Performance Optimization of a Low-Temperature Chilled Water Plant Serving a Suite of Operating Rooms

DesignBuilder's Energy Management System (EMS) functionality was used to optimize the performance of a low-temperature chilled water plant serving a suite of operating rooms (ORs). As a result of this study, AKF was able to identify a potential controls adjustment that would result in an annual cost savings of up to $20,000 for the low-temperature OR HVAC scope.

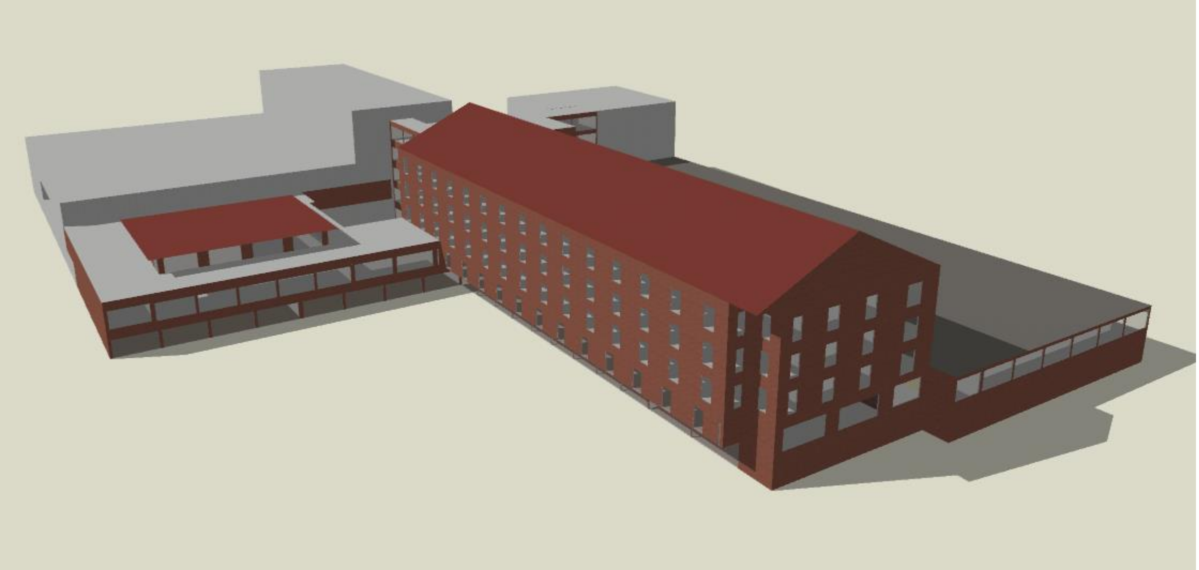
By Michael Sweeney, BEMP, LEED AP

At a Glance

An energy model was developed using DesignBuilder EnergyPlus to optimize the annual cooling performance of several low-temperature air handlers and the chilled water plants serving them. The air handlers serve a suite of fifteen ORs, and each room requires a high volume of supply air at a low temperature setpoint.

The new operating suites are located within a mixed new/existing healthcare facility on Penn Medicine Chester County Hospital's campus. In addition to the design and modeling of the entire facility, the unique air and thermal requirements of the OR suites warranted a separate focused study.

DesignBuilder's EnergyPlus-based EMS system allows the energy modeller to introduce highly-specific and novel controls strategies that would otherwise be unavailable within traditional hourly simulation engines or static energy calculations. As a result of this functionality, AKF was able to identify a potential controls adjustment that would result in an annual cost savings of up to $20,000 for the low-temperature OR HVAC scope.



DesignBuilder model used in the analysis

Project Scope

- Mixed new/renovation healthcare facility within existing campus, 236,000 total SF
- Low-temperature OR scope is approximately 20,000 SF
- In addition to the low-temperature ORs, there is a varied healthcare program including a bed tower, exam room, and lobby/waiting space
- Location: West Chester, PA

Design Concerns

- The OR usage varies throughout the time of day and week, and air handlers are permitted to vary down when a room is not in use. This results in significant part-loading effects that lower the annual performance of the air-cooled chiller.
- An initial design was developed with each air handler serving ORs consisting of two chilled water coils in series: the first coil is fed by the campus chilled water loop and pre-cools the air to 48°F. The second coil is fed by the air-cooled chiller and brings the air down to 43°F. The goal of this strategy was to take as much conditioning from the campus loop as possible, and then satisfy the remainder with the less-efficient air-cooled chiller.
- During the design phase, the energy model was used to validate the setpoint used for the campus cooling coil to optimize the performance of the air-cooled chiller throughout the year.

Energy Modeling Parametric Analysis Goals

- Run several iterations with varying pre-cool setpoints in order to analyze the impact on the air-cooled chiller's performance.
- Develop a practically feasible BMS routine to optimize the air-cooled chiller's part-load efficiency by varying the campus coil's discharge temperature.

Project Details

Low-temperature ORs

- Cooling Setpoint: 65°F
- Air Change Requirement: 30 air changes per hour (ACH)
- Supply Air Temperature (SAT) Setpoint: 43°F
- Above setpoints and ACH requirements relax in an OR when it is not in use

Low-temperature Air Handlers

- Three 30,000 cfm air handlers serve the rooms, each equipped with (two) separate chilled water coils.
- Campus chilled water coil pre-cools the air and a second chilled water coil, supplied by a low-temperature air-cooled chiller, cools the air to the 43°F setpoint.
- Air handlers are permitted to vary down when individual ORs are not in use.
- A series of models were developed to determine the ideal pre-cool setpoint for the campus chilled water coil, and DesignBuilder's EMS interface was used to develop a load optimization strategy to optimize the air-cooled chiller's performance.

Chilled Water Plant

- Campus Chilled Water Plant (existing): 42°F water temp, serves entire campus loop.
- Air-cooled Chiller Plant (new): 110 tons, 36°F water temp designed for a coil supply air discharge of 43°F. Chiller equipped with variable speed drive (VSD) operation and a glycol loop. Serves only low-temperature air handlers.

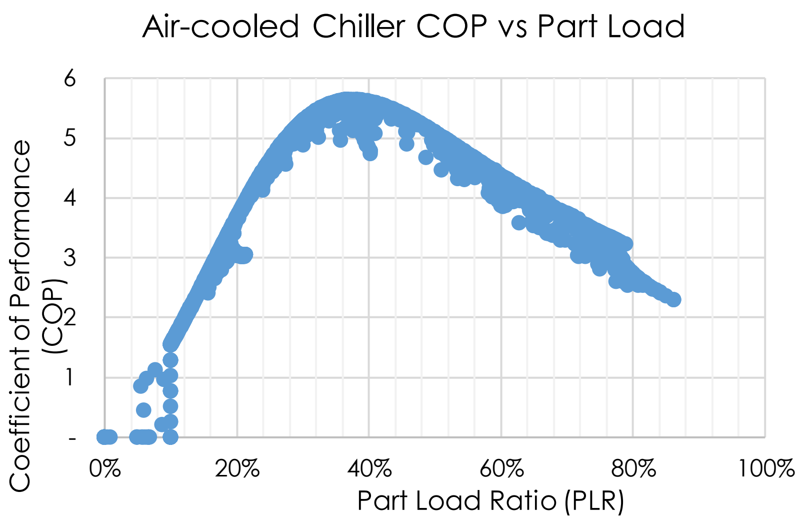
Energy Modeling Approach

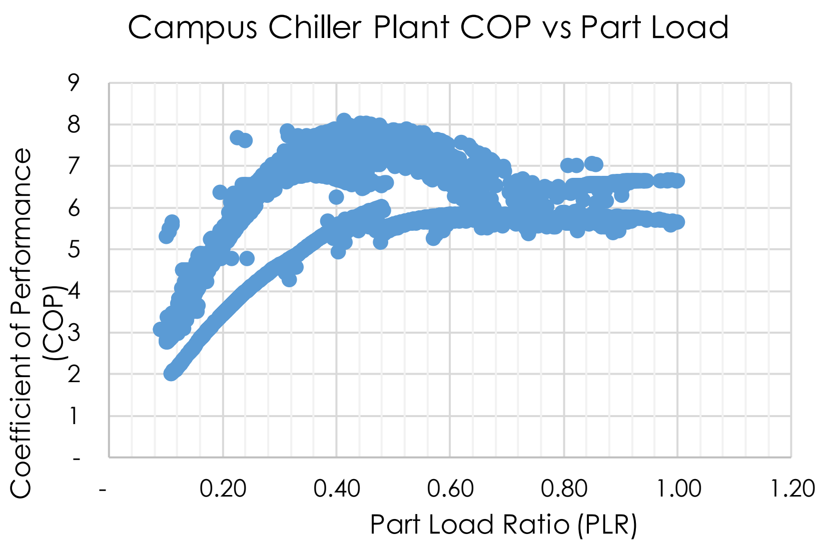
General Approach and Analysis

EnergyPlus was initially chosen for the model over eQuest due to the ability to model dual cooling coils within a single air handler. The model and all iterations were developed entirely within DesignBuilder using their Detailed HVAC interface and supplemented by their integrated EMS module.

Chilled Water Plant Efficiencies

The following scatter plots show the part load ratio (PLR) vs. coefficient of performance (COP) for both the campus cooling plant and the low-temperature air-cooled chiller plant. These plots are based on actually modeled results. See the Appendix for further detail on how the central plant loads and efficiencies were modeled.





As can be seen in these two charts, both chiller plants operate at their peak efficiency in the 30%-45% range. However, due to the sheer size of the campus plant in comparison to the OR scope, it is unlikely that the OR sequence will significantly impact the campus plant's PLR at any given point in time. In contrast, the new air-cooled chiller plant's PLR is entirely dependent upon the portion of low-temperature air handler load satisfied by the upstream campus cooling coil. For this reason, the campus cooling coil's setpoint was chosen as the primary optimization variable.

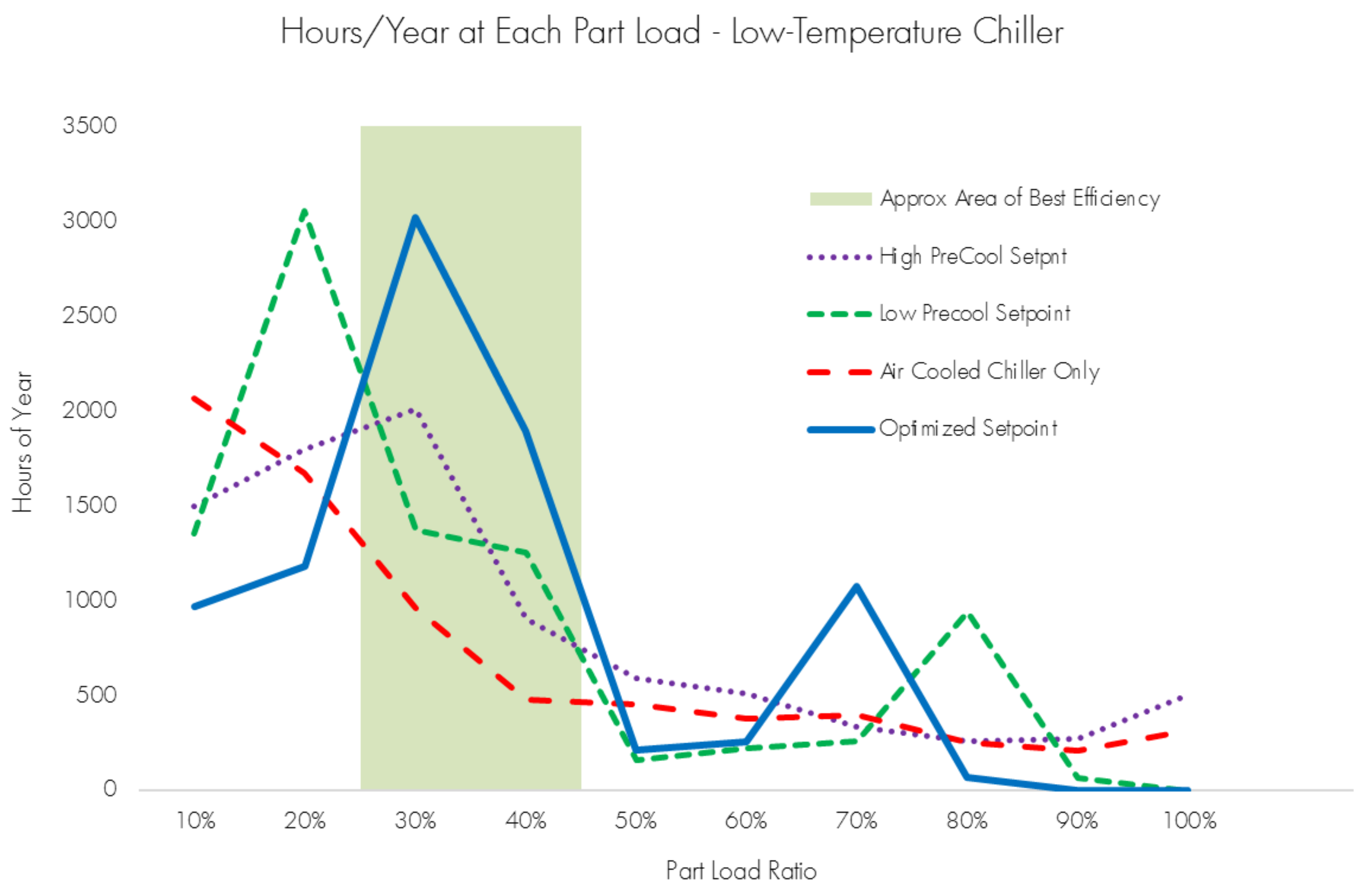
The following design iterations were developed:

1. Air-cooled chiller only, satisfying entire load (two chillers identical to proposed design assumed to satisfy entire load)
2. Campus cooling to 54°F (SAT) with air-cooled chiller satisfying remainder of load
3. Proposed design: campus cooling to 48°F (SAT) with air-cooled chiller satisfying remainder of load
4. Optimized Load Management: modulate campus cooling setpoint in order to optimize air-cooled chiller part loading

Energy Model Parametric Results

As expected, the initial design's low campus precool option compared favorably to the air-cooled chiller only and high campus precool iterations. However, the Optimized Campus Precool strategy led to savings of roughly $2,000 per year or ~2.5% of total OR HVAC cost. This is not an enormous savings and it remains to be seen if the practical and financial hurdles associated with controls programming are worth the cost savings.

HVAC Cost Summary	ACC Only	54°F Campus Precool	48°F Low Campus Precool	Optimized Campus Precool
Cooling-Elec	$94,914	$71,409	$42,228	$ 39,418
Cooling - Campus	$0	$18,280	$32,785	$ 32,548
Pumps - Total	$1,426	$2,031	$1,672	$ 2,056
Total	$96,340	$91,720	$76,684	$ 74,022



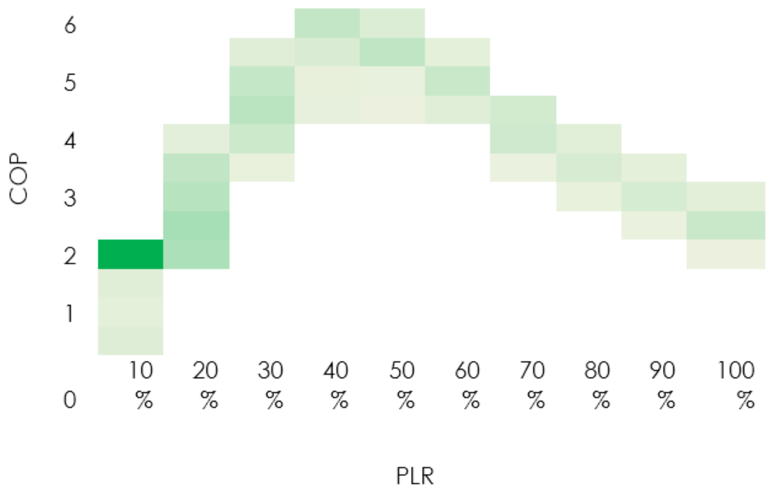
The graph above shows the hours per year at each part load for the low-temperature chiller. **The green band is the "sweet spot" of best efficiency. As can be seen, the optimized setpoint routine shifts the most operational hours into this area.**

Parametric Heat Maps

The following heat maps show the number of hours at each part-load and COP range for each design iteration. Darker green indicates more hours at a given point of operation; lighter green indicates fewer hours. A higher COP indicates better chiller performance.

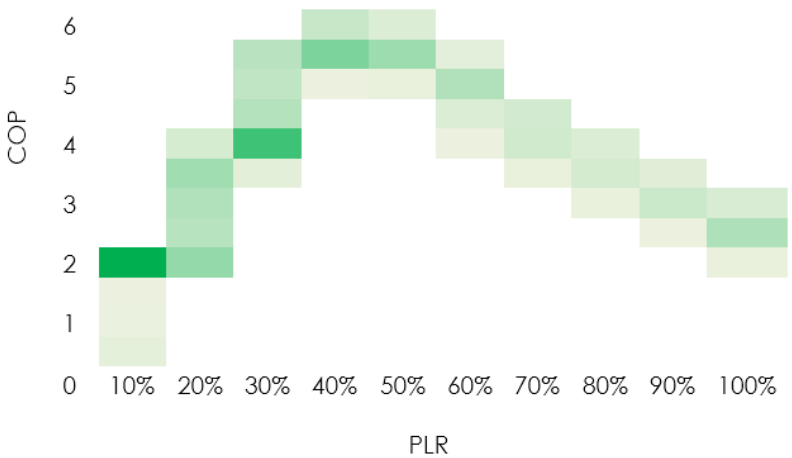
Heat Map of COP vs. PLR: Air-cooled Chiller Picking up Entirety of OR Load

~2,400 hrs/year are spent at a COP above 4.5, resulting in an average annual COP of 2.5 for the air-cooled chiller.



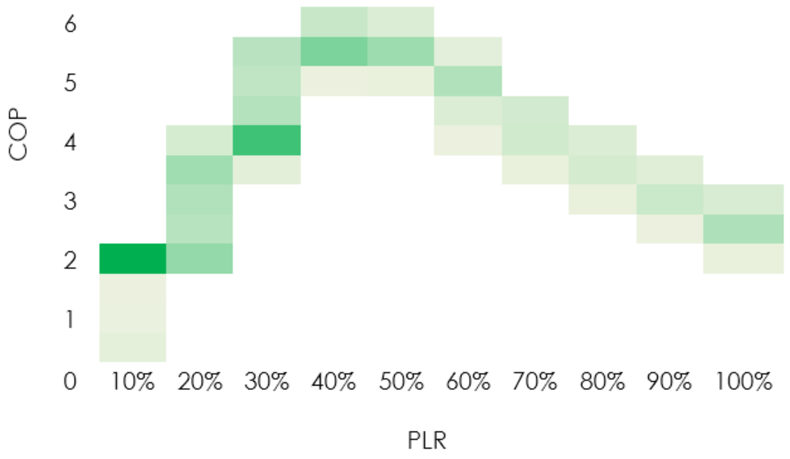
Heat Map of COP vs. PLR: Campus Chiller Plant Only Precools to 54°F

~3,100 hrs/year are spent at a COP above 4.5, resulting in an average annual COP of 3.4 for the air-cooled chiller.



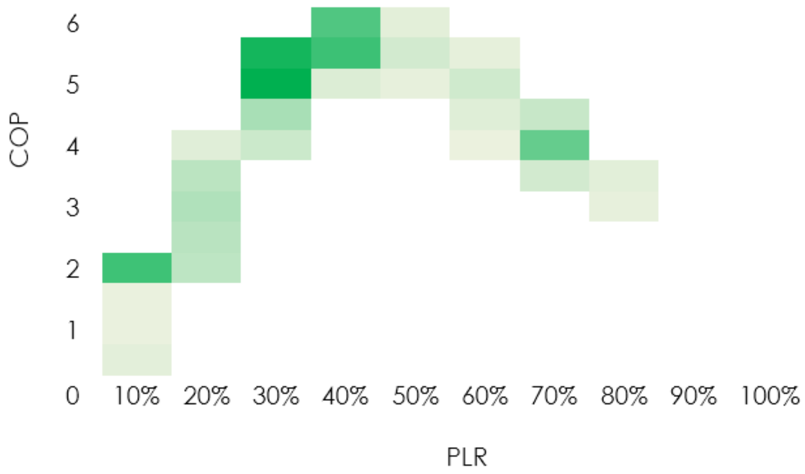
Heat Map of COP vs. PLR: Campus Chiller Plant Precools to 48°F

~3,000 hrs/year are spent at a COP above 4.5, resulting in an average annual COP of 3.0 for the air-cooled chiller.



Heat map of COP vs. PLR: Optimized Load Management

~5,400 hrs/year are spent at a COP above 4.5, resulting in an average annual COP of 4.1 for the air-cooled chiller.



Summary

DesignBuilder's simulation results and its built-in EMS functionality provided the tools required to make fully-informed plant optimization decisions that had real-life design impacts.

The ability to quickly take a previously-developed LEED model, strip out the important components and run HVAC iterations quickly in DesignBuilder's detailed HVAC mode afforded the design team a confidence in the performance and controls of a complex cooling strategy that otherwise would not be available with a static model based on load calculations.

DesignBuilder helped the design team validate their existing calculations and also provided ways to yield more real-life operational cost savings throughout the year.

Michael Sweeney, BEMP, LEED AP is a mechanical engineer with In Posse, AKF's in-house high performance building lab. Michael excels in energy modeling and documentation for LEED® and local incentive programs in New York and New Jersey, such as NYSERDA Flex Tech and NJ Clean Energy P4P. He has experience with CFD modeling using Six Sigma, as well as working knowledge of Python. Michael is a strong team player and is admired for his positive attitude, his excellent organizational skills, and his diligence in accomplishing project goals.

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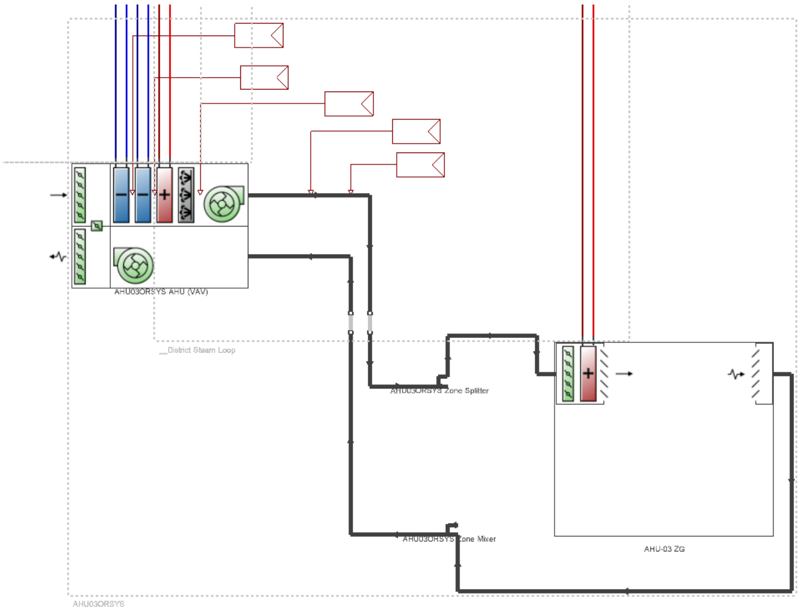
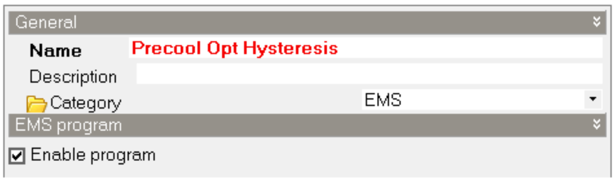
Appendix – Inputs and Details

A. DesignBuilder image of one of three 30,000 cfm air handlers serving the suite of ORs: the first cooling coil at each air handler is supplied by the campus chilled water plant and precools the air prior to being run through the low-temperature cooling coil supplied by the air-cooled chiller



B. Screenshot of the EMS code used to vary the campus cooling coil supply air setpoint based on the air-cooled chiller's part load




```
EnergyManagementSystem:Sensor,
   CH_PLR
   Chiller 1,
   Chiller Part Load Ratio;
EnergyManagementSystem:Actuator,
   Schedule_Value_PRE_COOL_SETPOINT,
   PRE COOL SETPOINT,
   Schedule:Compact,
   Schedule Value;
EnergyManagementSystem:ProgramCallingManager,
   PROGRAMCALLINGMANAGER,
   InsideHVACSystemIterationLoop,
    TEMPOPT;
EnergyManagementSystem:Program,
TEMPOPT,
IF CH_PLR < 0.29,
SET Schedule_Value_PRE_COOL_SETPOINT = 12.22,
ELSE,
IF CH_PLR > 0.35,
SET Schedule_Value_PRE_COOL_SETPOINT = 8.5,
ENDIF,
ENDIF;
```

C. OR Load Assumptions:

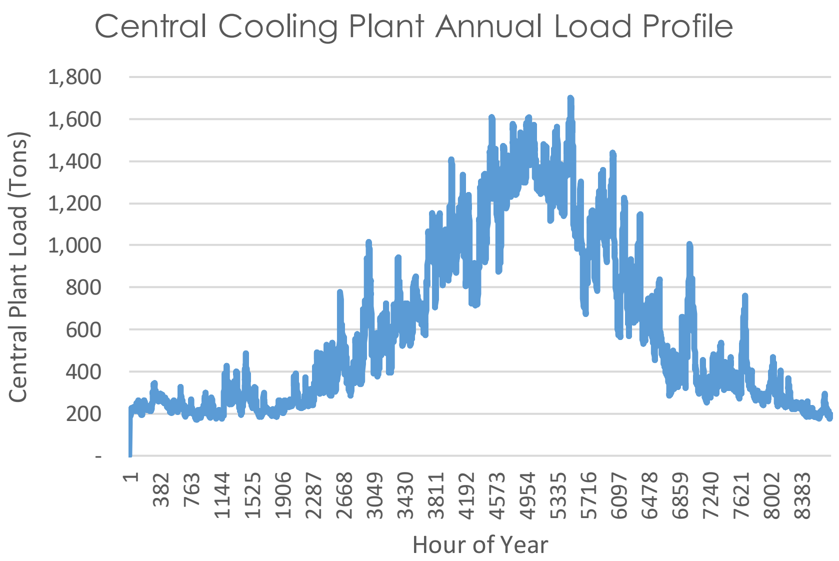
- Equipment Power Density: 4 watts/SF
- Lighting Power Density: 0.7 watts/SF
- Occupancy: 200 SF/person

D. The below table shows the variation assumed in the OR suites throughout the day/week and the corresponding total supply air requirements supplied by each of the three air handlers.

Fraction of Full Load	**Daytime (8am – 8pm)**	**Evenings (8pm-Midnight)**	**Overnight (Midnight-8am)**	**Weekends (All Hours)**
AHU-01	100%	100%	100%	60%
AHU-02	100%	60%	OFF	OFF
AHU-03	100%	OFF	OFF	OFF
Total CFM Delivered to Suite	90,000	48,000	30,000	18,000

E. Modeling the Campus Chiller Plant:

The campus chilled water plant was simulated in a separate energy model using an hourly load profile developed using actual metered load data. The results of this simulation were used to calculate the approximate cost per BTU of campus cooling load on an hourly basis. Because at any given hour the portion of load satisfied by the air-cooled chiller vs. the campus plant may change, it was important to consider if there are any hours when the optimization strategy used was not ideal in comparison to the hourly performance of the campus plant.



Annual Load Profile of Air-cooled Chiller at 48°F Campus Precool Conditions: