:** 1 Auto-size <150 tons (Chiller 1), 1 Auto-size <150 tons (Chiller 2)
- Chiller Efficiency:** 4.100 COP (Chiller 1), 4.100 COP (Chiller 2)
- Pump Head / Flow:** [] ft [] gpm (Chiller 1), [] ft [] gpm (Chiller 2)
- Pump Eff / Control:** High Single Speed (Chiller 1), High Single Speed (Chiller 2)

At the bottom, there is a 'Wizard Screen' dropdown set to '1 of 3', a 'Help' button with a question mark icon, and navigation buttons: 'Previous Screen' (left arrow), 'Next Screen' (right arrow), and 'Return to Navigator' (star icon).

eQUEST: Modeling of Thermal energy storage system

In the following screen change the capacity control to 'Variable Speed Fan'.

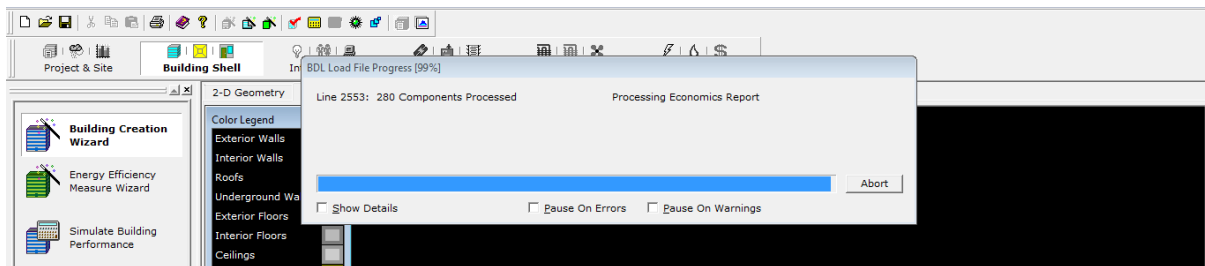


The screenshot shows the 'eQUEST DD Wizard: CHW Plant Equipment' window. The title bar includes a help icon, a close button, and the text 'eQUEST DD Wizard: CHW Plant Equipment'. The main area is titled 'Primary Equipment Heat Rejection' and contains a section for 'Water-Cooled Condenser / Cooling Tower'. The settings are as follows:

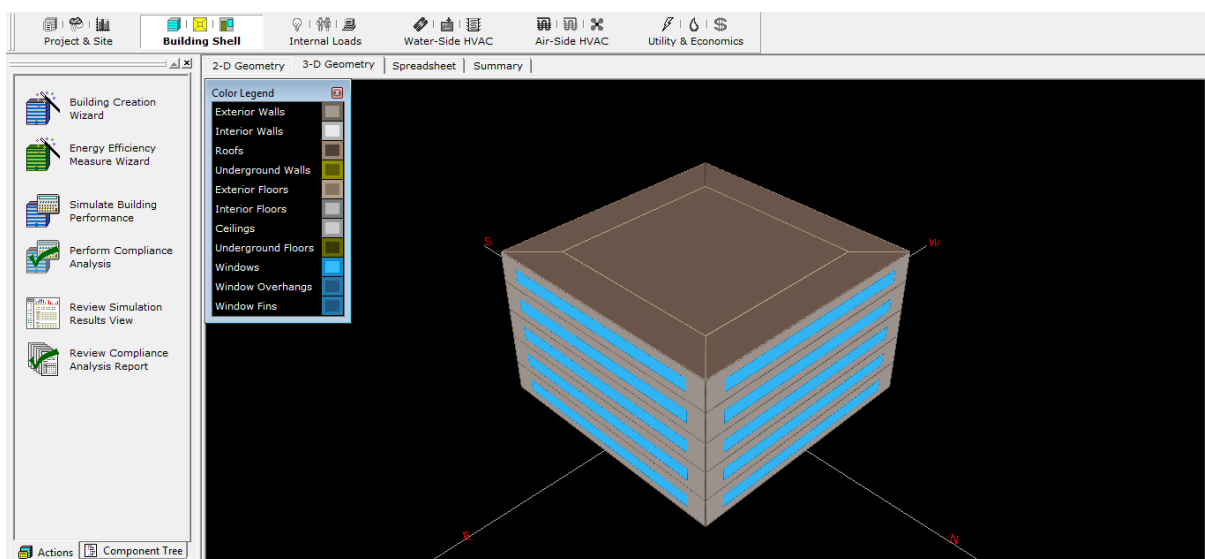
- Cnd. Water Loop: Head: 61.6 ft, Design DT: 10.0 °F
- Condenser Pump: Head: [empty] ft, Flow: [empty] gpm
- Condenser Configuration: Open Tower (dropdown)
- Temperature Control: Fixed (dropdown), Setpoint: 85.0 °F
- Capacity Control: Variable Speed Fan (dropdown)
- Fan Efficiency and Type: High (dropdown), Centrifugal (dropdown)

The bottom of the window features a 'Wizard Screen' dropdown set to '2 of 3', a 'Help' button, and navigation buttons: 'Previous Screen', 'Next Screen', and 'Return to Navigator'.

Once the above information is added, click finish and complete the project.

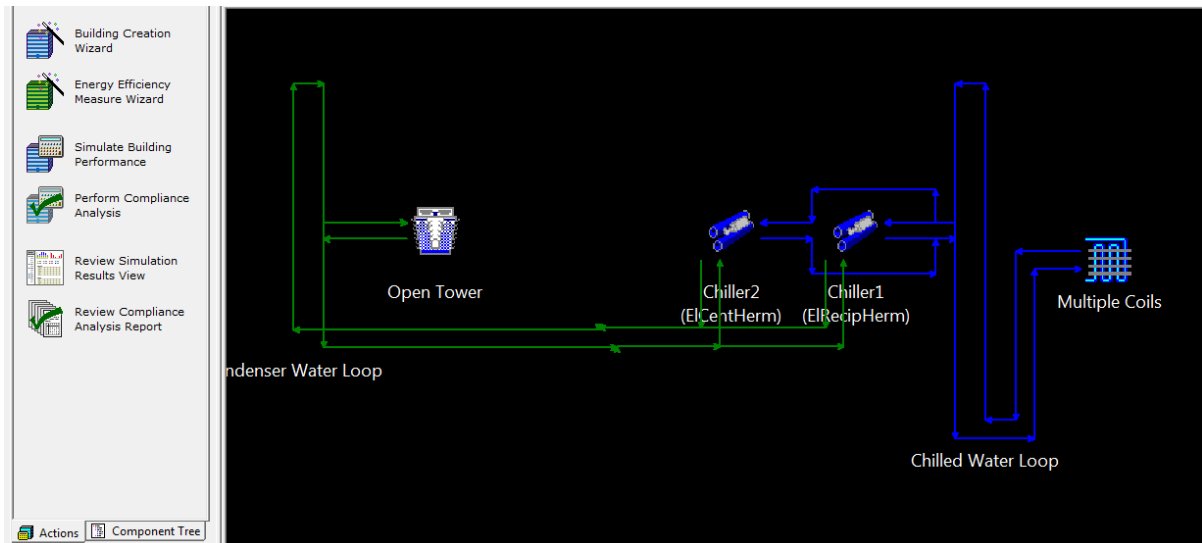


A 3D image of the building will be displayed. We can run the simulation.



eQUEST: Modeling of Thermal energy storage system

Clicking on the Water-Side HVAC tab will give you a layout of the system before adding a thermal storage.



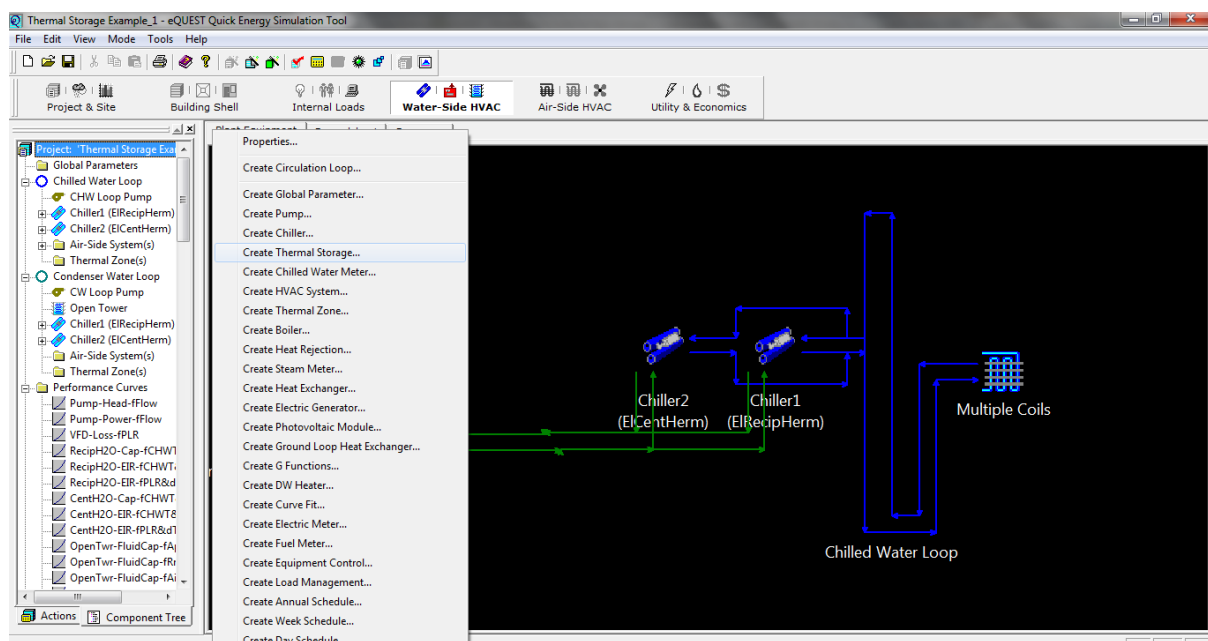
Save the Project with desired name, e.g Tut_no_thermal_storage.

4. System with Thermal storage

Open the previous model and save it as a different file with a different file name, e.g. Tut_thermal_storage.

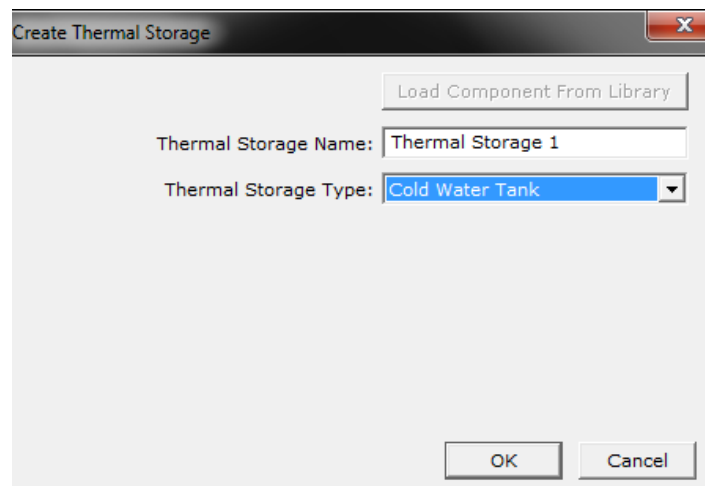
Now that we have modelled the building with two identical chillers, the next task is to model the thermal storage.

To add a thermal storage system, go to Water-Side HVAC and right click on the project and 'Create Thermal Storage'

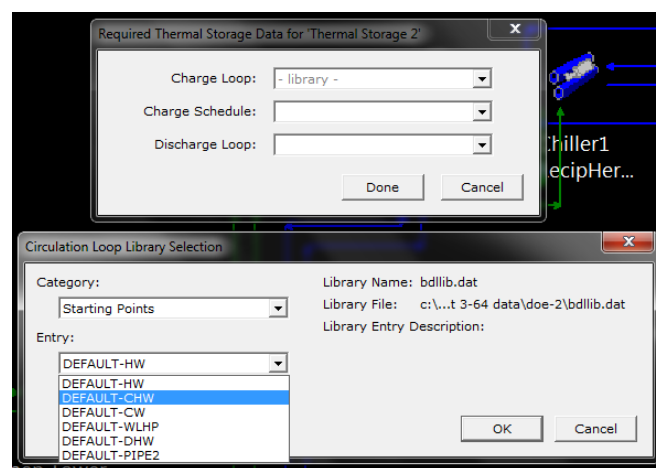


eQUEST: Modeling of Thermal energy storage system

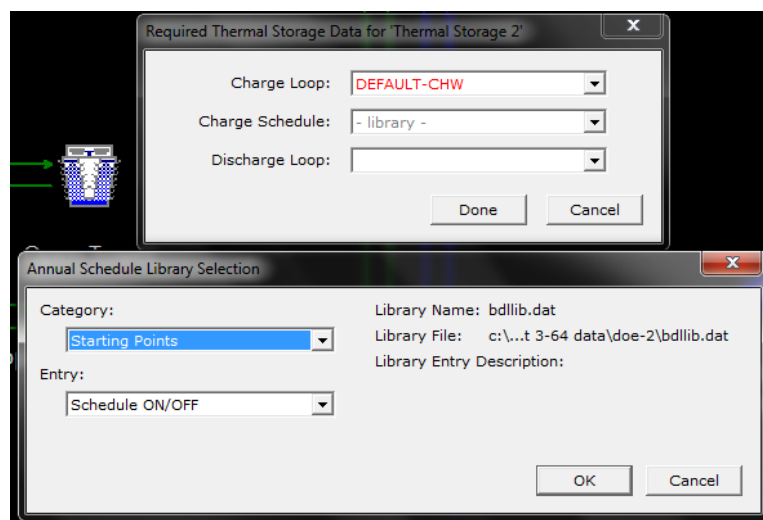
Name your thermal storage system and define the type as Cold Water Tank



In the next window, select Charge loop from the library which opens in a new window. We have to now select the entry as “Default-CHW” and click OK.

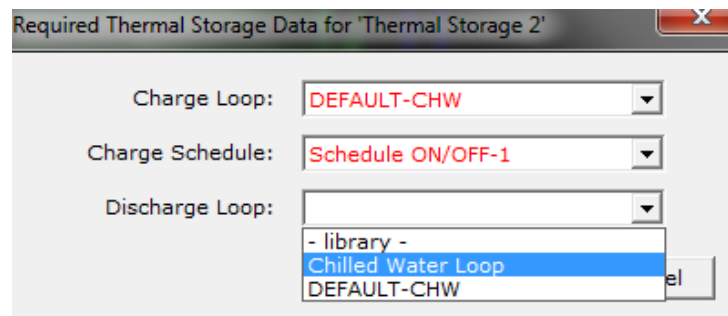


For Charge Schedule, select the library and enter the schedule as “Schedule ON/OFF”

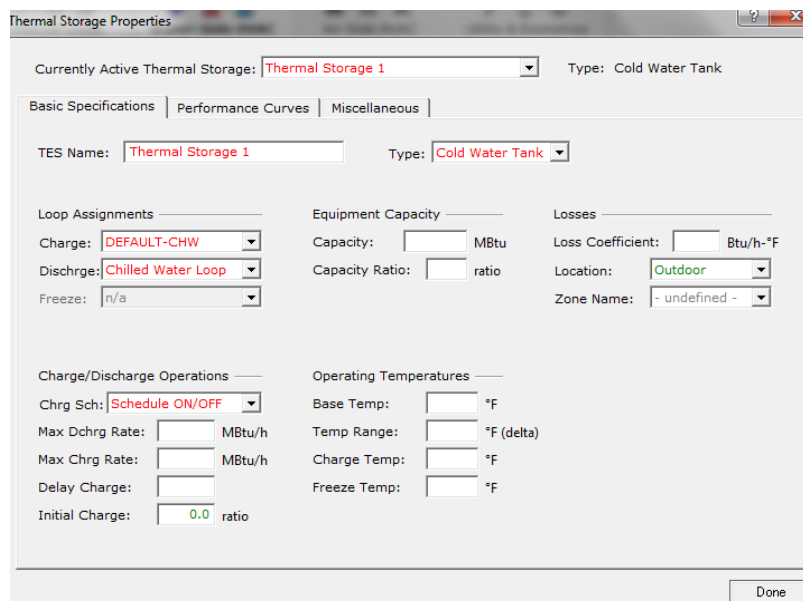


eQUEST: Modeling of Thermal energy storage system

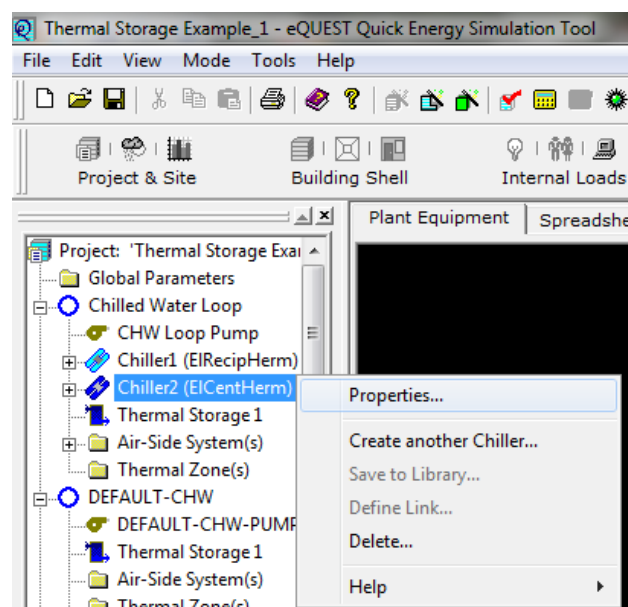
Now select the discharge loop as 'Chilled Water Loop'



Once the required data is entered we get the thermal properties of the Thermal Storage.



Now right click on Chiller 2 from the component tree and select properties



eQUEST: Modeling of Thermal energy storage system

Now in Loop assignments, assign the “Default-CHW” for CHW.

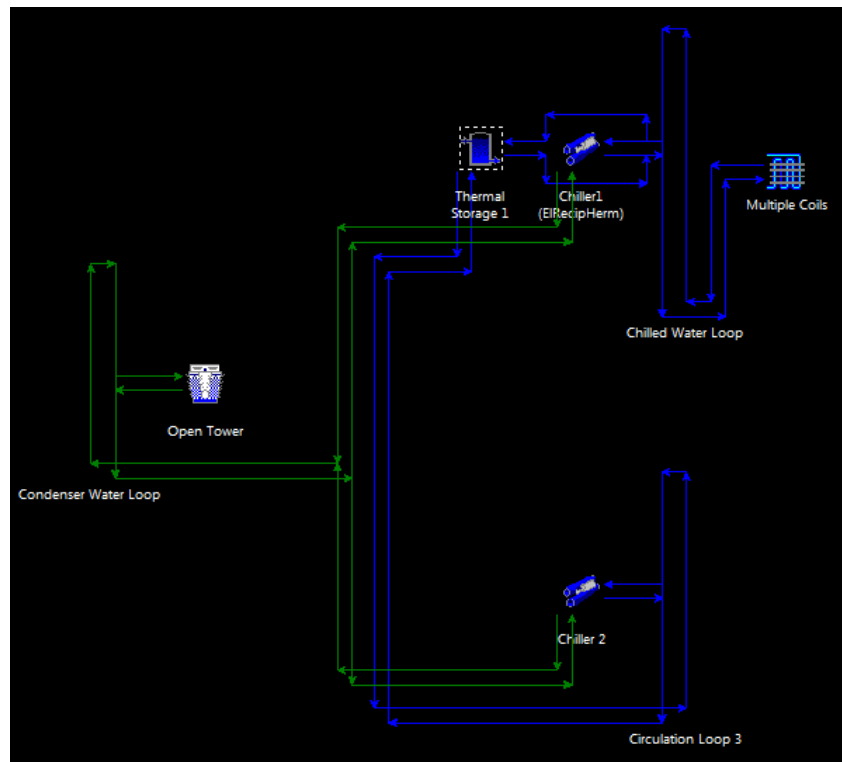
The screenshot shows the 'Chiller Properties' dialog box for 'Chiller2 (ElCentHerm)'. The 'Loop Assignments' tab is active, showing the following settings:

- CHW: DEFAULT-CHW
- CW: Condenser Water Lo
- HW: n/a
- HTRec: - undefined -

The 'Design vs. Rated Conditions' section shows the following values:

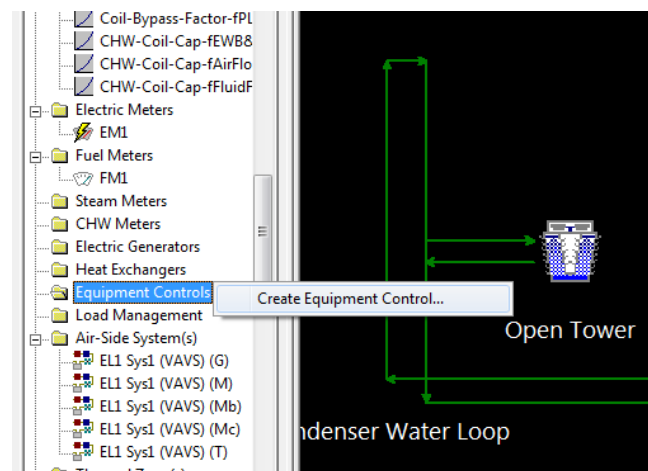
Design Conditions	Rated Conditions
Chilled-Wtr Temp: 44.0 °F	Chilled-Wtr Temp: 44.0 °F
Condenser Temp: 85.0 °F	Condenser Temp: 85.0 °F
Design/Max Cap: 0.920 ratio	Condenser Flow: 3.00 gpm/ton

The Water-Side HVAC Module will now show the Thermal Storage and the two chillers.

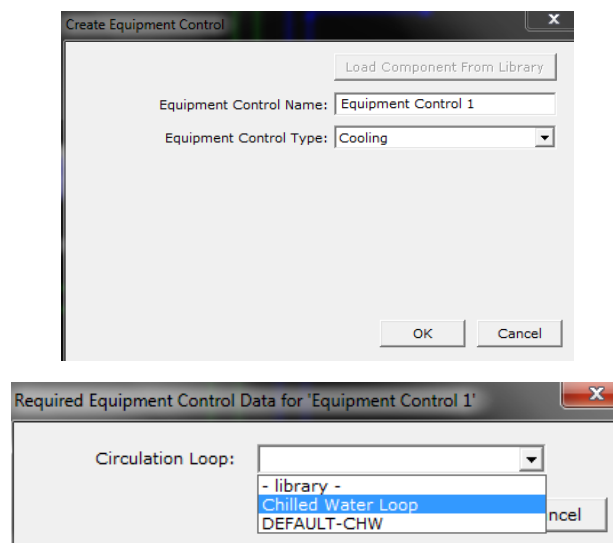


eQUEST: Modeling of Thermal energy storage system

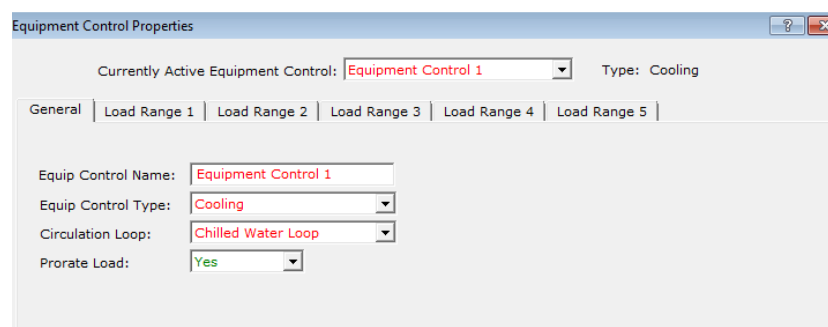
We have created the thermal storage system and now we need to add controls to it. For that we need to come down to Equipment control in the component tree, right click and 'Create Equipment Control'



Define the Equipment Control Name and the Control Type as 'Cooling'. In the next screen select the circulation loop as 'Chilled Water Loop'



The Equipment Control Properties will now be displayed as below.



Under load range tab add Chiller1 and Sequence as 1 and define the Storage sequence as 2, which implies that the load is shifted to thermal storage when the maximum load on the Chiller1 is 999 MBtu/hr.

Equipment Control Properties

Currently Active Equipment Control: **Equipment Control 1** Type: Cooling

General Load Range 1 Load Range 2 Load Range 3 Load Range 4 Load Range 5

Loads Through: MBtu/h

	Chiller Name	Seq	Max Load
1	Chiller1 (ElRecipHerm)	1	999.00
2	- undefined -	2	999.00
3	- undefined -	3	999.00
4	- undefined -	5	999.00
5	- undefined -	6	999.00
6	- undefined -	7	999.00
7	- undefined -	8	999.00
8	- undefined -	9	999.00
9	- undefined -	10	999.00
10	- undefined -	10	999.00

Storage Sequence: **2.0** Max Load: **999.0** MBtu/h

Meter Sequence: Max Load: **999.0** MBtu/h

Examine Load Management

Done

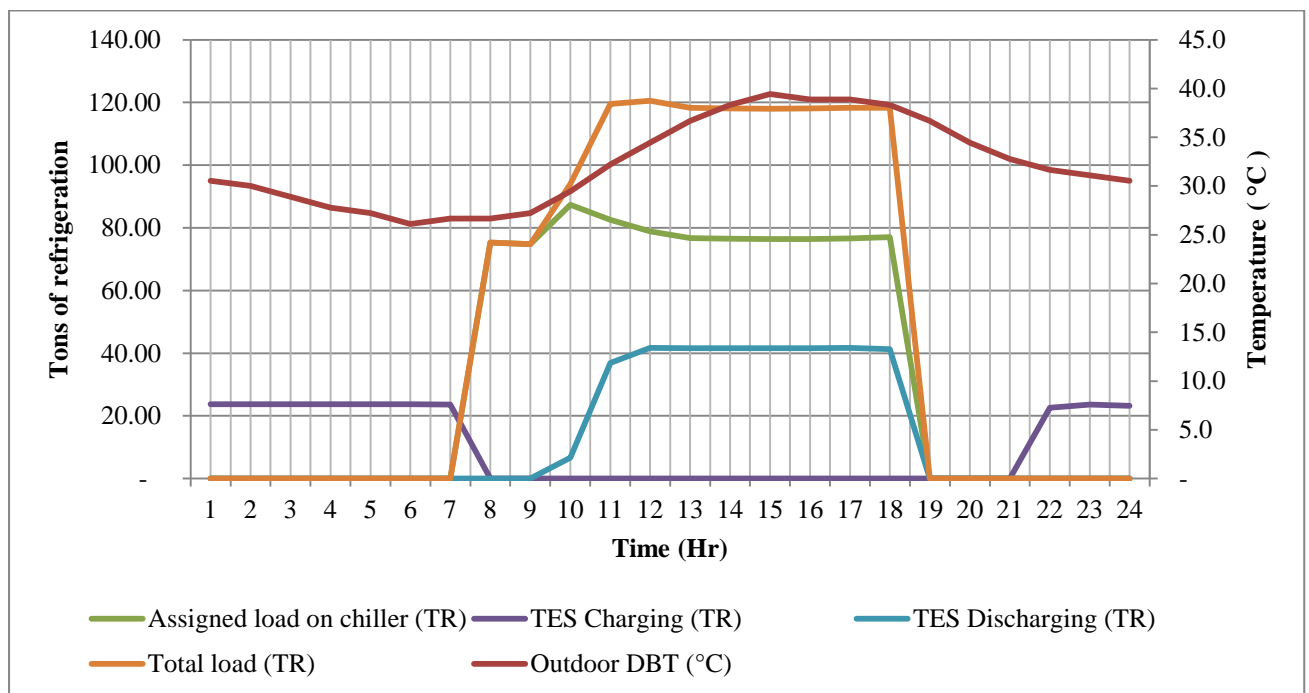
5. Comparison

For the comparison purpose and to identify the potential saving by using the Thermal Energy Storage, simulate both the models, with and without thermal storage. You will get results similar to the table given below.

The charging and discharging load of thermal energy storage, the total load and the assigned load on chiller after using the Thermal Energy Storage are all described in the table for every hour in the day with the corresponding Outdoor Dry Bulb Temperature.

Time	Outdoor DBT (°C)	Assigned load on chiller (TR)	TES Charging (TR)	TES Discharging (TR)	Total load (TR)
1	30.6	-	23.74	-	-
2	30.0	-	23.74	-	-
3	28.9	-	23.74	-	-
4	27.8	-	23.72	-	-
5	27.2	-	23.72	-	-
6	26.1	-	23.71	-	-
7	26.7	-	23.65	-	-
8	26.7	75.34	-	-	75.34
9	27.2	74.78	-	-	74.78
10	29.4	87.33	-	6.69	94.02
11	32.2	82.58	-	36.91	119.49
12	34.4	78.85	-	41.67	120.52

13	36.7	76.71	-	41.63	118.34
14	38.3	76.50	-	41.63	118.14
15	39.4	76.39	-	41.64	118.03
16	38.9	76.47	-	41.64	118.11
17	38.9	76.64	-	41.64	118.28
18	38.3	77.00	-	41.29	118.29
19	36.7	-	-	-	-
20	34.4	-	-	-	-
21	32.8	-	-	-	-
22	31.7	-	22.60	-	-
23	31.1	-	23.58	-	-
24	30.6	-	23.25	-	-



This graph represents how the Thermal Energy Storage is getting charged (purple line) during the night (from 9pm to 7am) and is getting discharged (blue line) in the morning (from 9am to 7pm). The orange line indicates the total load and the Green one indicates the assigned load on chiller when used in combination with Thermal Energy Storage. We can see how the peak load is being shedded by the Thermal Energy Storage.