CSU Decarbonization Framework Task 6: Simultaneous Heating and Cooling Study

Table of Content

Section 6.1: Background

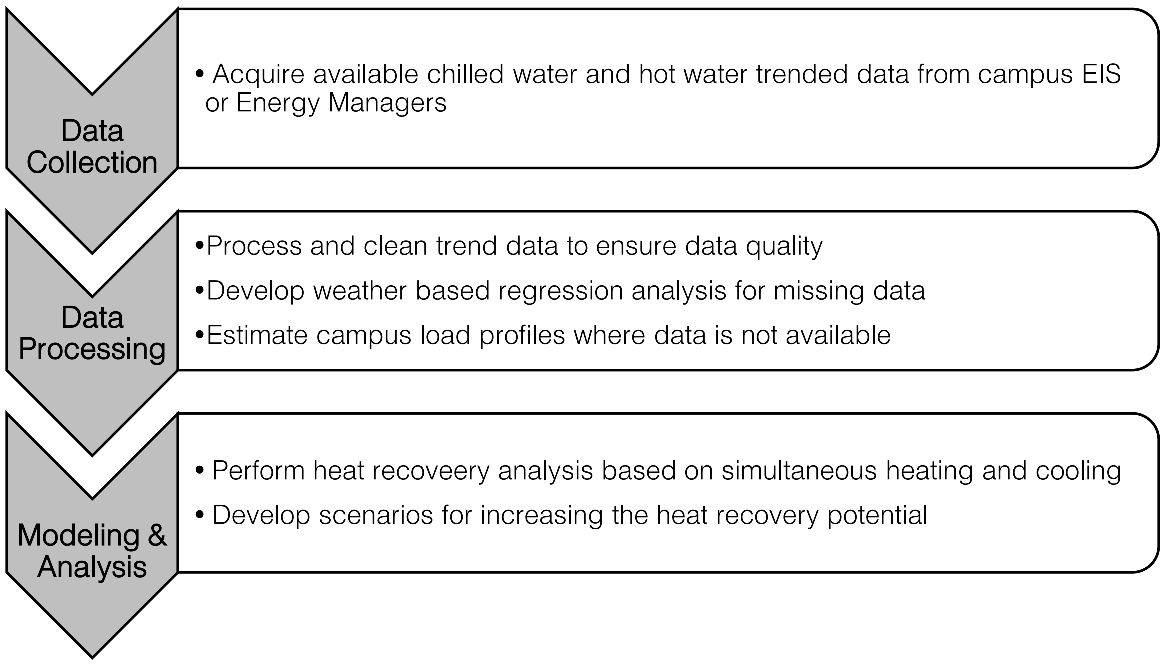
Simultaneous heating and cooling is the presence of heating and cooling load at the same time. Heat recovery is a process that collects waste heat from one process to be used in another process. All CSU campuses have overlapping cooling and heating loads on campus to some degree, typically through simultaneous production of chilled water and hot water or steam. This creates an opportunity to meet campus loads through heat recovery by capturing and repurposing waste heat that otherwise would be rejected from cooling towers.

A single electrically powered heat recovery chiller can be used to meet both the cooling and heating demand, instead of traditional decoupled chiller and boiler designs. Air-to-water heat pumps (AWHP) and water-to-water heat pumps (WWHP) with heat recovery, often referred to as heat recovery chillers, can produce cooling and heating simultaneously. This type of equipment operates efficiently by recovering "free" heat that otherwise would have been waste. Heat recovery chillers, can have a combined efficiency rating between 6 and 8 COP, making it highly attractive as a solution to cost effectively reduce a campus' natural gas consumption and carbon footprint. As noted in Section 5: Conceptual Guidelines, it is important for the CSU system to prioritize reducing waste heat on campus as a first step in decarbonizing. For more detail regarding load reduction strategies, please reference Section 5.

It's important for campuses to have a fundamental understanding of campus heating and cooling load profiles to understand the potential for heat recovery. This report presents a high-level study of potential simultaneous heating and cooling that occurs on CSU campuses based on available chilled water, hot water and steam data. This report is based on current conditions and existing load profiles and does not account for load reduction strategies that may occur in the future. The goal of this study is to provide insight to campus heat recovery potential and inform campuses on what technologies may further their decarbonization plans. In addition, campuses should implement strategies to balance heating and cooling loads to ensure heat recovery equipment operates at high efficiency, these are explored through various scenarios presented in this analysis. It is recommended that each campus builds upon this high-level study when making decisions about investing in heat recovery systems on campus.

Section 6.2: Process

Outlined below is the process of gathering data from each of the 23 CSU campuses and analyzing them to understand potential simultaneous heating and cooling occurring at each campus.



6.2.1 Data Collection

CSU campuses are in the process of hosting their facility operation data on an Energy Information System (EIS) to facilitate central data collection and analysis. However, not all campuses have complete usage profiles on EIS. Central plant chilled water and hot water usage data was collected from campus EIS where available or provided by energy managers from Building Automation System (BAS). In cases where data was limited or not available, monthly estimates were developed based on methodology described in section 6.2.2.

Outlined below is a summary of data provided by the campuses and notes about how missing points were extrapolated for use in this study.

Table 6.1 - Data Availability and Quality

CSU Campus	CHW Data	HHW Data	Basis for Analysis
Bakersfield	Not available	Not available	Monthly estimate
Channel Islands	15-minute interval data 4/4/2019 - 4/3/2020	15-minute interval data 4/4/2019 - 4/3/2020	Available hourly profile
Chico	Not available	Not Available	Monthly estimate
Dominguez Hills	Hourly interval data 10/1/2019 – 2/29/2020	Hourly interval data 10/1/2019 – 2/29/2020	Campus specific regression to estimate monthly usage abased on available interval data
East Bay	No Central Loops, Distributed Boilers	No Central Loops, Distributed Boilers	Monthly estimate, assuming 75% of building has cooling and 80% has heating.
Fresno	Not Available	Not Available	Monthly estimate
Fullerton	15-minute interval data 7/1/2019-5/11/2020	15-minute interval data 7/1/2019-5/11/2020	Available hourly profile, and regression for 5/10/2019-6/31/2019
Humboldt	No Central Loops, Distributed Boilers	No Central Loops, Distributed Boilers	Monthly estimate, assuming 75% of building has cooling and 80% has heating.
Long Beach	15-minute interval data 2/11/2019 - 2/10/2020	15-minute interval data 2/11/2019 - 2/10/2020	Available hourly profile
Los Angeles	Not Available	Not Available	Monthly estimate
Maritime	No Central Loops, Distributed Boilers	No Central Loops, Distributed Boilers	Monthly estimate, assuming 75% of building has cooling and 80% has heating.

Monterey Bay	Campus load study from 2017 with 15-year forecast of hourly campus load	Campus load study from 2017 with 15-year forecast of hourly campus load	15-year campus load forecast, hourly profile
Northridge	15-minute interval data for 2019, for both central plant and satellite plant	15-minute interval data for 2019, for both central plant and satellite plant	Available hourly profile, combining CP and SP load
Pomona	Hourly interval data 2/1/2029-1/31/2020 from Central plant, excludes housing services load	Hourly interval data 2/1/2029-1/31/2020 from Building 16 HHW Plant, excludes housing services and CLA plant	Available hourly profile. Because majority of HHW is distributed boilers, HHW load from Building 16 plant is scaled up to account estimate full-campus load. Assume all buildings served by central CHW plant also have heating.
Sacramento	Not Available	Not Available	Monthly estimate
San Bernardino	15-minute interval data for 2019	5-minute interval data for 2019	Available hourly profile
San Diego	5-minute interval data for 2019	Daily steam usage received for 2019, significant leak in the steam system (40-50% distribution loss) caused data to be unreliable in representing campus load	Monthly estimate of heating profile using other steam campus load (San Jose), monthly total of cooling profile based on data provided
San Francisco	Not Available, no CHW loop	Not Available	Monthly estimate
San Jose	Hourly interval data 2/1/2019- 1/31/2020	Hourly interval data 2/1/2019- 1/31/2020	Available hourly profile
San Luis Obispo	Hourly load from electrification analysis based on 208 load profile	Hourly load from electrification analysis based on 208 load profile	Available hourly profile
San Marcos	Hourly interval data 12/01/2018-11/24/2019	Hourly interval data 12/01/2018-11/24/2019	Available hourly profile, estimated 11/25/2019-11/30/2020
Sonoma	Not Available	Not Available	Monthly estimate
Stanislaus	Hourly interval data 4/1/2018- 3/31/2019	Hourly interval data 4/1/2018- 3/31/2019	Available hourly profile

6.2.2 Data Processing

After data was collected from campuses, they were assessed for completeness and data quality. There were often missing or incomplete data points, in addition, campuses also use different time intervals to record their data. Raw data was processed and aggregated by the following methods to be used for this study.

Consistent Timestep

Heating and cooling load profile data that was provided in a more granular interval was transformed into an hourly time step so to maintain consistency.

Small Data Gaps

When small portions of load profile data was unavailable (less than a few days), hourly data from days prior or after were taken to fill the gap, while accounting for difference in weather.

Data Unavailable / Large Data Gaps

Where larger portion of data was missing (months) or where campuses did not have the required metering and trending capabilities in place to provide any data, a weather-based regression was performed using profiles from similar campuses, normalized by area served by cooling and heating systems. This process resulted in a monthly cooling and heating profile for each campus to be used for further analysis. The following methodology was implemented:

1. Identified campuses that have complete hourly data for a year and obtained hourly outside air temperature readings from EIS. Using campus Critical Infrastructure Reports to obtain area served by chilled water and hot water systems, performed calculations to determine monthly kBTU/sf for CHW and HHW at each campus.
2. For all campuses with known data, monthly cooling degree days (CDD) and heating degree days (HDD) were calculated. HDD and CDD provide basis to estimate the amount of heating and cooling energy that will be required to maintain thermal comfort in building. Degree days are calculated as the difference between the average daily temperature and base temperature. Existing data show that campuses start to require cooling above 50°F and heating below 75°F, these temperatures were used as base temperature for CDD and HDD. If the average daily temperature is 70°F, 20 cooling degree days will occur (70 - 50 = 20) and if the average daily temperature is 60°F, 15 heating degree days will occur (75 - 60 = 15). Summed daily CDD50 and HDD75 over a month, and plotted cooling usage per square foot were against CDD50 and heating usage per square foot were against HDD75. Campuses that are representative of load were selected to generate a linear regression result, whereas campuses that are outliers were ignored.

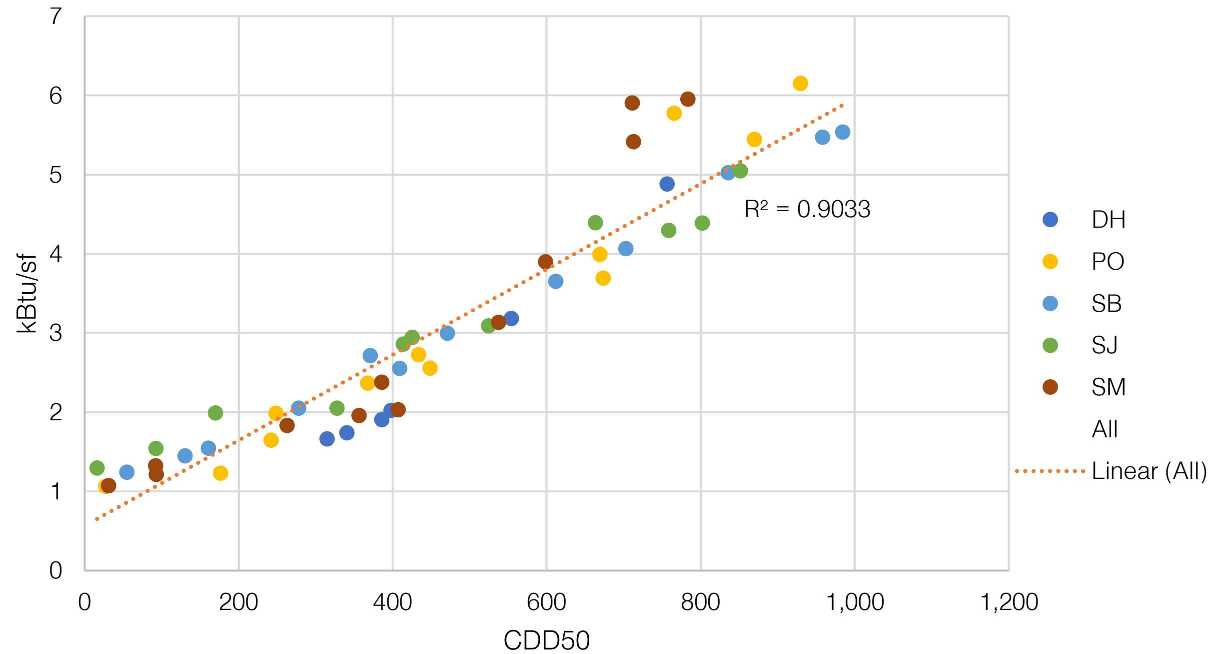


Figure 6.1 - Campus Cooling kBTU/sf vs CDD50 Regression

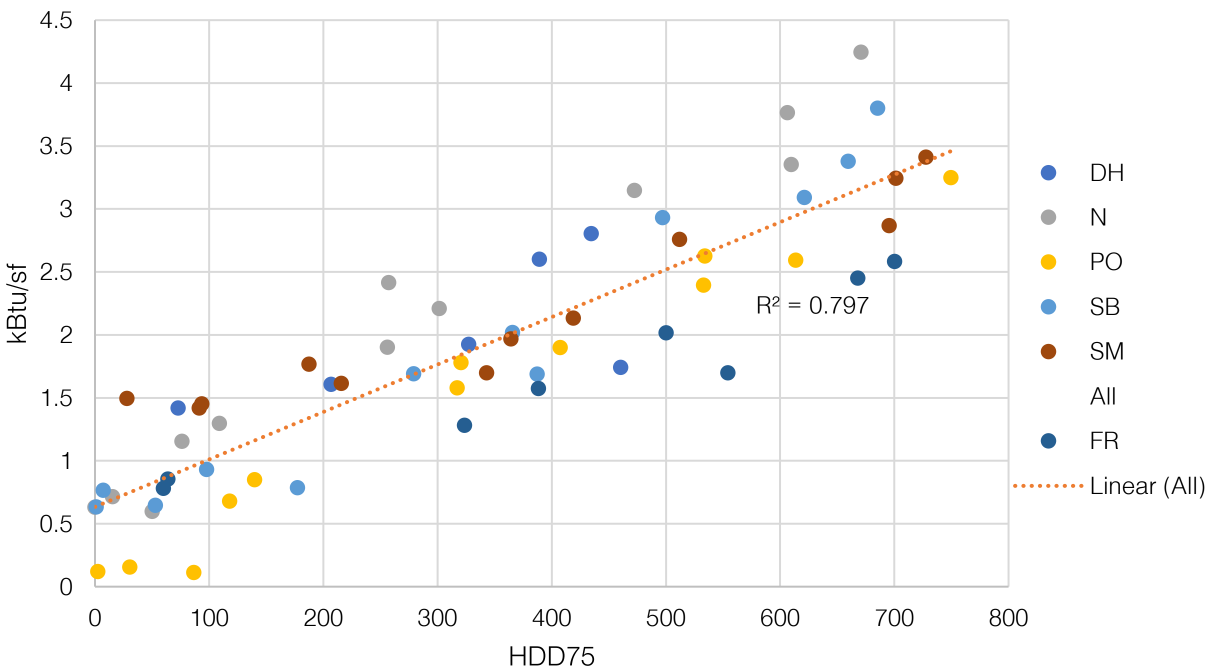


Figure 6.2 - Campus Heating kBTU/sf vs HDD75 Regression

3. The result showed a statistical R^2 value of 0.9 for cooling energy and 0.8 for heating energy. The regression result was satisfactory to conduct a rough estimate of campus cooling and heating needs but is not intended to be highly accurate because load profile is dependent on how the campus is operated. Factors that may impact the accuracy of this approach are:
    a. Whether campus has summer/winter shutdown for CHW or HHW systems

b. Whether campus air systems have free cooling through economizer
c. How much of campus has cooling and/or heating
d. Campus loop temperature and control strategies
e. Other operational conditions

4. Daily weather data for campuses with missing data were obtained from EIS, CDD50 and HDD75 are calculated. Using these results and above linear regression, campus chilled water and hot water usage kBTU/sf were estimated. For Dominguez Hills and Fresno campuses, partial data was received, and campus specific regression results were used to produce closer estimates.

Table 6.2: Campus Cooling Degree Days [CDD50]

Month	BA	CH	DH	EB	FR	HU	LA	MA	SA	SF	SO
Jan-19	86	5	177	49	24	6	173	14	10	31	9
Feb-19	44	4	65	28	23	0	66	13	9	11	4
Mar-19	172	55	396	143	205	18	434	133	115	155	74
Apr-19	438	344	490	350	500	94	573	366	425	276	293
May-19	437	445	484	313	520	149	539	350	514	249	283
Jun-19	921	877	606	622	974	228	692	612	881	385	606
Jul-19	1103	1039	764	590	1149	270	855	529	915	306	639
Aug-19	1099	1064	857	660	1155	332	928	608	963	397	679
Sep-19	815	718	793	570	886	261	835	598	765	399	579
Oct-19	519	461	756	492	610	106	768	498	542	326	438
Nov-19	289	287	554	333	378	78	545	326	333	222	277
Dec-19	98	19	341	80	114	24	308	73	71	110	43

Table 6.3 - Campus Heating Degree Days [HDD 75]

Month	BA	CH	DH	EB	FR	HU	LA	MA	SA	SF	SO
Jan-19	719	878	599	752	810	835	604	818	853	763	837
Feb-19	749	872	643	744	793	873	644	779	828	761	829
Mar-19	611	763	379	640	570	843	343	652	670	620	721
Apr-19	319	407	260	401	267	668	188	386	332	474	460
May-19	339	332	291	462	258	628	240	425	268	526	492
Jun-19	11	23	148	158	7	522	98	179	30	367	170
Jul-19	0	2	59	191	0	505	31	246	14	469	145
Aug-19	0	5	8	146	0	443	2	181	12	378	122
Sep-19	77	130	39	204	48	490	39	182	92	351	193
Oct-19	259	314	73	289	183	672	74	281	237	449	342
Nov-19	486	511	207	436	388	734	220	447	440	537	513
Dec-19	713	857	435	708	668	833	468	718	741	667	776

6.2.3 Data Analysis

After data was processed or aggregated, analysis was performed to understand how heat recovery can utilize simultaneous heating and cooling to reduce campus reliance on fossil fuel heating. Each campus data is parsed into a dashboard where the load profile was trended, and calculation was performed to evaluate the potential for heat recovery and its impact on campus energy usage.

Key Performance Indicators **(KPI's)**

Several KPI's were developed to quantify the effectiveness of heat recovery strategies. The dashboard also allows user to evaluate how these KPI's change as one changes the strategy or changes the hot water temperature. This further illustrates the relationship between hot water temperature and heat recovery potential as discussed in Section 4 and 5. Below is a summary and description of each KPI.

1. Heat Recovery Capacity: potential capacity for heat recovery equipment, expressed in Ton. This is not estimated for campuses that were aggregated on a monthly basis, because more detailed data is required to assess heat recovery capacity.
2. Natural Gas Reduction: potential reduction in natural gas usage for heating by utilizing heat recovery equipment, expressed in Therm.
3. Additional Electricity Usage: additional electricity usage in place of natural gas heating, expressed in kWh.
4. Overall Heating COP: heating coefficient of performance (efficiency), accounting for both electric heat recovery equipment and natural gas boilers.
5. Heat Recovery as % of Cooling: portion of annual cooling load covered by heat recovery equipment
6. Heat Recovery as % of Heating; portion of annual heating load covered by heat recovery equipment. This is also referred to as heat recovery potential.

Scenarios

To help campuses understand optimization strategies for decarbonized systems, scenarios were analyzed to illustrate how campuses can increase simultaneous heating and cooling and therefore increase heat recovery potential. In addition to reducing hot water temperature, these strategies allow campuses to better operate the existing system to further optimize heat recovery equipment. Below is a general description of these strategies which are described in detail in Section 5 Conceptual Guidelines.

Standard

The heat recovery potential was estimated based on existing hourly load profiles on campus without optimization strategies. This was only provided for campuses where hourly data was available.

False Cooling (Economizer Operation)

Heat recovery equipment operates most efficiently when in simultaneous heating and cooling, but campus cooling and heating load is rarely equal especially in the winter months where heating is more dominant than cooling. In cases where heating load is greater than cooling load, campus may not fully realize the benefit of heat recovery equipment. One strategy to increase simultaneous heating and cooling is creating false cooling load by disabling air-side economizers when it's beneficial to do so to increase plant efficiency. During times when there is not enough cooling load to produce all the heating capacity necessary for campus, air-side economizers can be disabled to increase cooling load and enable the heat recovery equipment to produce more heating to meet the load. Operating the heat recovery chiller to produce heating and cooling simultaneously instead of using backup heating will result in higher plant efficiency to offset the added cooling energy. However, care must be taken to ensure economizers are disabled at the appropriate times, and controls are in place to prevent excessive false cooling load where not necessary. While there are other strategies to generate false cooling load, this analysis only accounts for false cooling through disabling air-side economizers.

Thermal Energy Storage (TES)

Many CSU campuses have thermal energy storage on site. The most commonly installed are central chilled water TES systems. Campuses typically operate TES to shift load to evening times when chillers can operate with better efficiency and when electricity price is lower. TES can also be utilized with decarbonized heating system to further increase plant efficiency and heat recovery potential. During times when heating load is higher than cooling load, TES can serve as load balancing equipment to allow heat recovery equipment to operate in simultaneous heating and cooling mode and send excess chilled water to TES to be stored and used later. If a campus has a hot water TES tank, heat recovery chillers can operate during peak cooling and send the excess hot water to TES to be used during morning warm up or in the evening. TES allows cooling and heating load to be coincidental, which can also allow a campus to reduce the size of heat recovery equipment and lower the first cost of such capital projects.

The impact of TES is calculated by assuming that TES can shift and balance campus heating and cooling load over a 3-day period. While this is only a rough estimate, it illustrates how a campus can utilize TES to enhance simultaneous heating and cooling potential. For all campuses where there is not enough data to extract hourly heating and cooling profiles, monthly load estimates were made, and therefore the results assume that there is TES tank capable of balancing load over the month.

<u>False Cooling + TES</u>

This scenario combines false cooling via disabling economizer and thermal energy storage to provide most optimal solution for decarbonized campus.

Assumptions

To simplify and standardize the analysis across all campuses, several assumptions were made for the analysis:

1. Assume existing condition uses natural gas boiler with 80% efficiency. Although some campuses have more condensing boilers, 80% efficiency is used as basis of analysis across campuses.
2. Heat recovery equipment was assumed to be water-source heat recovery chiller. Several equipment manufacturers' cutsheets were collected and equipment COP were tabulated at various hot water temperature. All equipment selections assumes 44°F chilled water supply temperature with a 10°F temperature difference. Hot water temperature assumes 30°F temperature difference between heating hot water supply and return, and performance is related to hot water supply temperature. This is used to estimate a linear relationship between hot water temperature and equipment efficiency.

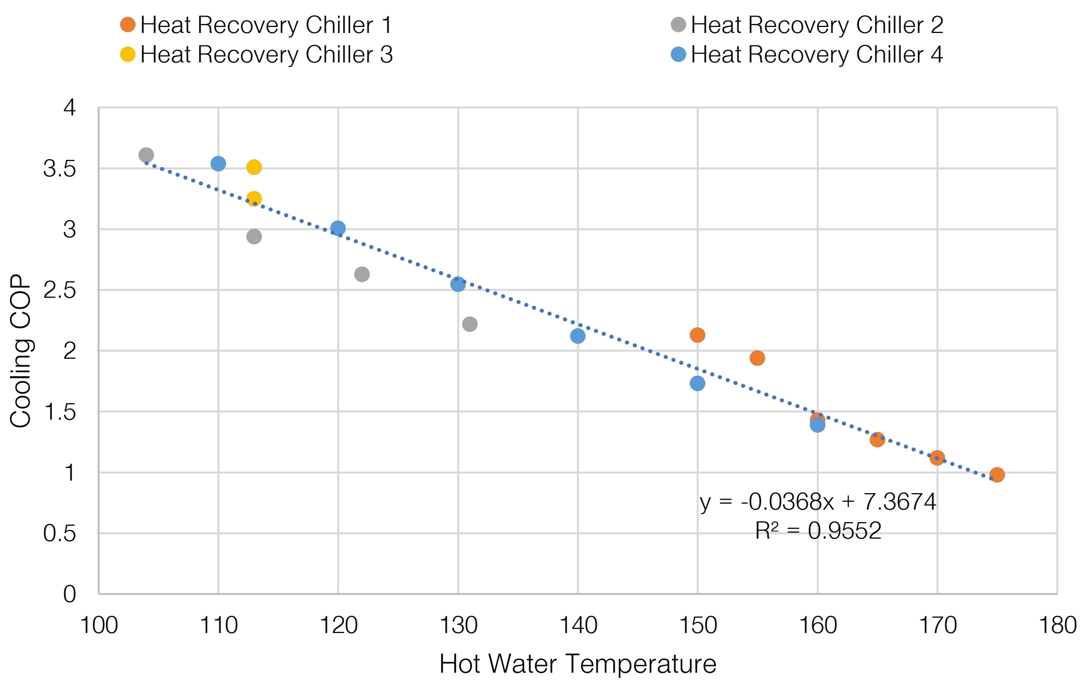


Figure 6.3 - Assumed Cooling Efficiency vs Hot Water Temperature

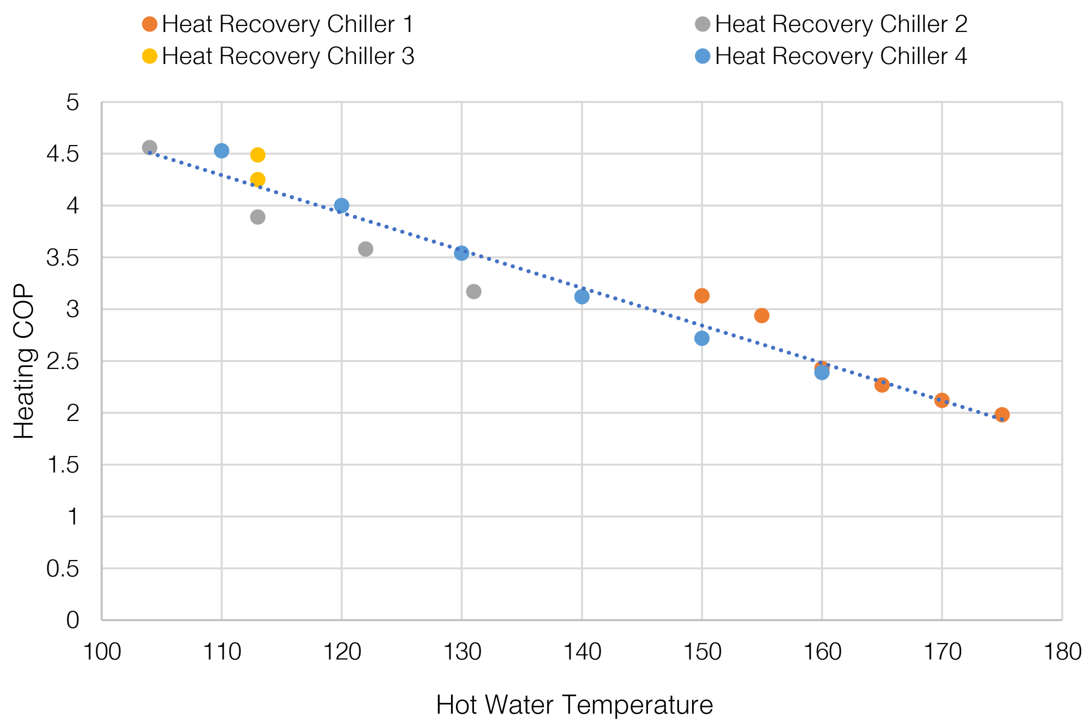


Figure 6.4 - Assumed Heating Efficiency vs Hot Water Temperature

3. To estimate the impact of false cooling load via disabling air-side economizers, hourly outside air temperature was used to determine the amount of false cooling load available to each campus. During the analysis period, whenever heating load is higher than cooling load, and additional cooling load is available by disabling economizer, additional false cooling load from economizer control was utilized to increase simultaneous heating and cooling. Some assumptions were made for all campuses, these assumptions are meant to standardize the calculation across campuses and are conservative as to not overestimate the potential for campus to disable economizers.
   a. Campus with distributed cooling equipment were assumed to have 75% of building area require cooling, and 15% of that building area assumed to have ability to disable economizers.
   b. All other campus false cooling loads were calculated based on area connected to chilled water distribution, outlined in Campus Infrastructure Master Plans.

Table 6.4 - Campus Airside Assumptions for False Cooling

Description	Assumption
Supply Air Temperature	55°F
Return Air Temperature	70°F
Building airflow	1 cfm/sf
Minimum OSA %	0.3
Fraction of building with cooling and can disable economizer	0.15

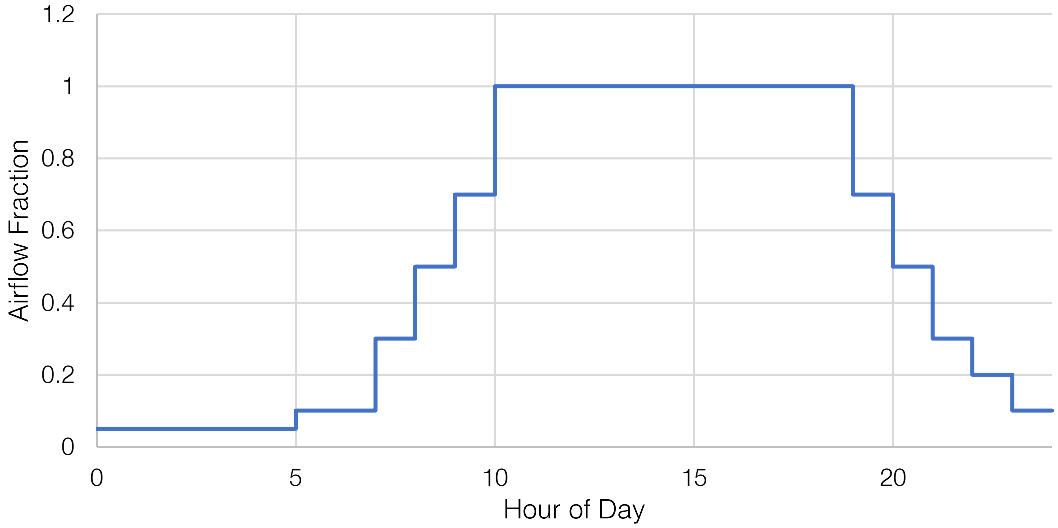


Figure 6.5 - Typical Campus Daily Airflow Profile for False Cooling Calculation

6.3. Results

The results for above analysis are captured in Power BI dashboard for each campus; they illustrate the ability for each campus to utilize simultaneous cooling and heating loads to reduce reliance on natural gas. The table below summarizes the heat recovery potential and natural gas reduction at each CSU campus for each of the scenarios analyzed, assuming 150°F hot water temperature.

Table 6.5: Campus Heat Recovery Potential and Natural Gas Reduction Potential

Campus	Annual Cooling (MBTU)	Annual Heating (MBTU)	Standard		False Cooling[1]		TES		False Cooling[1] + TES	
			Heat Recovery Potential [%]	Natural Gas Reduction [Therms]	Heat Recovery Potential [%]	Natural Gas Reduction [Therms]	Heat Recovery Potential [%]	Natural Gas Reduction [Therms]	Heat Recovery Potential [%]	Natural Gas Reduction [Therms]
Bakersfield	27,586	16,762	-	-	-	-	74.5%	156,000	87.1%	183,000
Channel Islands	11,156	28,479	26.6%	95,000	33.1%	118,000	40.5%	144,000	47.4%	169,000
Chico	62,421	47,405	-	-	-	-	59.1%	350,000	71.3%	422,000
Dominguez Hills	38,630	20,650	-	-	-	-	99.8%	257,729	100.0%	258,120
East Bay	37,174	34,007	-	-	-	-	73.6%	313,000	86.4%	367,000
Fresno	76,645	30,226	-	-	-	-	90.2%	341,000	99.2%	375,000
Fullerton	89,027	43,363	85.6%	464,000	89.8%	487,000	95.9%	520,000	99.5%	539,000
Humboldt	21,707	54,325	-	-	-	-	55.7%	379,000	73.1%	496,000
Long Beach	145,316	67,034	72.3%	606,000	74.9%	628,000	97.7%	819,000	98.7%	827,000
Los Angeles	102,092	44,615	-	-	-	-	88.6%	494,000	95.8%	534,000
Maritime	10,299	9,834	-	-	-	-	70.4%	87,000	82.8%	102,000
Monterey Bay	13,726	64,655	25.0%	202,000	32.5%	263,000	29.6%	239,000	37.2%	301,000
Northridge	61,779	68,073	38.1%	325,000	49.5%	421,000	57.5%	489,000	69.3%	590,000

Pomona	83,405	38,985	71.4%	348,000	80.4%	392,000	82.5%	402,000	92.4%	450,000
Sacramento	78,164	52,739	-	-	-	-	64.0%	422,000	77.6%	512,000
San Bernardino	61,282	35,801	72.0%	322,000	83.2%	372,000	79.4%	355,000	89.0%	398,000
San Diego	265,465	213,574	-	-	-	-	89.7%	2,394,000	93.4%	2,492,000
San Francisco	44,552	63,548	-	-	-	-	78.1%	620,000	89.1%	707,000
San Jose	109,163	155,860	59.7%	1,164,000	67.6%	1,318,000	65.8%	1,281,000	73.9%	1,440,000
San Luis Obispo	61,282	35,801	72.0%	322,000	83.2%	372,000	79.4%	355,000	89.0%	398,000
San Marcos	30,928	22,474	73.1%	205,000	83.7%	235,000	82.4%	232,000	92.1%	259,000
Sonoma	73,419	75,800	-	-	-	-	65.9%	625,000	77.7%	736,000
Stanislaus	6,627	17,151	17.8%	38,000	35.7%	77,000	39.4%	84,000	58.3%	125,000
Total	**1,511,843**	**1,243,329**	**-**	**-**	**-**	**-**	**73.3%**	**11,385,729**	**81.8%**	**12,707,120**

[1]*False cooling via disabling economizers only, see Scenarios Section for more detail.*

Based on the results of this analysis it is estimated that the CSU system collectively can provide 73.3% of the annual heating load with heat recovery when optimized with TES tank. This could reduce system-wide natural gas consumption by 11.3 Million Therms. With further optimization of simultaneous heating and cooling potential by generating false cooling load through economizer controls, campus can offset 81.8% of heating load, reducing natural gas consumption by 12.7 Million Therms.

Below are static reports from Power BI dashboard, and the interactive dashboards will hosted online. At the center of the dashboard is campus cooling heating profile over a year. The light blue and red represent campus heating and cooling load on an hourly, 3-day, or monthly interval, and the darker blue and red represent the amount of simultaneous cooling and heating load that can be met through heat recovery equipment. Users can utilize “MODEL INPUTS” portion to adjust the range of date he or she is interested in and adjust hot water temperature to understand impact of reducing or increasing loop temperature. The static reports below assume 150F hot water temperature, assuming campuses will be able to reduce loop temperature through strategies described in Section 5. Under “SCENARIOS” sections are buttons that user can click to toggle between results of various scenarios outlined in Section 6.2.3. Campuses where hourly data is available also have additional “VIEW” buttons that allow user to adjust level of detail by toggling between hourly/3-day view or monthly view. All key performance indicators described in Section 6.2.3 are also shown on the dashboard, including natural gas reduction, overall heating COP, and heat recovery as % of heating and cooling.

Links to sample interactive dashboards can be viewed here: Northridge San Luis Obispo San Marcos San Jose Stanislaus