Campus Energy Project Summary Report

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- Building Energy Modeling & Validation:

The aim of building energy modeling is to calibrate existing OpenStudio models using EnergyCap, the buildings that were calibrated so far are Starzer welcome center, Elm hall, Maple hall and Weaver Towers.
This was done by first importing the buildings geometry from Sketchup, then analyzing the construction drawings provided along with the building automation system (BAS).
The OpenStudio results were calibrated with the real energy usage for a selected year from EnergyCap.
The goal is to get the coefficient of variance of the root mean square error (cvRMSE) of the results of each building within +-15% of the utility data.
All of the buildings were modeled with Denver County, Colorado ASHRAE 169-2006 Climate Zone (5B). The schedule sets were chosen based on the building and climate type. (i.e: climate zone 5 -office construction set, or climate zone 5- office- restroom schedule set, etc..), the schedule sets were assigned differently to each thermal zone type (classroom, closed offices, restrooms, corridors…).

The first step is to compare the energy bills for different years for each building, then choose a weather file where the energy billing data was aligned with the weather file conditions.
After the buildings geometries are imported, the construction drawings and building automation system are analyzed, the space is divided into different thermal zones based on the internal space layout and the HVAC equipment and load conditions.
Inside the schedules and loads tabs in OpeStudio, we updated the lighting, electric equipment & occupants' schedules, changed the hot water, chilled water, AHUs setpoint and deck temperatures, changed the summer & winter thermostat temperature setpoints, added Infiltration & Ventilation and turned on the ideal air loads for unconditioned spaces (storage, electric rooms, etc,..) and more. The modeling processes for each building is summarized in the following sections.

1- Starzer Welcome Center:

Starzer welcome center is a low-rise office building (5 floors) that was built on 10/1/2015 with a net area of 31,580 ft^2.
The building geometry was provided, however the Openstudio model needed more calibration to minimize the error. The HVAC System of this building consists of:

1- one air handling unit that is serving the whole building, the thermal zones are connected to fan powered variable air volume units (FPVAV) with one coil only (can be used as heating or cooling coil). These coils are supplied with hot/chilled water from the heating/chilled water systems.
2- Hot water system that supplies both the heating coils in the AHU and the domestic hot water. The building hot water system is connected to the central heating plant via one heat exchanger.
3- Chilled water system that supplies the cooling coils in the AHU and connected to the central plant chilled water loop via one heat exchanger.
4- On BAS, the hot/chilled water loops are showing a separated glycol loop, however, on Openstudio, these loops were simulated by adding the glycol percentage in the supplied water (i.e: 20% in chilled water & 30% in hot water).

For this building, we choose the 2017 weather file. The comparison between the different years (2016-2019) are shown in the figures 1, and 3 below for electricity, cooling and heating, all the main and secondary equipment were added and most of the values were modeled using the autosized option.

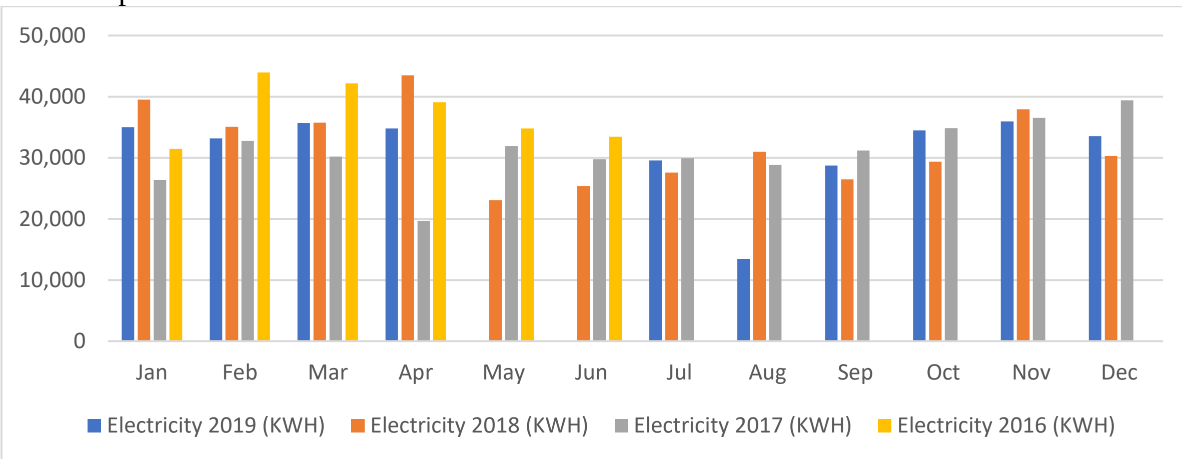


Figure 1_SWC Electric load (2016-2019)

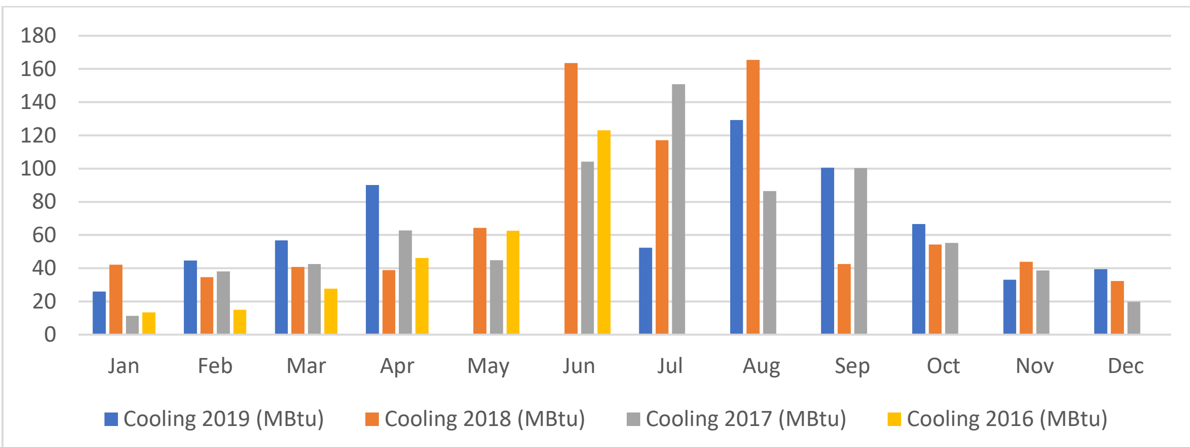


Figure 2__SWC Cooling load (2016-2019)

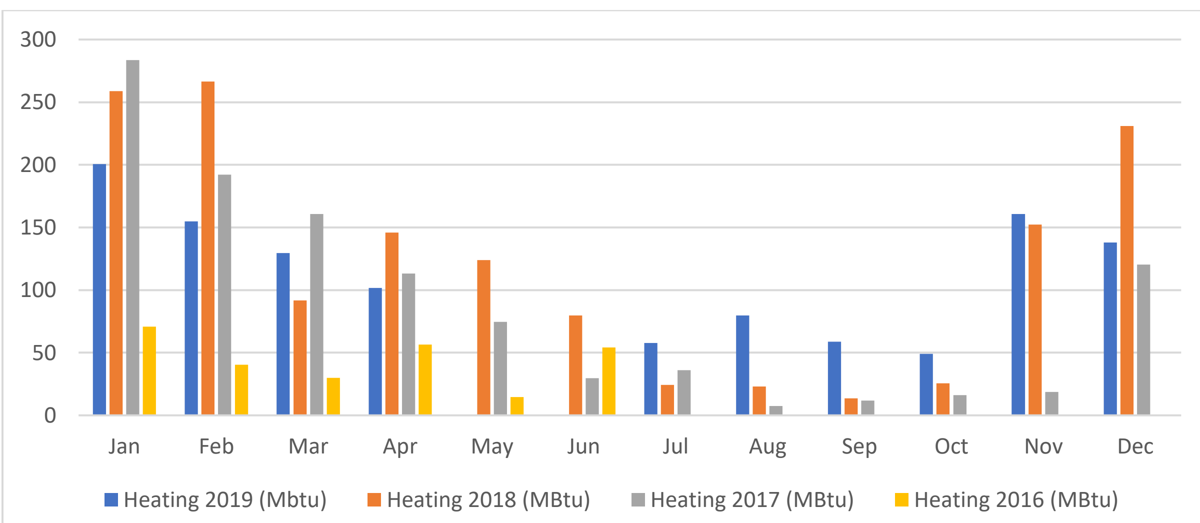


Figure 3__SWC Heating load (2016-2019)

For this building, we compared our results with another ready prototype OpenStudio model to make sure our values for different loads were reasonable. After running the simulation multiple times, each with a different changes, we got the results shown in figures 4,5 and 6 for electricity, cooling and heating respectively compared to the original file we started with, the cv(RMSE) value was 11.5%. Which is below the maximum value recommended by ASHRAE (+-15%):

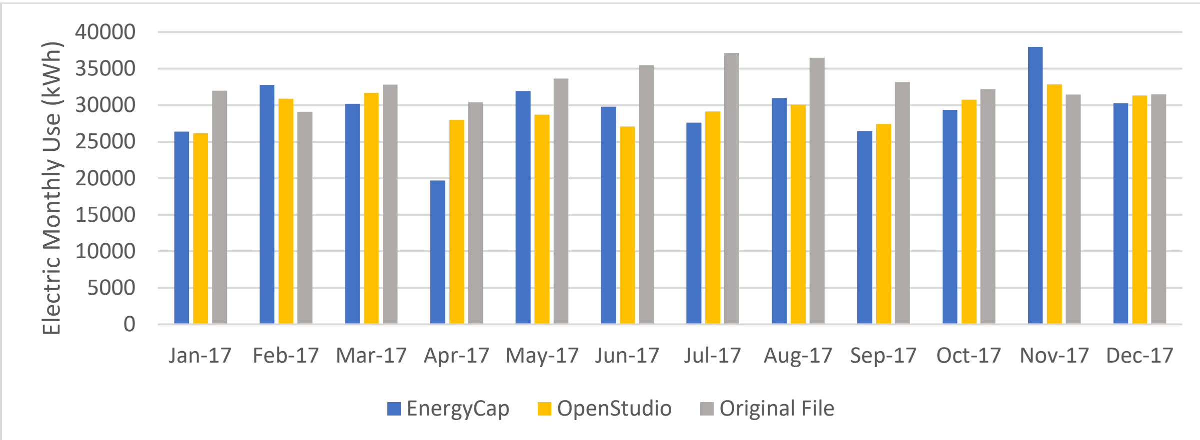


Figure 4_Electric monthly use

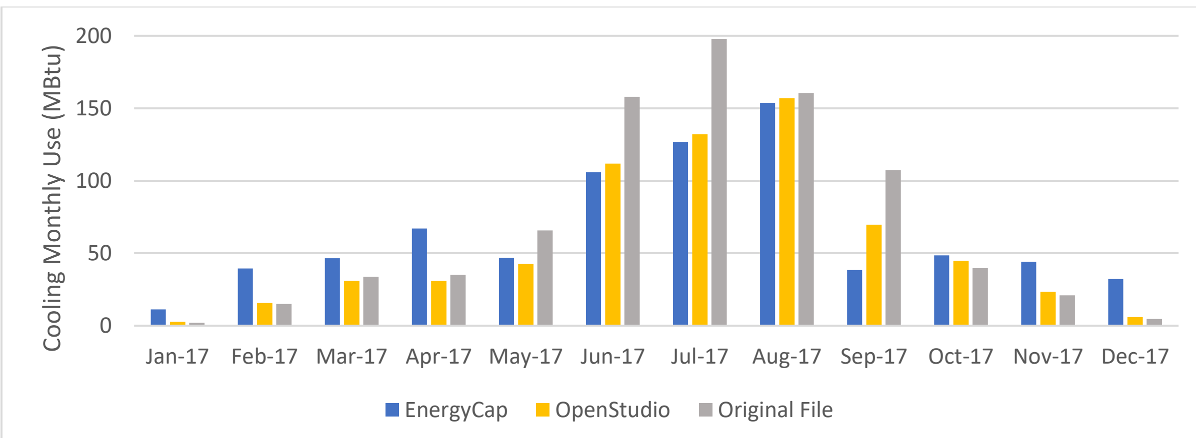


Figure 5__Cooling monthly use

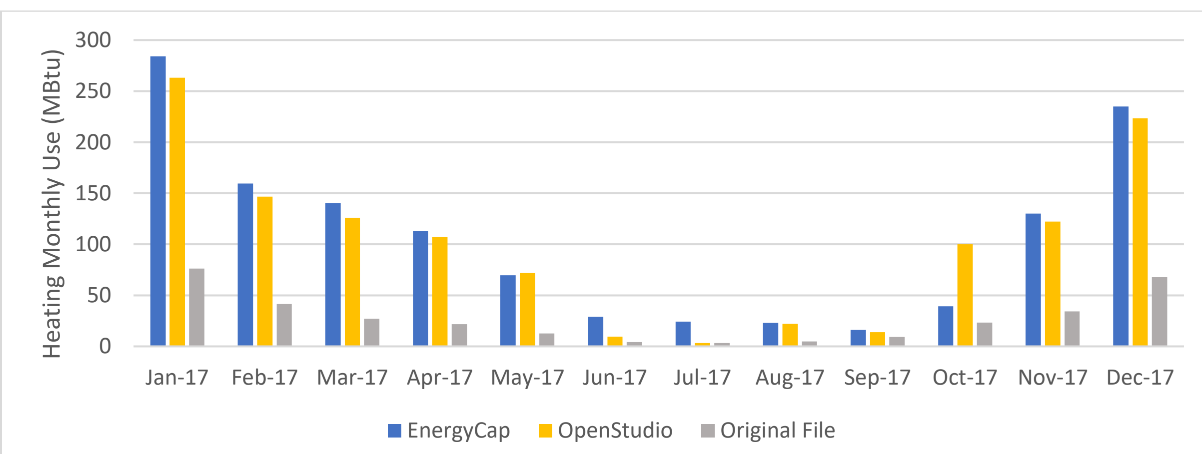


Figure 6__Heating monthly use

2- Elm Hall:

Elm hall is a combination of a restaurant, a low-rise office building, and a residential mid-rise apartment building (5 floors). It was built in 1/1/2015 with a net area of 94,862 ft^2. The building geometry was also provided, the HVAC system of this building consists of:

1- Five air handling units:
   - AHU-1 is a 100% outside air unit and serves the Dining and kitchen areas in the 1st and 2nd floors.
   - AHU-2 & 3 are a 100% outside air units, that serves the West & East residential areas respectively in the 3rd, 4th and 5th floors. Each zone in AHUs 2 and 3 are connected to a fan coil unit with 4 pipe fan coil type that is supplied with hot/chilled water from the district hot/chilled water loops.
   - AHU-4 & 5 serve the West & East office areas respectively in the 2nd floor.

2- Hot Water loop: the steam (primary source of heating) generated at the central plant heats the building water via two heat exchangers and supplies it to the heating coils and to two other heat exchangers for domestic water use.

3- Chilled water loop: the chilled water generated at the central plant cools the water supplied to the cooling coils via one heat exchanger.

4- Refrigeration system: Mines market is on the first floor of this building, five refrigeration systems (3 walk-in freezers & 4 walk-in coolers) were added to the model. This had a huge effect on the cooling load in the building.

For this building, the year 2017 was also chosen for modeling after comparing the billing data from (2014-2019) as shown in figures 7,8 and 9:

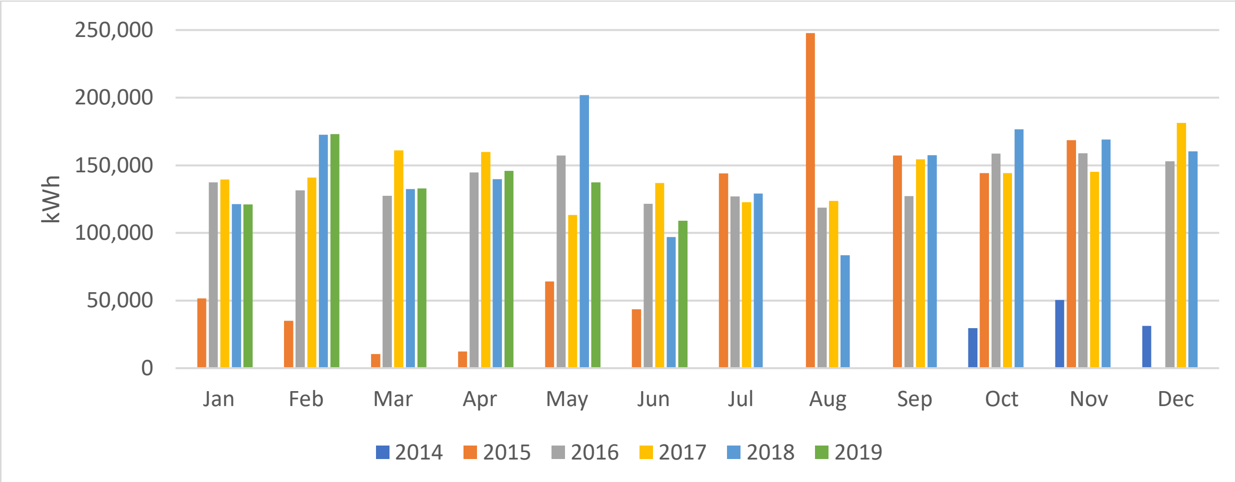


Figure 7_Elm Electric load (2014-2019)

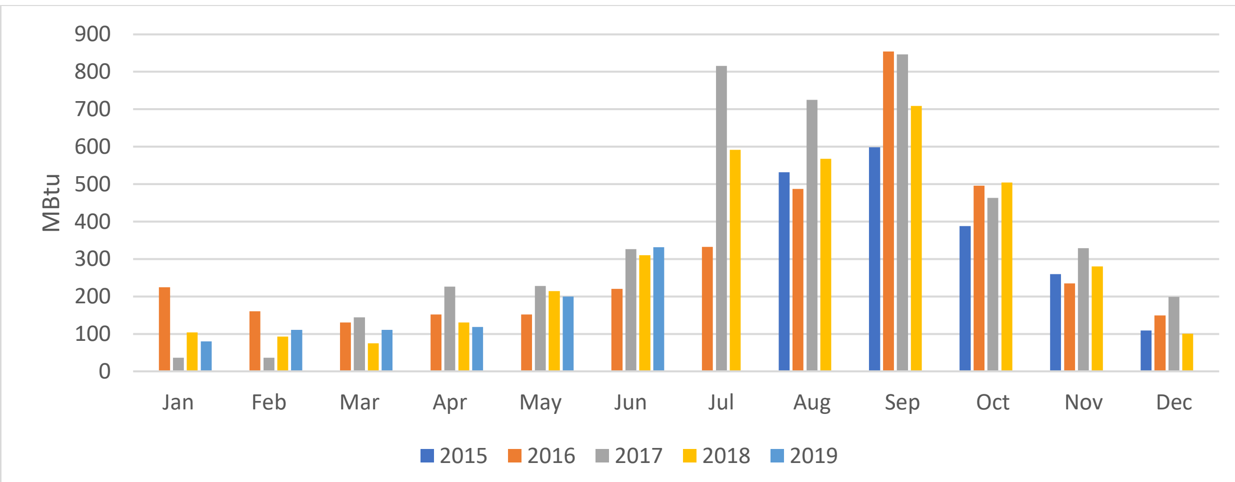


Figure 8_Elm Cooling load (2014-2019)

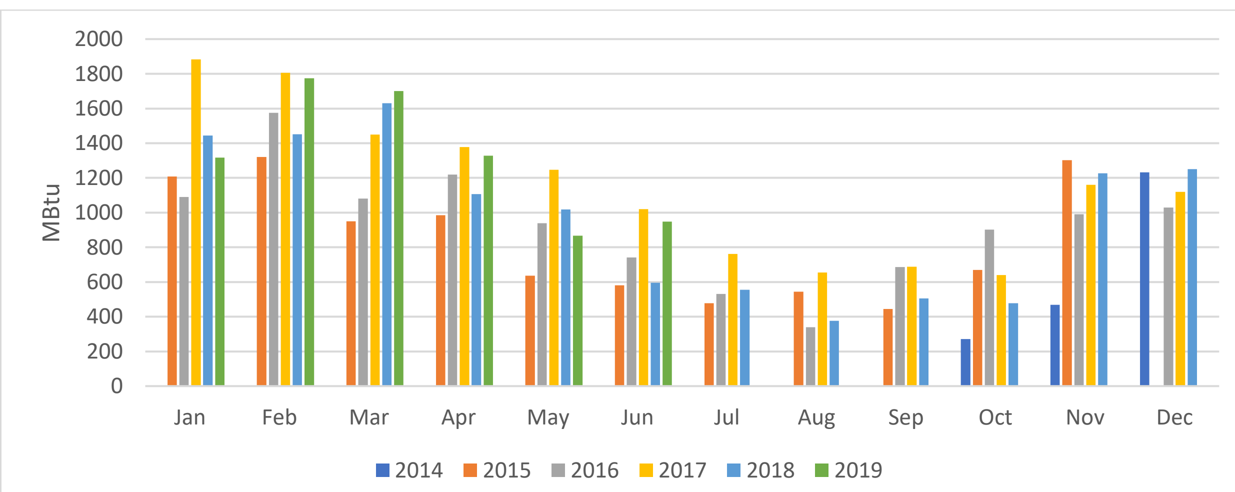


Figure 9_Elm Heating load (2014-2019)

The model that we started with needed modifications in connecting the thermal zones to the air equipment, figure 10 shows how we reconnected the zones to their AHUs:

Elm Hall AHU's Thermal Zones

AHU 1	5	12	26	32	41	47
	6	13	27	33	42	48
	7	17	28	34	43	49
	8	18	29	36	44	50
	9	24	30	37	45	51
	11	25	31	40	46	52
AHU 4	15					
	20					
	38					
	39					
AHU 5	10					
	16					
	19					
	21					
	22					
	23					
	35					
AHU 2 & 3	Rest					

(purple)	1st Floor
(yellow)	2nd Floor East
(green)	2nd Floor West Offices
(orange)	2nd Floor East Offices

Figure 10_Connecting thermal zones

After connecting the zones and adding the secondary equipment (FCUs, UHs, Diffusers) we modeled the refrigeration system in the first floor at Mines market as shown in figure 11 and table 1 below, we had 5 walk-in refrigeration systems operating at different temperatures, different areas and different thermal zones.

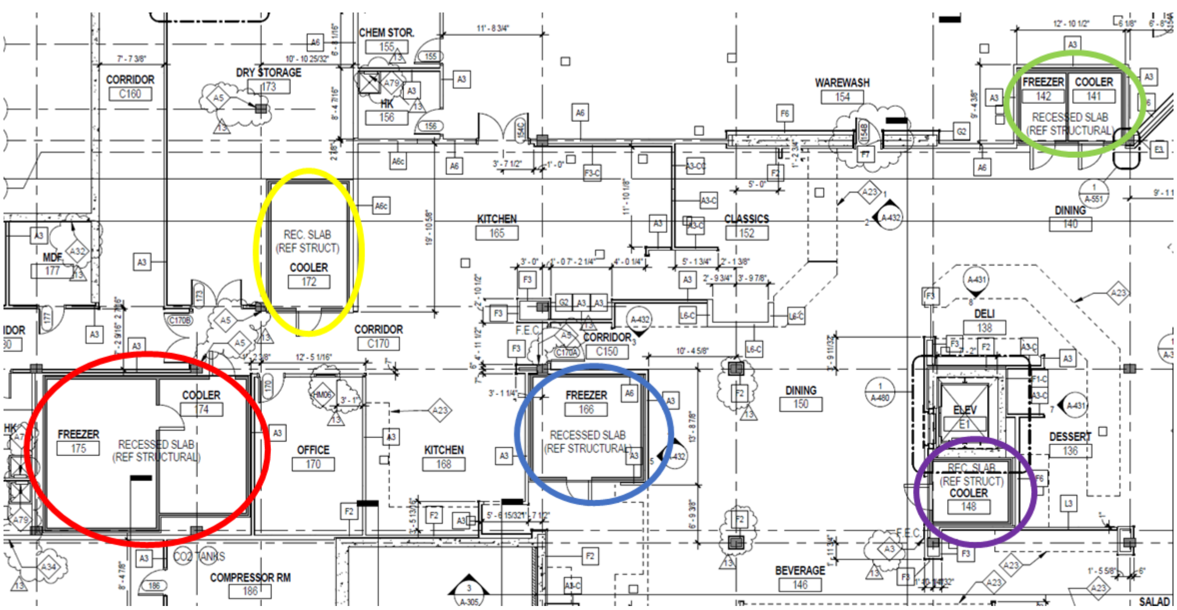


Figure 11_Walk-in refrigeration systems location

Table 1_Walk-in refrigeration design values

Walk in Refrigerator	Thermal Zone	Area (ft^2)	Operating Temp (F)
Freezer 1	28	240	8
Freezer 2	34	150	-6
Freezer 3	49	64	4
Cooler 1	28	160	28
Cooler 2	41	130	35
Cooler 3	30	63	37
Cooler 4	49	64	38

Air handling units designing values were taken from the mechanical drawings. Table 2 summarizes the air flow rates in cfm for each AHU in the building.

Table 2_Air handling units cfm designing values

CFM \ AHU	AHU-1	AHU-2	AHU-3	AHU-4	AHU-5
Supply Fan Total	35,000			5,000	8,100
Supply Fan Outside Air	35,000			1,500	2,500
Return Fan Total	35,000				
Supply Air Total (Heat Recovery)		4,500	5,100		
Exhaust Air Total (Heat Recovery)		4,500	5,100		
Coil Heating	35,000	4,500	5,100	2,500	2,500
Coil Cooling	35,000	4,500	5,100	5,000	5,000

These are the main conditions that were changed in this building, many other conditions were modeled and edited, and after each run it was revised and ran again. The final results for electricity, cooling and heating compared to the original file are shown in figures 12, 13 and 14, the cv(RMSE) was 11.9%.

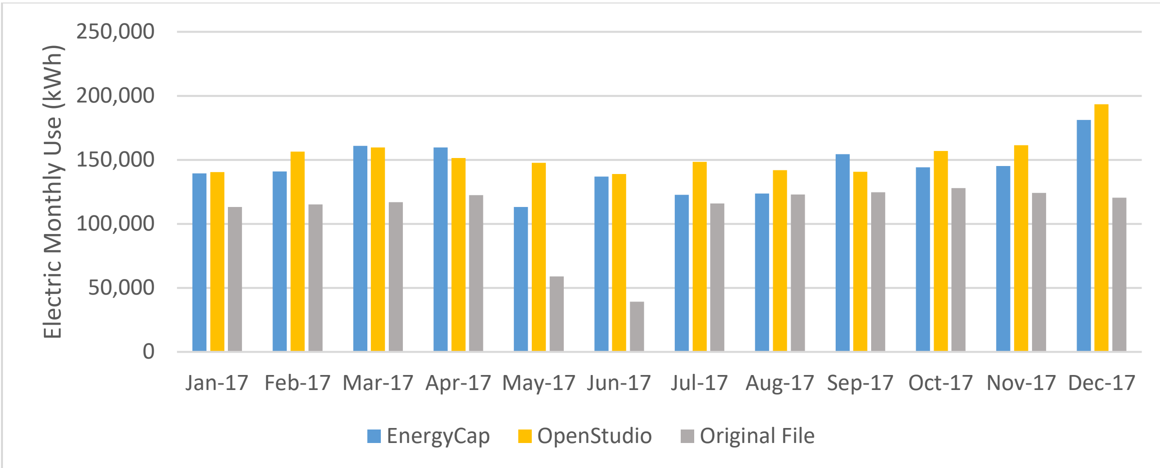


Figure 12_Elctricity monthly use

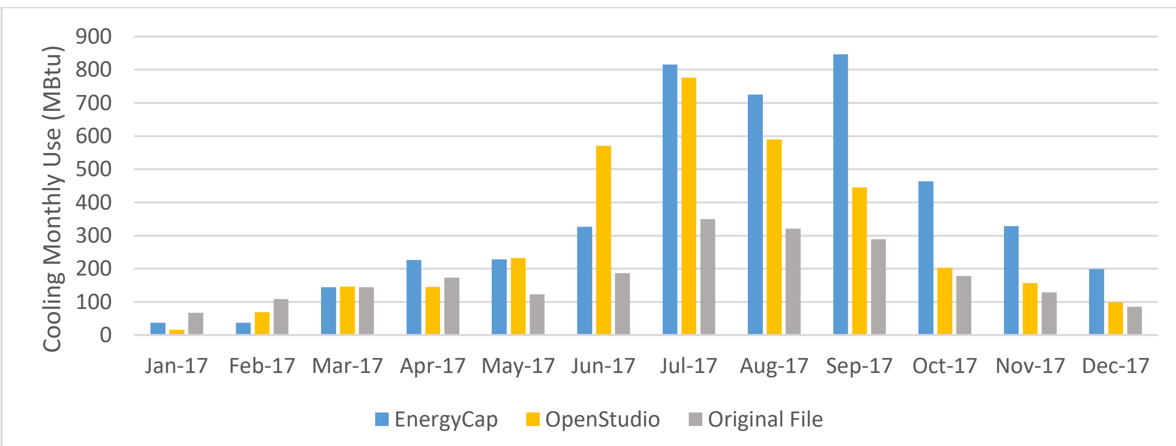


Figure 13_Cooling monthly use

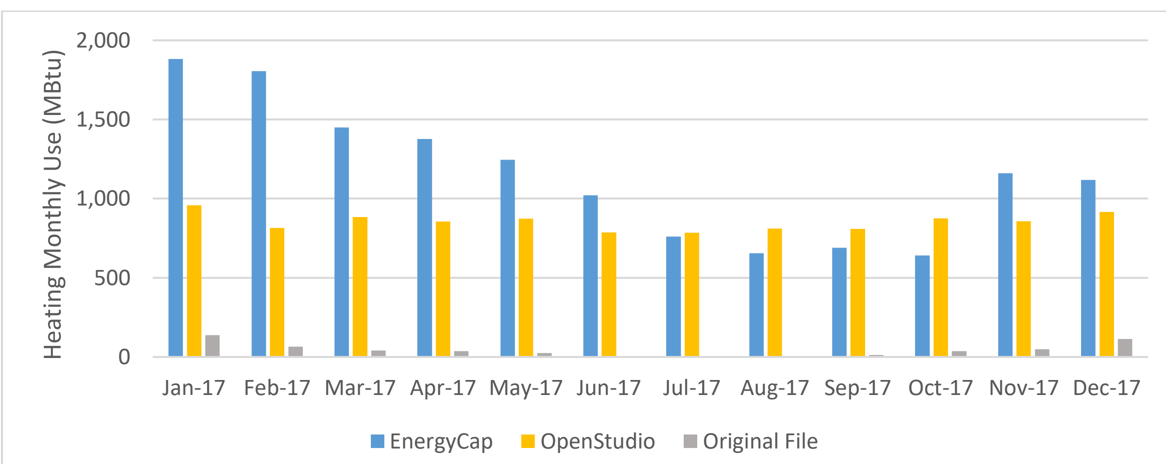
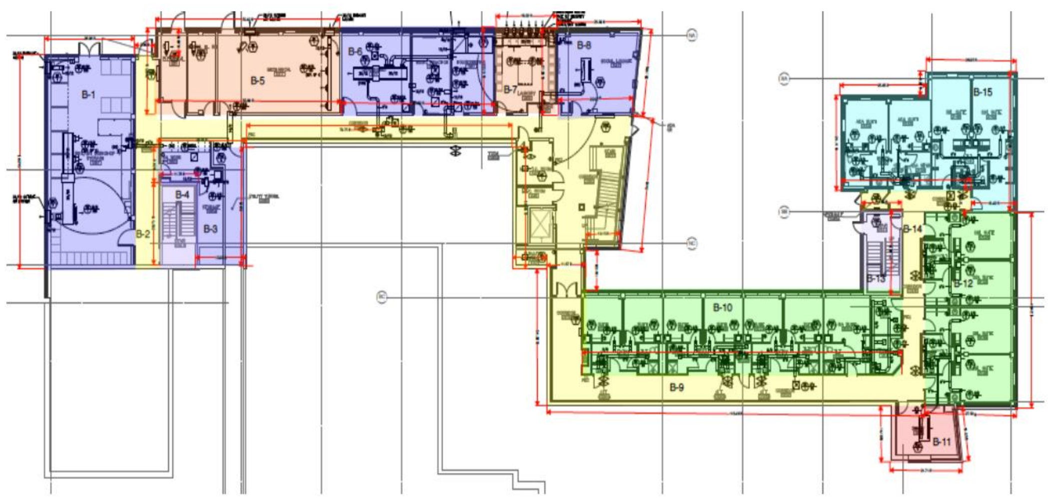


Figure 14_Heating monthly use

3- Maple Hall:

Maple hall is a residential mid-rise apartment building (5 floors). It was built in 8/1/2011 with a net area of 97,665 ft^2.
The HVAC system of this building consists of:

1- Air handling units (AHUs-1 & 2) serving the north and south sides of the building respectively and are operating at full load capacities each zone is connected to a secondary equipment (Fan coil unit or unit heater).
2- Hot water loop: the district hot water is supplied to the heating coils in the FCUs, UHs, water radiators and to the domestic water use.
3- Chilled water loop: the district chilled water at the central plant is supplied to the cooling coils inside the AHUs and FCUs.



The 2017 weather file was also chosen. The comparison between the electric, cooling and heating loads for the years 2016, 2017 and 2018 are shown in figures 15,16 and 17.

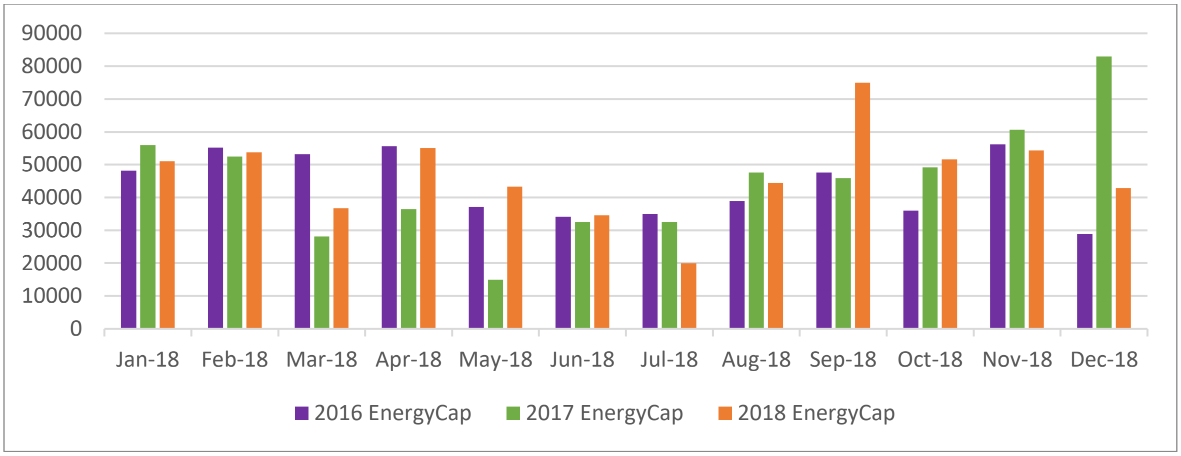


Figure 15_Maple electric load (2016-2018)

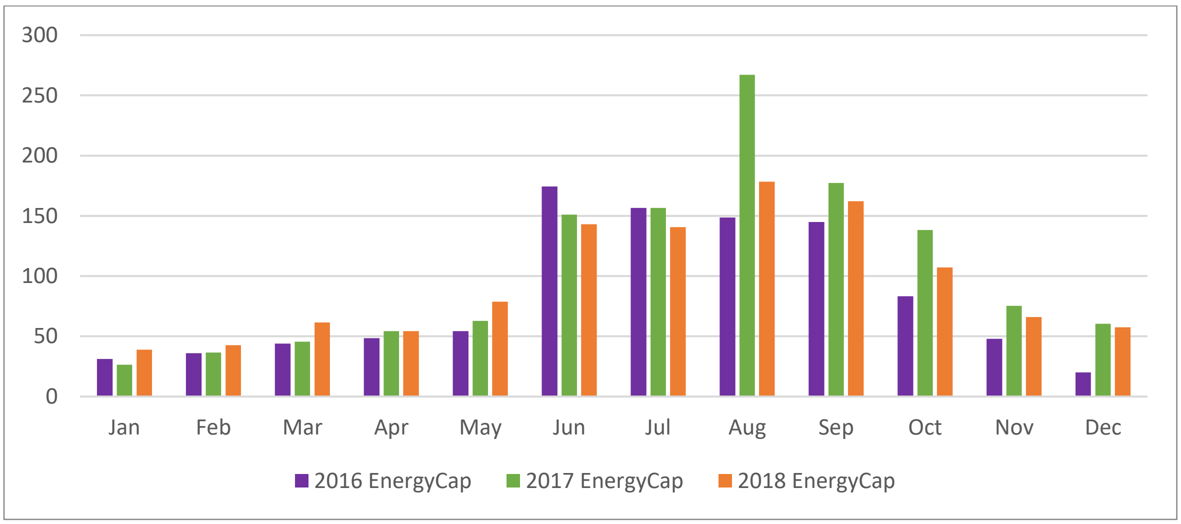


Figure 16_Maple cooling load (2016-2018)

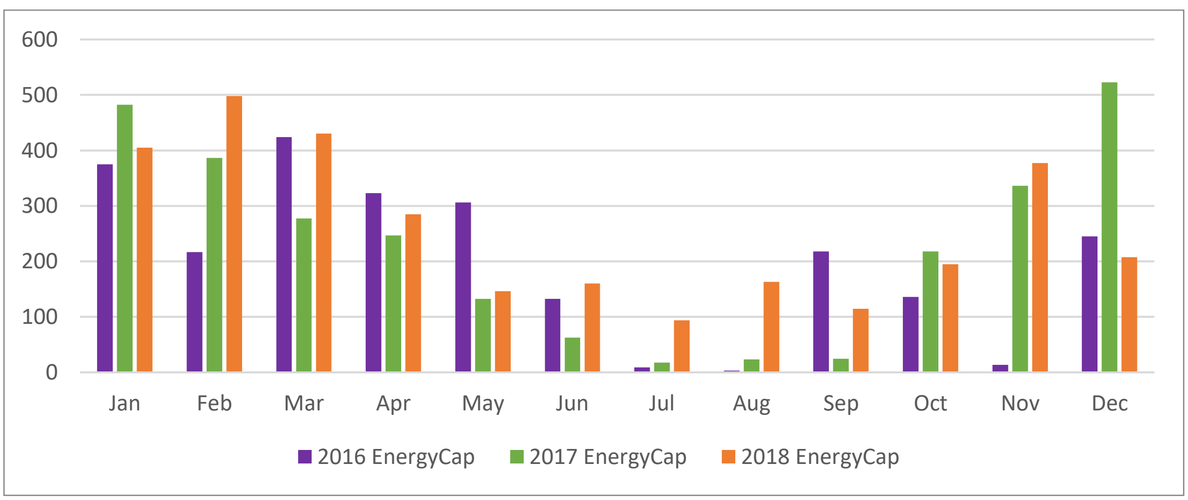


Figure 17_Maple heating load (2016-2018)

This building also (similar to Elm hall) had an incorrect number of AHUs and zones served by each. The building originally had one air handling unit for each floor (total of 5). So, we had to start with the building geometry and remodel everything again (all the zones were deleted, and 2 air handling units were made and connected to their zones). Table 3 shows the zones of the building with their secondary equipment in 4 colors, the light blue is for the fan coil units in AHU-1 serving the north side, dark blue in for the fan coil units in AHU-2 serving the south side. The black color is for the water radiators in the shared bathroom areas on the first floor, and finally the orange is for the unit heaters. Figure 18 shows an example of how the thermal zones were divided for the 1st floor of the north side of the building.

Table 3_reconnecting the AHUs and secondary equipment

Floor/AHU	North (AHU-1)			South (AHU-2)		
Basement	1	2	3	9	10	11
	4	5	6	12	13	14
	7	8		15		
1st Floor	1	2	3	13	14	15
	4	5	6	16	17	18
	7	8	9	19	20	21
	10	11	12			
2nd Floor	1	2	3	8	9	10
	4	5	6	11	12	13
	6-B	7		14	15	17
				18		
3rd Floor	1	2	3	8	9	10
	4	5	6	11	12	13
	6-B	7		14	15	17
				17-1		
4th Floor	1	2	3	8	9	10
	4	5	6	11	12	13
	6-B	7		14	15	16
				17		

Water Radiators	Unit Heater	FCU

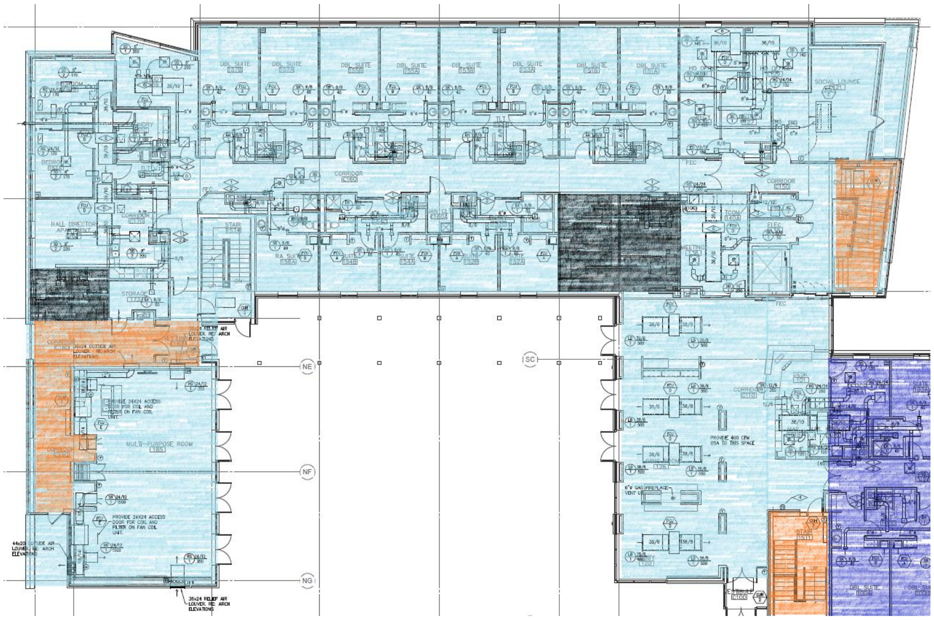


Figure 18_North side of the first floor (Maple)

All the secondary equipment were sized from BAS and mechanical drawings. an example of sizing the FCUs are shown, table 4 is the designing values from the mechanical drawings, table 5 shows how the flow rate values were entered after summing the cfm for the shared zones.

Table 4_FCUs design values from mechanical drawings

DESIG.	MFR.	MODEL	ARRANG.	CFM TOTAL AT 5400'
FCU-A	IEC	MMY 04	VERTICAL-MASTER	360
FCU-B	IEC	MSY 04	VERTICAL - SLAVE	360
FCU-C	IEC	CBY-12	HORIZONTAL-BOTTOM SUPPLY, BOTTOM RETURN	760
FCU-D	IEC	BPY-08	HORIZONTAL HS- HIDEAWAY WITH PLENUM	525
FCU-E	IEC	HBC-10	HORIZONTAL - BELT DRIVE	1300
FCU-F	IEC	CBY-04	HORIZONTAL - BOTTOM SUPPLY, BOTTOM RETURN	300
FCU-G	TEMTROL	QX-DH6	HORIZONTAL -100% OA UNIT	2600

Table 5_FCUs design values entered in OpenStudio model

Zones in AHU-1	FCU (CFM)	Zones in AHU-2	FCU (CFM)
B-1	525	**B-10**	2520
B-3	360	**B-11**	760
B-6	3125	**B-12**	1440
B-8	760	**B-15**	1440
1-1	2600	**1-13**	2625
1-3	1050	**1-15**	2160
1-5	525	**1-16**	2880
1-7	3405	**1-18**	1440
1-8	1800	**1-20**	760
1-9	760	**1-21**	525
1-11	525		
2,3,4-1	1440	**2,3,4-9**	760
2,3,4-4	3600	**2,3,4-11**	2520
2,3,4-5	2880	**2,3,4-13**	2880
2,3,4-6	760	**2,3,4-14**	760
		2,3,4-15	1440
		2,3,4-17	1440

The tables and screenshots down below are other examples of how the units and systems were designed and sized, figure 19 and table 6 shows the air handling units along with their design values for the cooling/heating values, energy recovery unit, and the setpoint manager, for Maple hall the deck temperature were not shown or recorded in BAS, so we used the “Multi Zone Cooling Average” for both AHU1&2 ranging between 55 - 65F.

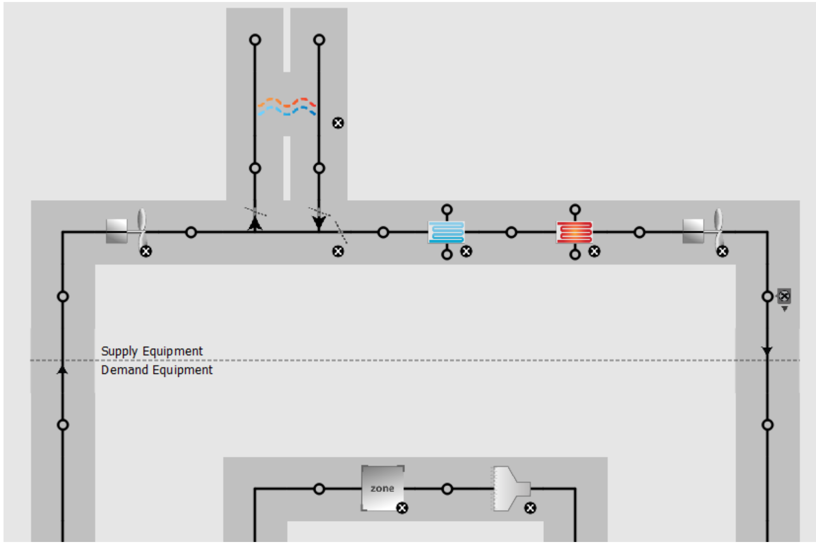
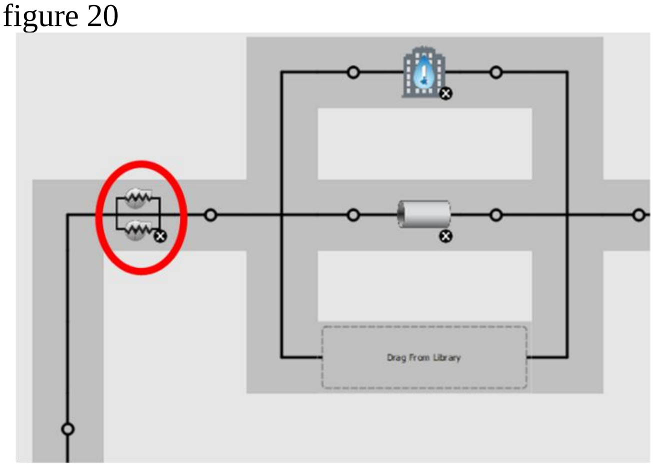


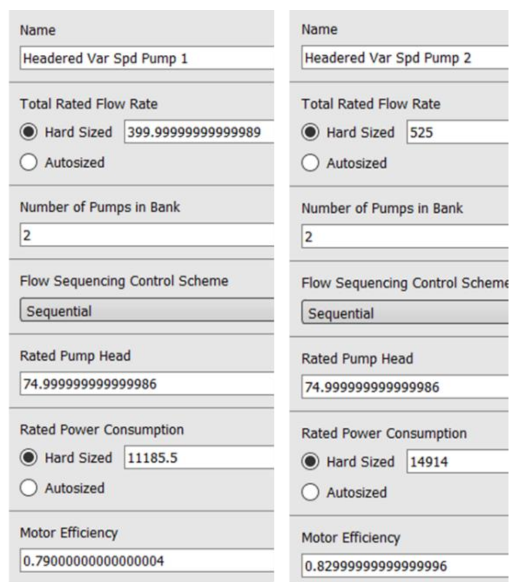
Figure 19_Designing the AHUs in OpenStudio

Table 6_AHUs coils design values in mechanical drawings

	COIL DATA										
	SERVICE	SURF. AREA SF	COIL CFM AT 5280'	ROWS	AIR ΔP IN W.C. AT S.L.	EAT °F DB	EAT °F WB	LAT °F DB	LAT °F WB	MBH	GPM
AHU-1	HEATING	16	8000	2	0.10	-5	-	80	-	612	65
	COOLING	16	8000	6	0.50	75	58	50	49	200	45
AHU-2	HEATING	16	8000	2	0.10	-5	-	80	-	612	65
	COOLING	16	8000	6	0.50	75	58	50	49	200	45

Designing the headered pumps in the campus, building and domestic hot water loops are shown in figure 20

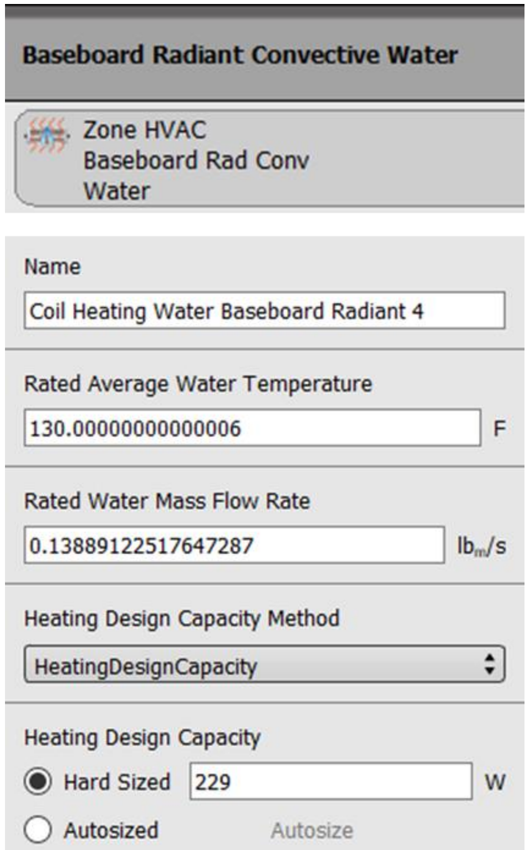




PUMP SCHEDULE									
DESIG.	MFR.	MODEL	PUMP TYPE	SERVICE	GPM	TOTAL DYNAMIC HEAD (FT.)	EFF. %	MIN. HP	RPM
HWP-1	ARMSTRONG	4302-8x8x10	VERTICAL-DUAL ARM	BUILDING HEATING WATER	400	75	79	15	1800
HWP-2	ARMSTRONG	4302-3x3x8	VERTICAL-DUAL ARM	GLYCOL HEATING WATER	140	65	55	5	1800
CWP-1	ARMSTRONG	4302-8X8X10	VERTICAL-DUAL ARM	BUILDING CHILLED WATER	525	75	83	20	1800

Figure 20_Designing the pumps in Openstudio

Designing the heating water radiators in the shared bathroom areas in the first floor (zones 1-10 & 1-2) is shown in figure 21:



	Avg. Temp.	Mass Flow Rate	Design Capacity
Water Radiators	130 F	0.14 lbm/s	780 Btuh
	54.4 C	1gpm	229 Watt

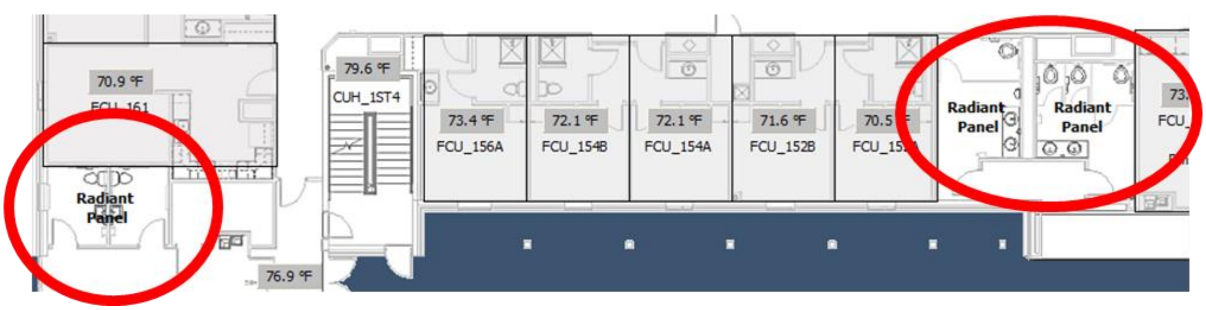


Figure 21_Designing the water radiators in OpenStudio

The results for electricity, cooling and heating compared to the original file are shown in figures 22, 23 and 24.

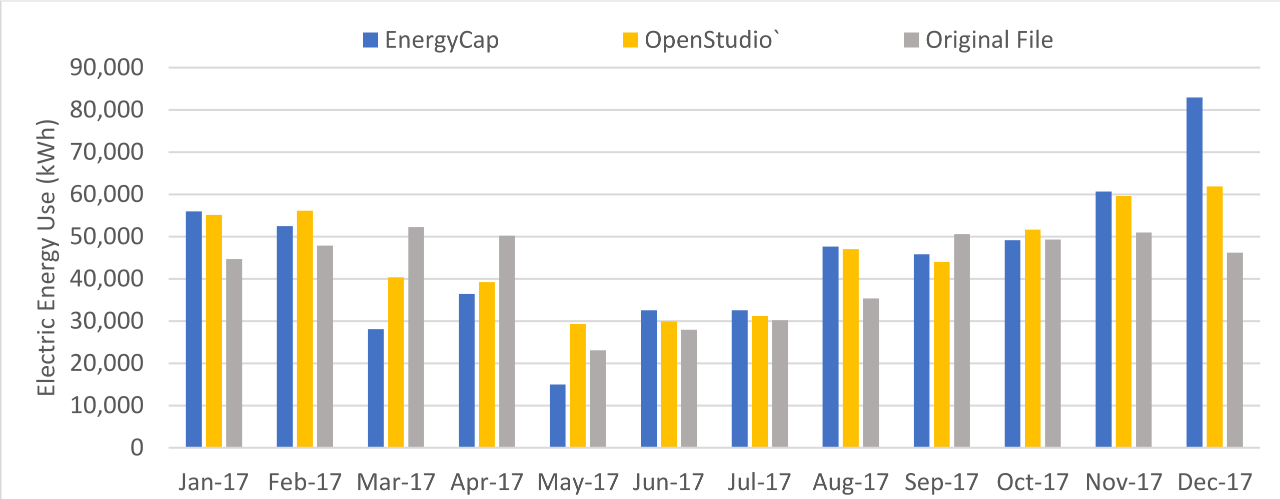


Figure 22_Electricity monthly use

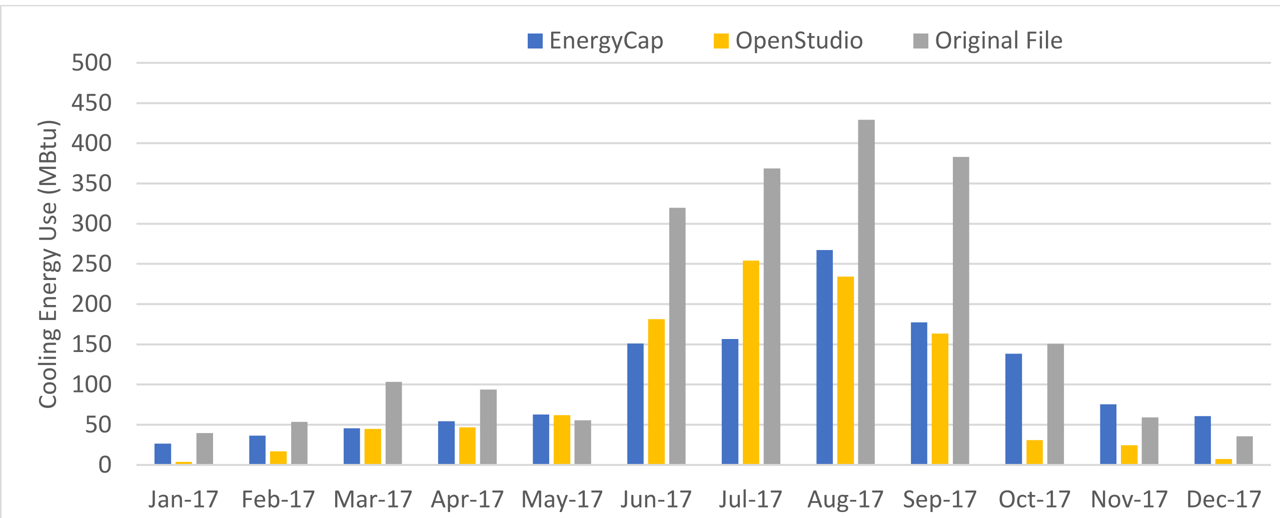


Figure 23_Cooling monthly use

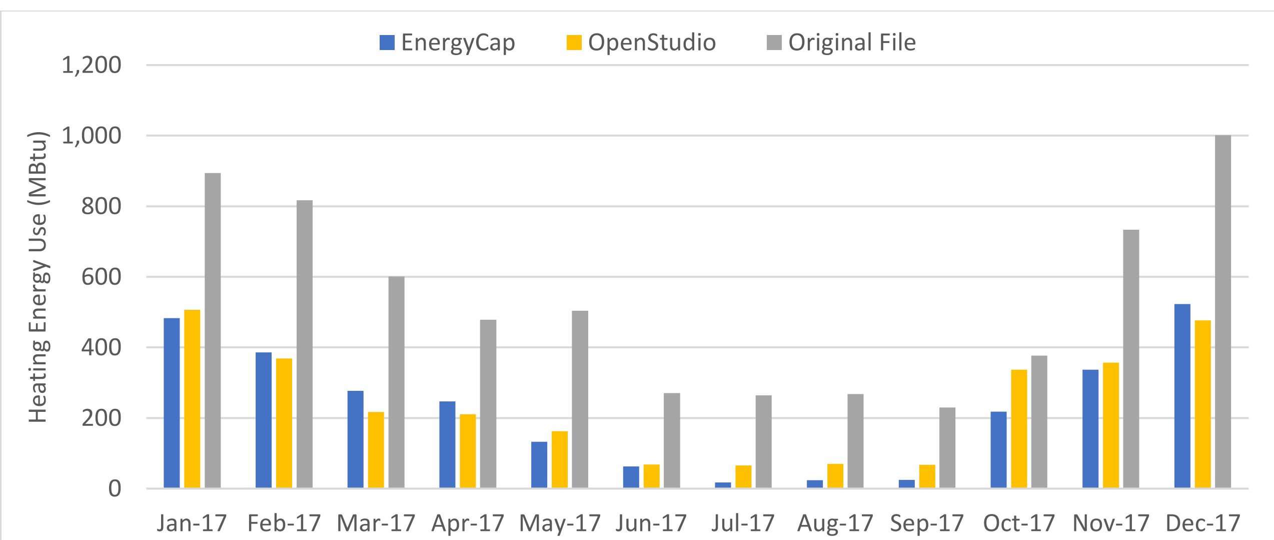


Figure 24_Heating monthly use

4- Weaver Towers:

Weaver Towers is a residential mid-rise apartment building with 5 floors and a net area of 57,660 ft^2. The HVAC system consists of:

1- Three makeup air units:
   - MAU-1: serving the west tower with 100% outside air.
   - MAU-2: serving the east tower with 100% outside air.
   - MAU-3: serving the central link with 100% outside air.
2- Hot water loop: the hot water generated at the steam plant supplies heat to two heat exchangers. The heat exchangers are connected to the domestic hot water heat exchanger for domestic use and the MAUs and heating coils in the FCUs.
3- Chilled water loop: the chilled water from the central plant is supplied to the cooling coils in the MAUs and the cooling coils FCUs.

For this building, weather file 2016 was chosen after comparing the energy use for the years (2013-2017) as shown in figures 25,26 & 27.

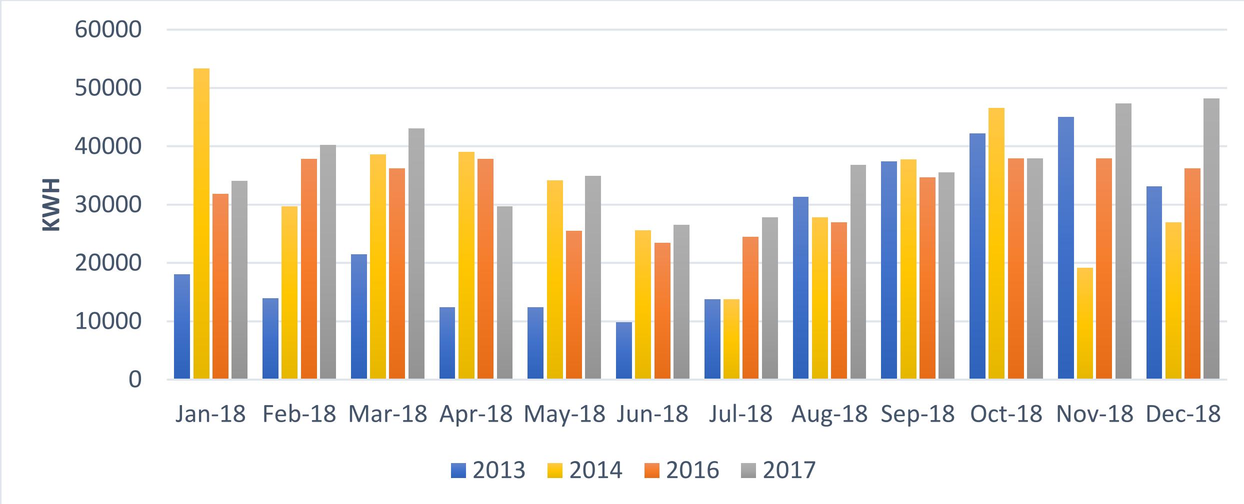


Figure 25_Weaver electric load (2013-2017)

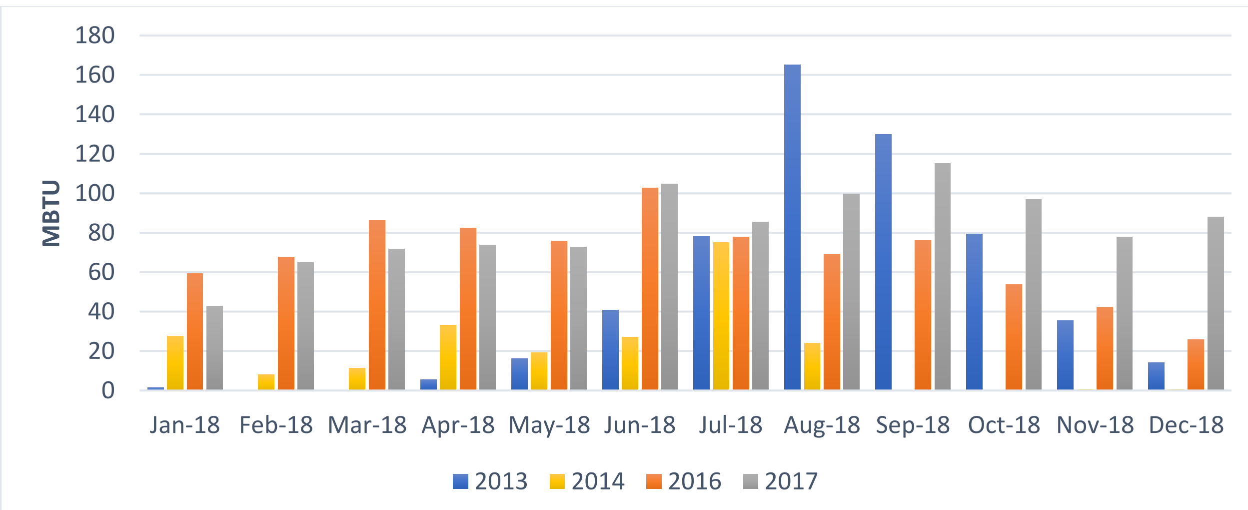


Figure 26_Weaver cooling load (2013-2017)

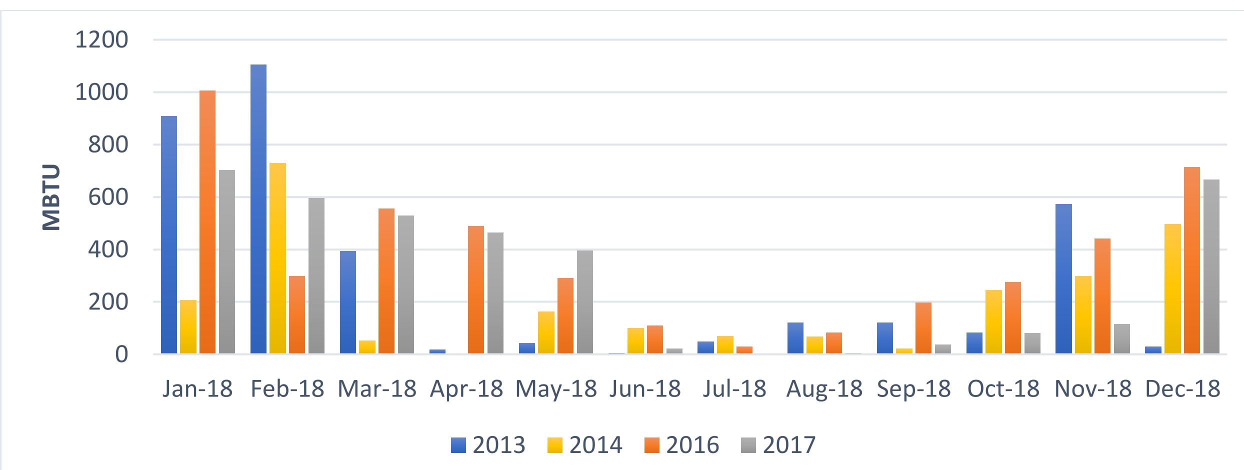


Figure 27_Weaver heating load (2013-2017)

All the secondary equipment were fan coil units or just diffusers (in the zones with no air devices). The zones were divided nicely in the original file which made the modeling much smoother. A summary of the fan coil unit's locations, air flow rates, water mass flow rates, heating and cooling MBH are shown in table 7 below after summing the values for the shared thermal zones along with the values in the mechanical drawings in table 8.

Table 7_Weaver fan coil units design values

Building			Air Devices Design (Fan Coil Units)			
Floor	**Wing**	**Room**	**CFM**	**GPM**	**Heating MBH**	**Cooling MBH**
Basement	**Middle**	**Basement**	No Air Devices	NA	NA	NA
1st		**1**	No Air Devices	NA	NA	NA
		2	No Air Devices	NA	NA	NA
	Right & Left	**1**	1520	7.3	54.5	38.5
		2	720	3	27.6	15.8
		3	720	3	27.6	15.8
		4	1770	7.8	68.5	42.8
		5	535	2.5	20.6	13.4
		6	1495	6.6	58.1	36.2
2nd		**1**	1665	7.2	64.9	38.8
		2	1770	7.8	68.5	42.8
		3	550	2.4	20.8	13.2
		4	1770	7.8	68.5	42.8
		5	1770	7.8	68.5	42.8
3rd		**1**	550	2.4	20.8	13.2
		2	1770	7.8	68.5	42.8
		3	1770	7.8	68.5	42.8
		4	1770	7.8	68.5	42.8
		5	1665	7.2	64.9	38.8
4th		**1**	1770	7.8	68.5	42.8
		2	275	1.2	10.4	6.6
		3	1770	7.8	68.5	42.8
		4	1770	7.8	68.5	42.8
5th		**1**	No Air Devices	NA	NA	NA
		2	1770	7.8	68.5	42.8

Table 8_fan coil units design values from the mechanical drawings

HYDRONIC FAN COIL UNIT SCHEDULE

TAG	TYPE	CFM	TSP	RPM	COOLING			HEATING			ELECTRICAL			MANUFACTURER & MODEL	NOTES
					MBH	GPM	WPD FT. HD.	MBH	GPM	WPD FT. HD.	WATTS	V	PH		
FCU-1	HORIZONTAL	225		1,450	7.20	1.2	6.96	9.70	1.2	1.1	125	115	1	YORK FHP-25	
FCU-2	HORIZONTAL	340		1,450	7.50	1.6	1.6	11.20	1.6	1.8	125	115	1	YORK FHP-25	1
FCU-4	HORIZONTAL	630		1,350	17.80	3.3	7.45	22.50	3.3	9.6	261	115	1	YORK FHP-40	1
FCU-5	HORIZONTAL	1,200		1,075	34.98	7	5.7	38.45	7	8.6	988	115	1	YORK FNP-12	1
FCU-8	VERTICAL	275		1,050	6.60	1.2	6.2	10.40	1.2	1.1	60	115	1	YORK FWX-C-03	
FCU-9	VERTICAL	445		1,050	9.20	1.8	0.8	17.20	1.8	0.6	80	115	1	YORK FWX-C-06	
FCU-10	VERTICAL	535		1,050	13.40	2.5	4.3	20.60	2.5	1.0	114	115	1	YORK FWX-C-08	

GENERAL NOTES:

A. PERFORMANCE IS AT SITE

B. CHILLED FLUID IS 20% PROPYLENE GLYCOL AT 44°F EWT AND 56°F LWT

C. HEATED FLUID IS 30% PROPYLENE GLYCOL AT 180°F EWT AND 160°F LWT

1 PROVIDE WITH CONDENSATE PUMP, INTERLOCK WITH UNIT POWER TO SHUT UNIT OFF WHEN HIGH LEVEL IS DETECTED OR PUMP OPERATION FAILS.

The heat exchangers and the pumps design values are also shown in figures 28 and 29 respectively.

HEAT EXCHANGER SCHEDULE

TAG	WATER SIDE GPM	EWT °F	LWT °F	WPD PSI	FLUID	FOUL. FACT.	STEAM SIDE PPH	ET °F	LT °F	WPD PSI	FLUID	FOUL. FACT.	MBH	WEIGHT LB.	MANUFACTURER & MODEL	NOTES
HX-1	134	160	180	1	30% PG	-	1338	227	227	-	STEAM	5E-04	1285	112	B&G SU85-2	
HX-2	134	160	180	1	30% PG	-	1338	227	227	-	STEAM	5E-04	1285	112	B&G SU85-2	
HX-3	17	40	140	1	DOM. WATER	-	883	227	227	-	STEAM	5E-04	-		PK08D	

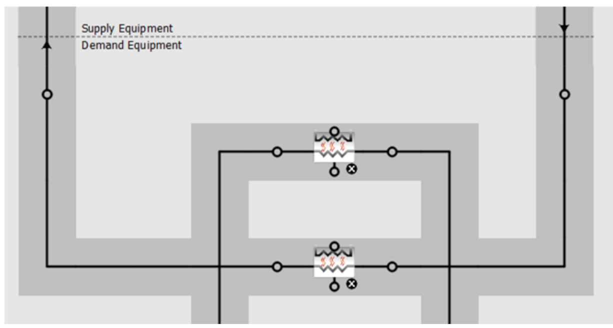


Figure 28_heat exchanger design values

PUMP SCHEDULE

TAG	PURPOSE	TYPE	GPM	FEET HEAD	RPM	EFF	VFD	ELECTRICAL HP	V	PH
CP-1	MAU CIRC PUMP	CENT.-IN-LINE	72	16	1,800	62.5	NO	3/4	200	3
CP-2	MAU CIRC PUMP	CENT.-IN-LINE	72	16	1,800	62.5	NO	3/4	200	3
CWP-1	CHILLED WATER PUMP	CENT.-BASE	270	60	1,800	91	YES	7 1/2	200	3
HWCP-1	DHW RECIRC PUMP	CARTRIDGE CIRC.	20	15	3,250	-	NO	1/6	115	1
HWP-1	HEATING WATER PUMP	CENT.-BASE	280	60	1,800	91	YES	7 1/2	200	3
HWP-2	HEATING WATER PUMP	CENT.-BASE	280	60	1,800	91	YES	7 1/2	200	3
SP-1	SUMP PUMP	SUBMERSIBLE	45	25	1,750	74	NO	1/2	200	3
SP-2	SUMP PUMP	SUBMERSIBLE	45	25	1,750	74	NO	1/2	200	3
SP-3	SUMP PUMP	SUBMERSIBLE	45	25	1,750	74	NO	1/2	200	3
HCPC-1	CONDENSATE PUMP						NO	1.5A	115	1

NOTES:
1 FLUID IS 20% PROPYLENE GLYCOL
2 FLUID IS 30% PROPYLENE GLYCOL
3 PROVIDE WITH SHAFT GROUNDING KIT.
4 ALL BRONZE PUMP CONSTRUCTION, SUITABLE FOR POTABLE WATER SERVICE, LEAD FREE MODEL.

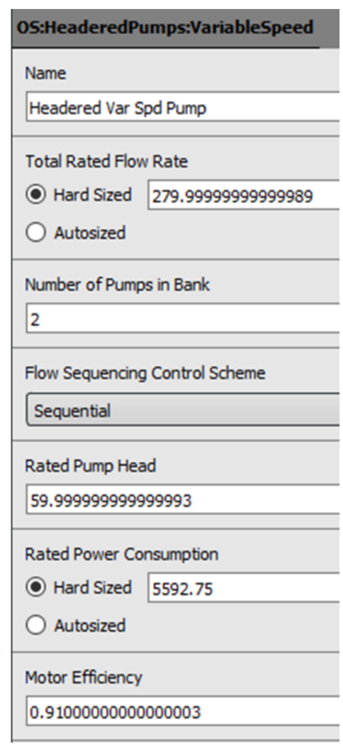


Figure 29_Pumps design values

The final results for weaver towers are shown in figures 30,31 and 32 for electricity, cooling and heating respectively compared to the original file, the cv(RMSE) value was 2.3%.

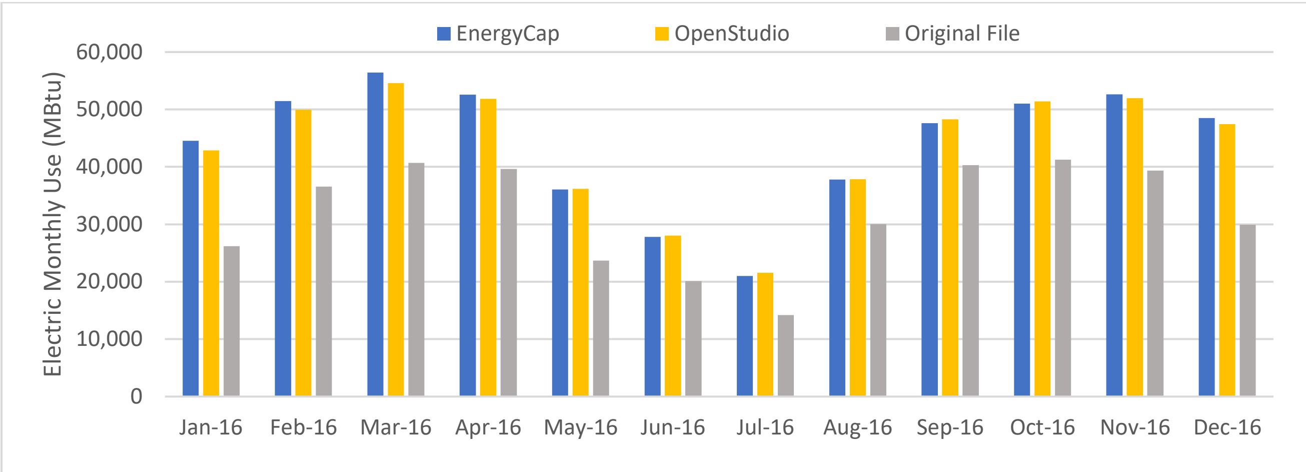


Figure 30_Electric monthly use

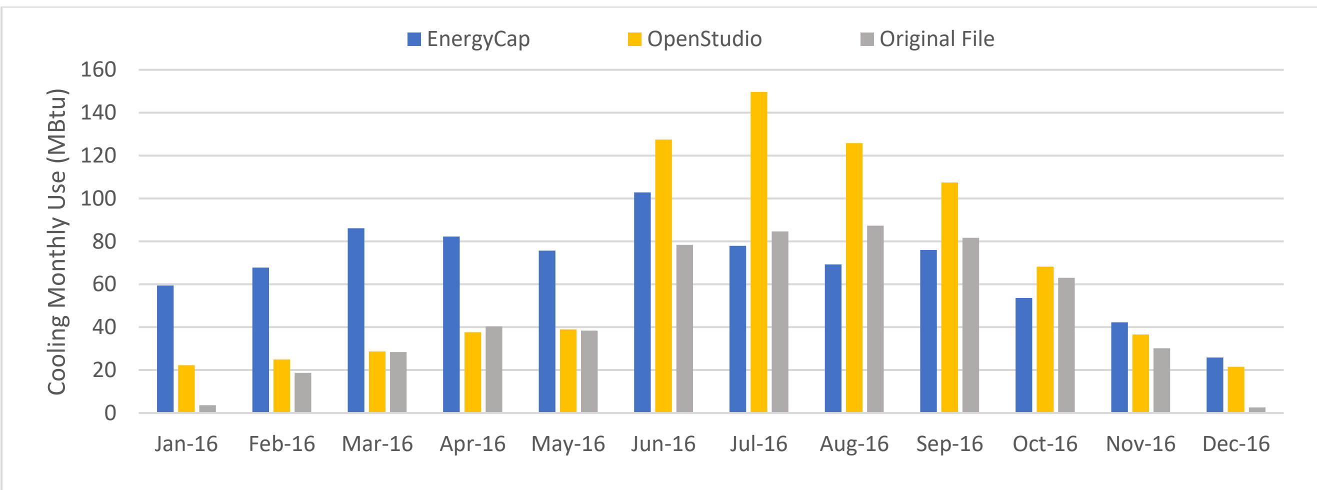


Figure 31_Cooling monthly use

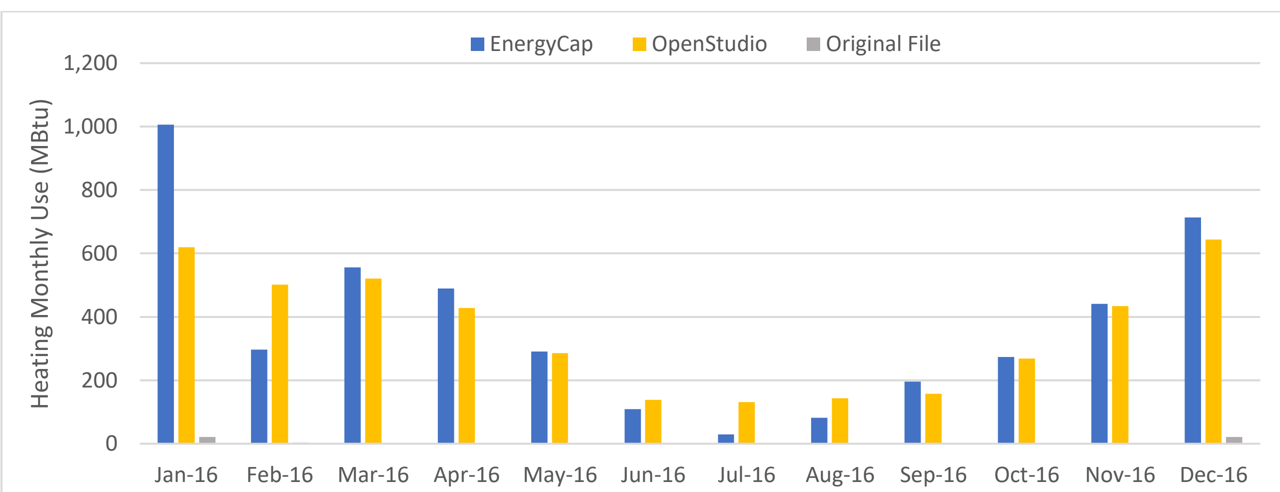


Figure 32_Heating monthly use

5- CoorsTek:

CoorsTek is a classroom and office building. It was built in 1/1/2018 with 4 floors and a net area of 89,720 ft^2. The HVAC system consists of:

1- Four AHUs:
   - AHU-1: serves all the basement, the labs and restrooms in floors 1,2&3
   - AHU-2: this air handling unit is defined in the construction drawings, but the serving zone was not shown in the BAS.
   - AHU-3: serving the labs and offices in floors 1,2 & 3 with different supply flow rates for the winter vs. the summer season.
   - AHU-4: serving only the cleaning room in the basement with different supply flow rates for the winter vs. the summer season.

2- Hot water system: the steam generated at the district heating plant supplies two heat exchangers that are connected to the air handling unit heating coils and to the domestic heat exchanger and the heating radiant floor.

3- Chilled water system: the chilled water in the central plant supplies a heat exchanger that is connected to the cooling radiant floor heat exchanger, the processed chilled water (to be used in the labs) and to the cooling coils of AHUs 1, 2 and 3. AHU 4 coil is connected to a separate heat exchanger (not directly to the chilled water system).

4- Radiant floors system for heating/cooling that serve the first floor of the building.

This building is not validated yet. The OpenStudio modeling was not completed. The final model includes the main HVAC system, Domestic hot water system and the Process water system.
all the main equipment including the air handling units, hot water systems, chilled water system, domestic hot water system, Labs chilled water & Cooling/Heating radiant floors, Heat exchangers and the pumps were all added, sized and scheduled based on the mechanical drawings and Niagara (BAS). The secondary equipment (fan coil units, Unit heaters, Terminal boxes & Radiators) were not added. The SketchUp model has to be fully created first in order to add the thermal zones and the equipment to it.
Choosing a weather file for this building was also tricky, since this building was built in 2018, we only have 2 weather file options to choose from (2018 or 2019), table 9 below shows the compared yearly energy loads with the missing months (in red) from EnergyCap for both years, also, we couldn't create a 2019 weather file since NREL data is still not uploaded to the system (the data is provided until July 2019).

Table 9_Available and missing data for CoorsTek on EnergyCap

	Missing Months								
Year	Month	Electrtricity (kWh)	Cooling (Mbtu)	Heating (Mbtu)	Year	Month	Electrtricity (kWh)	Cooling (Mbtu)	Heating (Mbtu)
	Jan	59465				Jan	111312	60	1570
	Feb	20535				Feb	112464	52	1227
	Mar	12000		536		Mar	132912	1	1190
	Apr	97201		795		Apr	138840	1	644
	May	90000		718		May	139278	2	376
2018	Jun	87890		661	2019	Jun	127980	11	154
	Jul	122264		458		Jul	149358	0	133
	Aug	72266	355	649		Aug	151878	500	169
	Sep	125284	247	628		Sep	161748	845	496
	Oct	150000	134	1020		Oct	196760	484	1212
	Nov	52968	367	1035		Nov			
	Dec	176472	50	1183		Dec			

Both AHU 1 & 2 have the same equipment and design values but attached to different thermal zones. Both are attached to one supply fan, evaporative cooler and heat recovery unit with 100% outside air, the AHU OpenStudio model and BAS system are shown in figure 33.

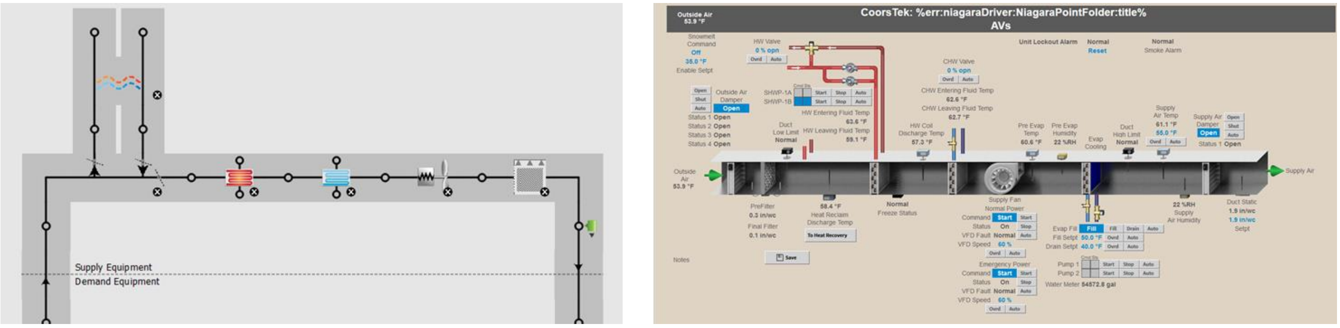


Figure 33_Openstudio and BAS AHU-1&2

AHU 3 has heat recovery unit and evaporative cooler with supply and return fans with different supply and return values for winter and summer, the AHU OpenStudio model and BAS system are shown in figure 34.

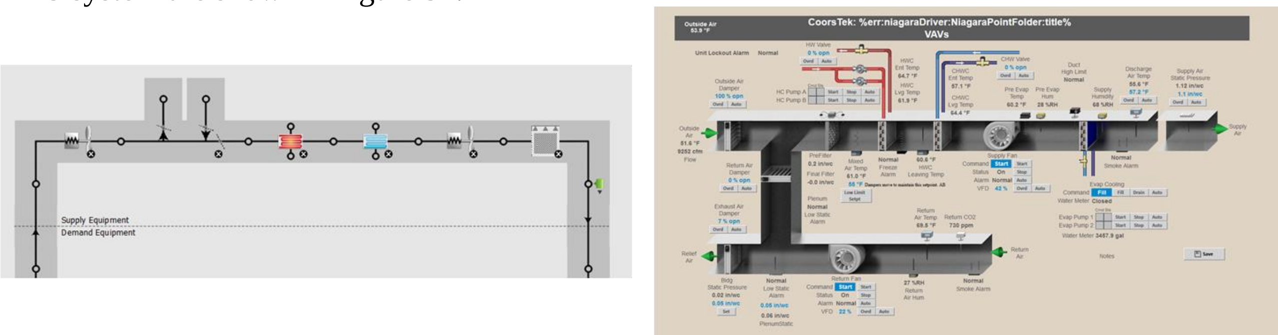


Figure 34_OpensStudio and BAS AHU-3

AHU 4 has one supply fan and is only serving the cleaning room, the outside air (O.A) in this AHU is the return air from the labs coming from AHUs-1&2, it also has different supply and return values for winter and summer, the AHU OpenStudio model and BAS system are shown in figure 35.

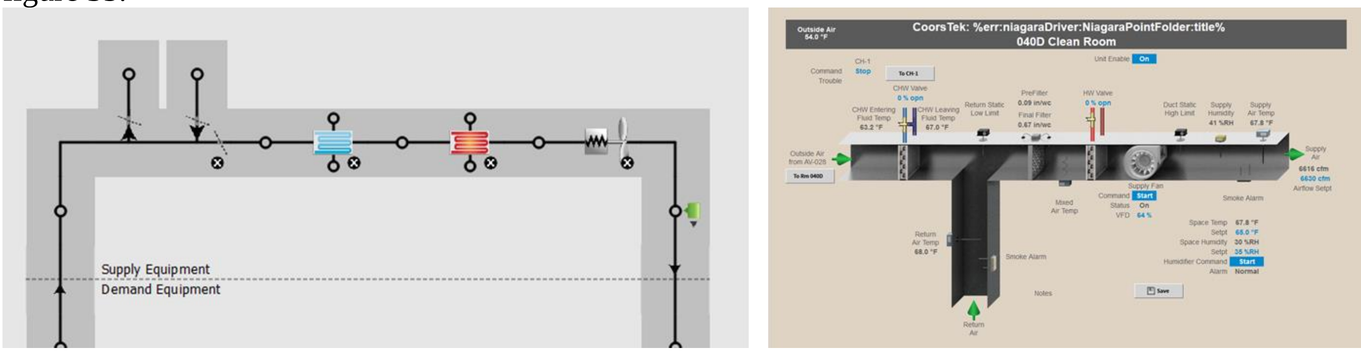


Figure 35_OpensStudio and BAS AHU-4

The chilled water system in this building is connected to one heat exchanger (PFHX-2) that is connected to another 3 heat exchangers (PFHX-1,CH-1 & PFHX-RC), one of the heat exchangers that are supplied by (PFHX-2) is (CH-1) which supplies cooled water to AHU-4 cooling coil. It was simulated as a separate loop on OpenStudio as shown in figure 36.

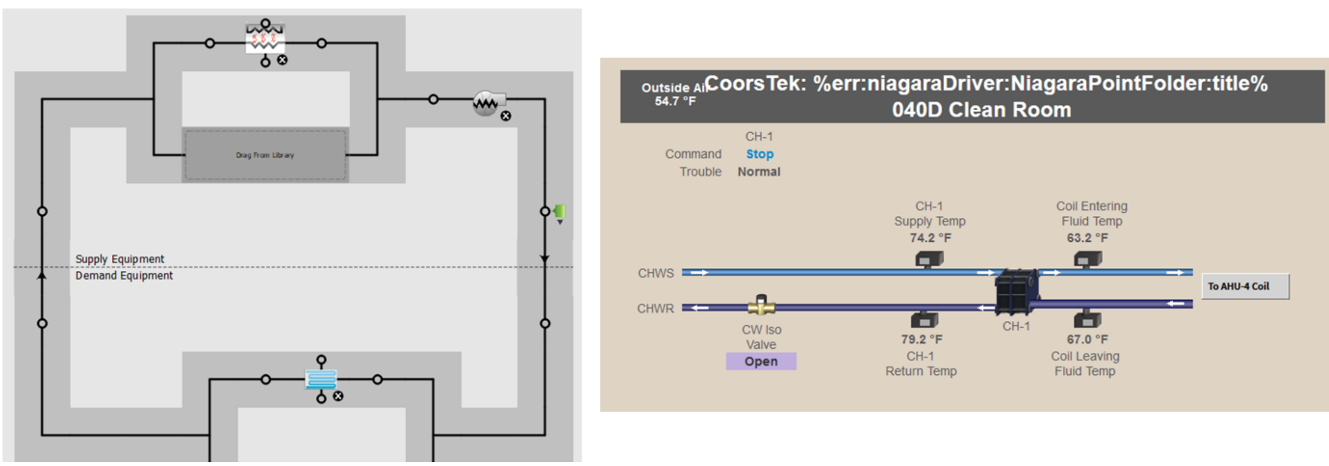


Figure 36_OpenStudio and BAS AHU-4 coil

The chilled water system includes 20% propylene glycol, CHWS was modeled with 2 loops on Open studio, with 2 headered variable speed pumps.

- First loop - Campus chilled water system: Connects the chilled water from the district cooling system to the chilled water heat exchanger (PFHX-2).
- Second loop - Building chilled water system: Connects the chilled water from heat exchanger (PFHX-2) to 3 heat exchangers (PFHX-1, CH-1 & PFHX-RC) and to AHU 1,2 & 3 cooling coils.

The hot water system includes 30% propylene glycol, and was also modeled with 2 loops on Open studio with one headered variable speed pump.

- First loop - Campus hot water system: Connects the hot water from the district heating system to the hot water heat exchangers (HX-1&2).

- Second loop - Building hot water system: Connects the hot water from heat exchangers (HX-1&2) to 2 other heat exchangers (PFHX-RH & DHWS-HX) & to AHUs heating coils.

The domestic hot water system has one heat exchanger connected to the heating water system and serving the building with 2 constant speed pumps (DWCP-1&2). The radiant floor system has 2 heat exchangers (PFHX-RH & PFHX-RC) and one constant speed pump. The building automation system shows that the Radiant floor cooling/heating system are only serving the 1st floor of the building. the domestic hot water system pumps were auto sized. The process cold water system supplies the labs with cold water for use, their pumps were auto sized also.
The HVAC basis of design values (Setpoint manager) is shown in table 10 below:

Table 10_HVAC basis of design (setpoint manager)

Setpoint Manager Schedules (F)	
AHU-1 Deck Temp.	55
AHU-2 Deck Temp.	55
AHU-3 Deck Temp.	55
AHU-4 Deck Temp.	45
AHU-4 Coil	30
Building CHWS	55
Building HWS	140
Campus CHWS	45
Campus HWS	180
Domestic HWS	140
Labs CHWS	60
Radiant Floor - Cooling	60
Radiant Floor - Heating	145
Occ. Cooling Thermostat - Zones served by AHU1,2&3	74
Occ. Heating Thermostat - Zones served by AHU1,2&3	70
Unocc. Cooling Thermostat - Zones served by AHU1,2&3	78
Unocc. Heating Thermostat - Zones served by AHU1,2&3	68
Thermostat - Zones served by AHU 4	68

- Thermal & Electric Peak Demand Analysis:

In this part of the project, the thermal and electric energy peaks for central plant 6 of the school were analyzed to help determine the contribution of several buildings and chillers on the total energy load. This loop is important since it has 7 main buildings in campus (Brown Building, CoorsTek, Maple Hall, Weaver Towers, Starzer Welcome Center, Elm Hall & Berthoud – figure 37).

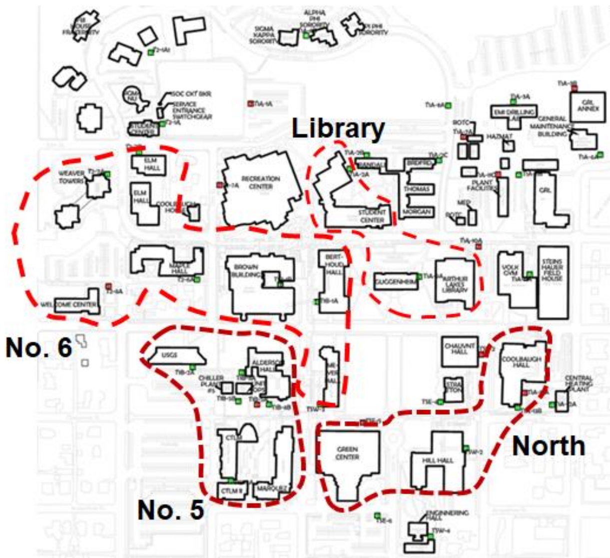


Figure 37_ Campus map showing the buildings in loop 6

The thermal and electric load peaks were calculated on the 12th of August (before the school started), and on the 19th of August (after the fall semester started). Some problems as shown in table-11 arose as some sensors were not connected to the BAS, for cooling loads we needed the temperature difference and the flow rates for each building. For Brown, SWC & Elm all the data was available, for CoorsTek & Maple some data was missing but we were able to get the cooling loads from the power sensors, for Weaver however we did not have enough information to determine the cooling load.
For the electric load analysis, all the electric consumptions for the buildings were available except for Elm and Berthoud.

Table 11_Available Data from BAS

Building	SupplyT	ReturnT	Flow Rate	Cooling load	Electric Load
Brown	Available	Available	Available	All Good	All Good
CoorsTek	Not Available	Available	Not Available	All Good/Downloaded	All Good
Maple	Available	Available	Not Available	All Good/Downloaded	All Good
Weaver	Not Available	Not Available	Available	Not Enough Info	All Good
SWC	Available	Available	Available	All Good	All Good
Elm	Available	Available	Available	All Good	Not Available
Berthoud	Not Available	Not Available	Not Available	System Down	System Down

Figure-38 shows the cumulative electric load. The peak was 961kW in the 12th of Aug and 1091.4 kW on the 19th, meaning that the electric peak has increased by 13.5%.
We can also notice that neither of the chillers reached their maximum loads of 4572kW (2286 kW for each chiller).

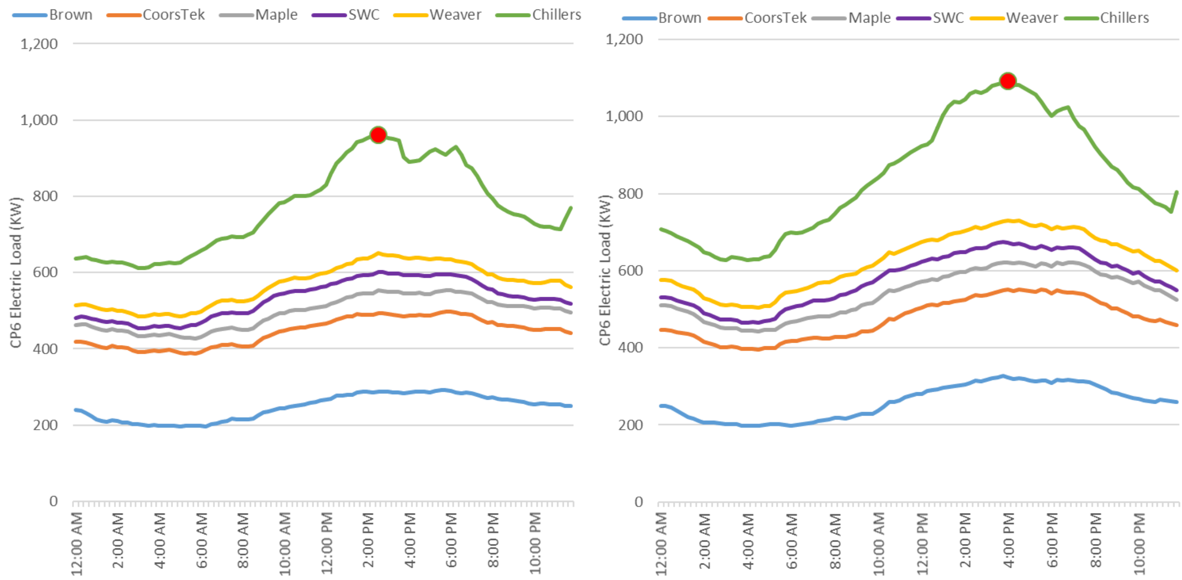


Figure 38_Electric load consumption in Aug 12th-right & Aug 19th-left

The peak for the thermal load was 660 kW in the 12th of Aug and 742 kW on the 19th, meaning that the thermal peak has increased by 12.3% and the chillers contribution to the peak was almost 35%. Since the chillers in CP6 are serving all the buildings in the loop, thermal loads for the missing buildings (Berthoud and Weaver) were found by subtracting the 5 available buildings supply cooling loads from the chillers cooling loads.

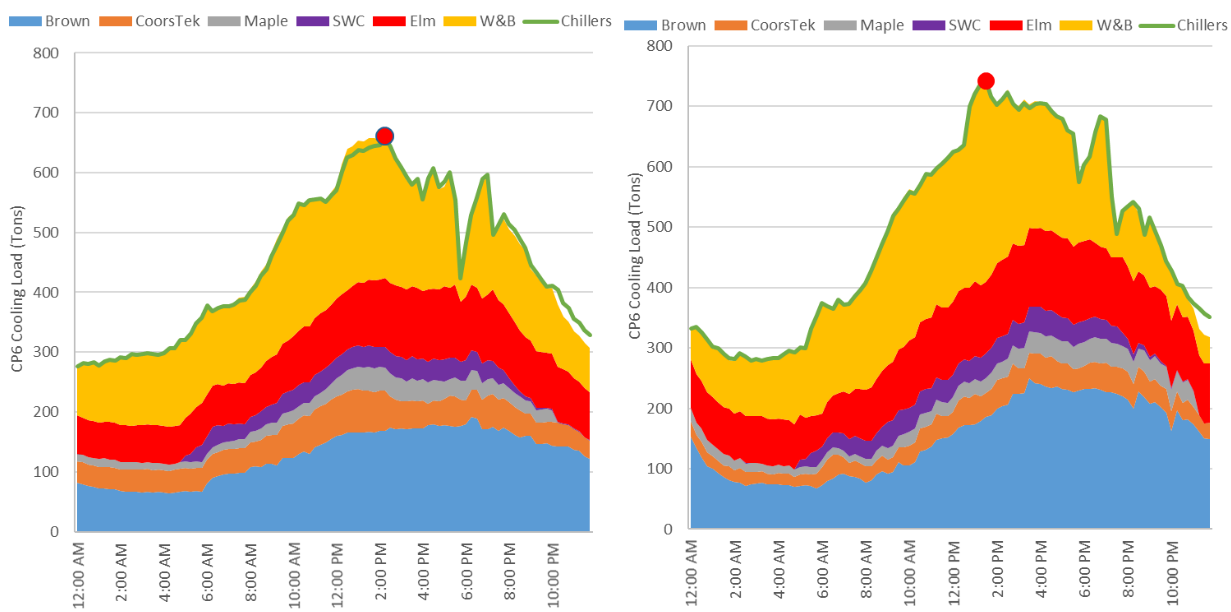


Figure 39_Cooling load consumption in Aug 12th-right & Aug 19th-left