Benchmarking, Calculating Energy Usage & Potential Savings

Kevin Thurston, P. Eng., CEM, CMVP, CCP
Thurston Engineering Services

AIA Quality Assurance

The Building Commissioning Association is a Registered Provider with The American Institute of Architects Continuing Education Systems (AIA/CES). Credit(s) earned on completion of this program will be reported to AIA/CES for AIA members. Certificates of the Completion for both AIA members and non-AIA members are available upon request.

This program is registered with AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Course Description

EBCx projects, energy audits and other energy investigations of existing facilities require detailed estimates of baseline conditions and estimated energy savings from potential Energy Conservation Measures (ECMs), especially when energy rebate programs are involved. In this presentation, I will address how to baseline a facility using utility bills & methods to estimate the consumption of various systems (boilers, chillers, lights, fans, pumps, and other HVAC components). I will provide examples from actual audits highlighting no-cost, low-cost, and high-cost ECMs. These will include VFDs, boiler & chiller replacement, % OA adjustments, filter replacement, heating/cooling coil cleaning, heat recovery systems, and more. This presentation intends to provide an overview of how you would approach these calculations, the applicable formulas to use, and how various climate zones affect what ECMs should be targeted.

Learning Objectives

1. Using energy/utility bills, benchmark a facility
2. Spotting potential Energy Conservation Measures (ECMs)
3. Calculate baseline energy consumption for the ECM
4. Estimate the potential savings from the ECM

Benchmarking

- From utility bills
- 3 years is optimal
- Ideal is to have a year before COVID
- Develop your own spreadsheet/template
- Use Energy Star Portfolio Manager (ESPM)

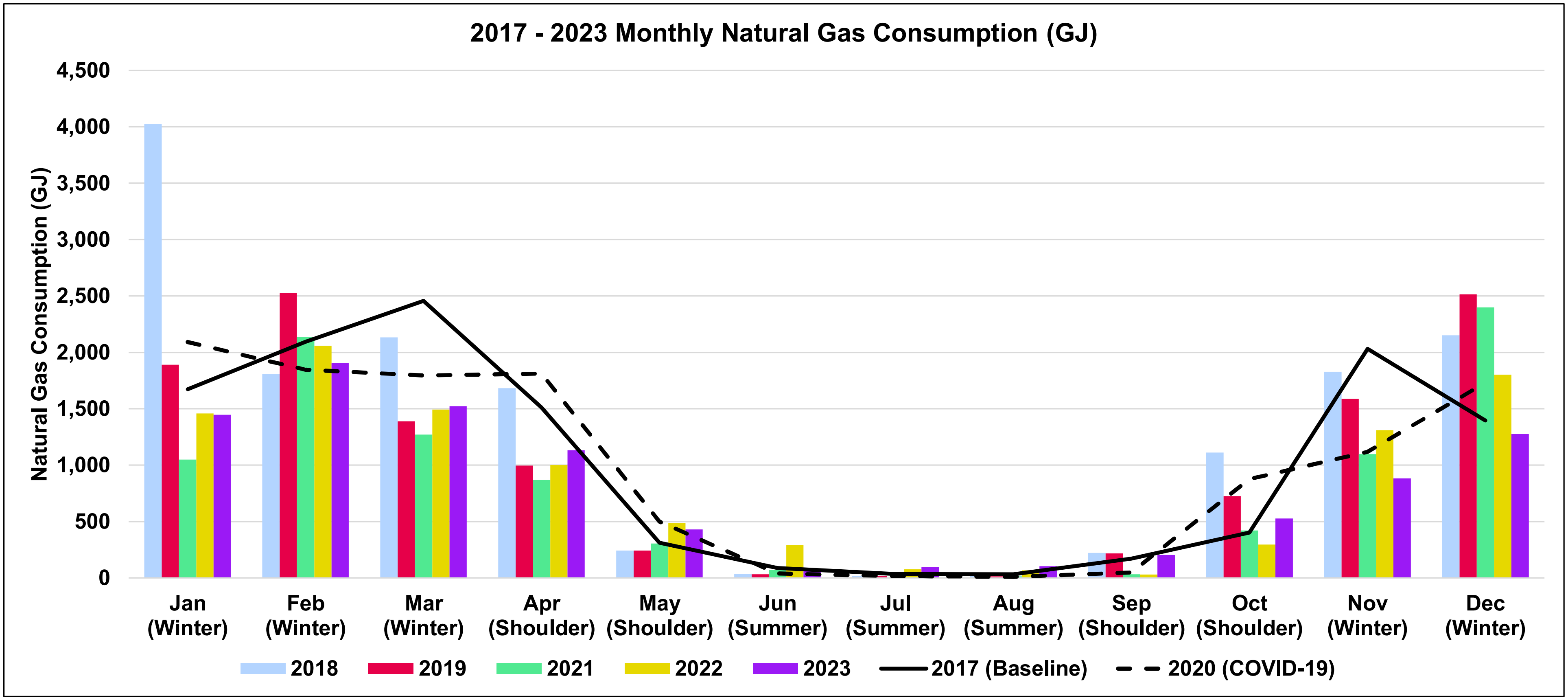
Benchmarking

- Utility Bills – Electric, Natural Gas, Propane, Oil, etc.

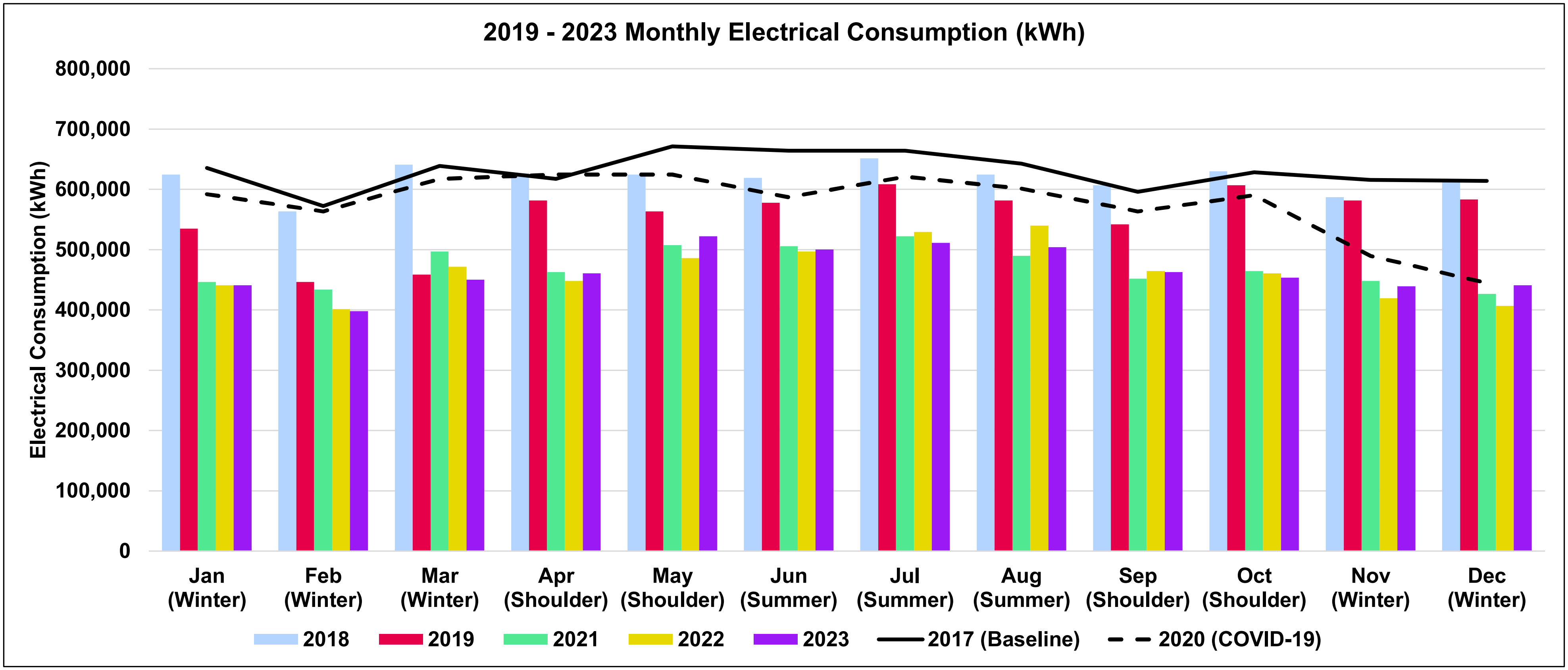
Gas	m^3	GJ
01-01-23	37,818	1,447
02-01-23	49,800	1,905
03-01-23	39,829	1,524
04-01-23	29,574	1,131
05-01-23	11,218	429
06-01-23	1,898	73
07-01-23	2,493	95
08-01-23	2,691	103
09-01-23	5,326	204
10-01-23	13,796	528
11-01-23	23,059	882
12-01-23	33,342	1,276

Electricity	kWh	GJ
01-01-23	441,000	1,588
02-01-23	397,800	1,432
03-01-23	450,000	1,620
04-01-23	460,800	1,659
05-01-23	522,000	1,879
06-01-23	500,400	1,801
07-01-23	511,200	1,840
08-01-23	504,000	1,814
09-01-23	462,600	1,665
10-01-23	453,600	1,633
11-01-23	439,200	1,581
12-01-23	441,000	1,588

Utility Bills-plot the various years



Utility Bills-plot the various years



Heating & Cooling Degree Days (HDD/CDD)

- What do you need
  - Hourly weather data
  - The Thermal Balance Temperature (TBT) (i.e., 18C, 64.4F)

If the OAT < 64.4F (18C), you have Heating Degree Days

If the OAT = 64.4F (18C), you are at the TBT

If the OAT > 64.4F (18C), you have Cooling Degree Days

Heating & Cooling Degree Days (HDD/CDD)

- HDD and CDD will range significantly with the climate zone.

Las Vegas (Climate Zone 2B)

2023-Las Vegas, NV		
Normalized	HDD	CDD
Jan	527	0
Feb	419	3
Mar	314	11
Apr	91	230
May	10	468
Jun	0	585
Jul	0	1,062
Aug	0	806
Sep	0	516
Oct	42	279
Nov	242	42
Dec	385	4
Total	2,030	4,005

Heating & Cooling Degree Days (HDD/CDD)

- HDD and CDD will range significantly with the climate zone.

  Saskatoon (ASHRAE Climate Zone 7)

  9,721 HDDs compared to 2,030 (Vegas)
  602 CDDs compared to 4,005 (Vegas)

  To convert HDDs or CDDs from F to C, divide by 1.8. These tables are deg F.

2023-Saskatoon, SK		
Normalized	HDD	CDD
Jan	1,689	0
Feb	1,576	0
Mar	1,652	0
Apr	892	0
May	216	83
Jun	81	169
Jul	133	136
Aug	128	144
Sep	244	66
Oct	780	4
Nov	1,064	0
Dec	1,266	0
Total	9,721	602

Heating & Cooling Degree Days (HDD/CDD)

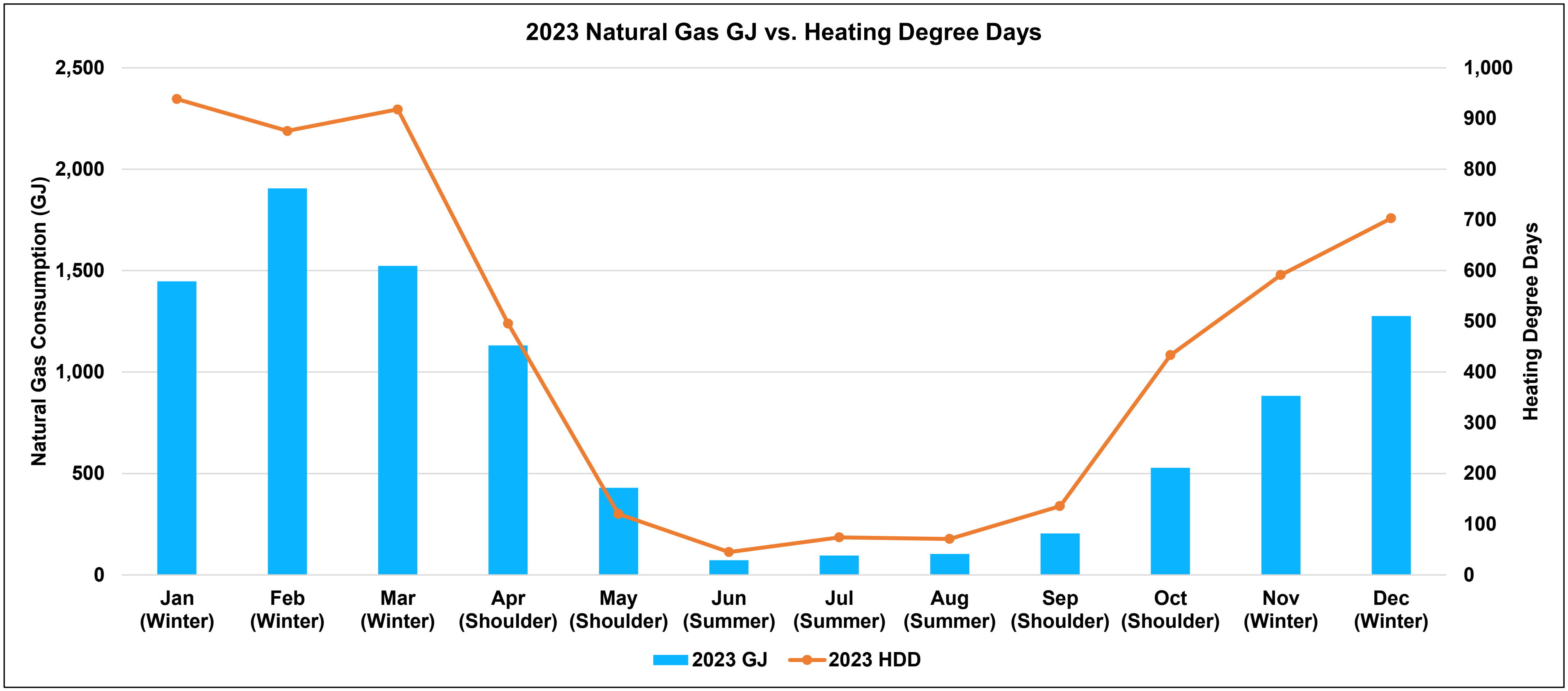
- Helpful Excel formulas

  Hourly HDD=if(OAT<TBT, (OAT-TBT)/24,0)

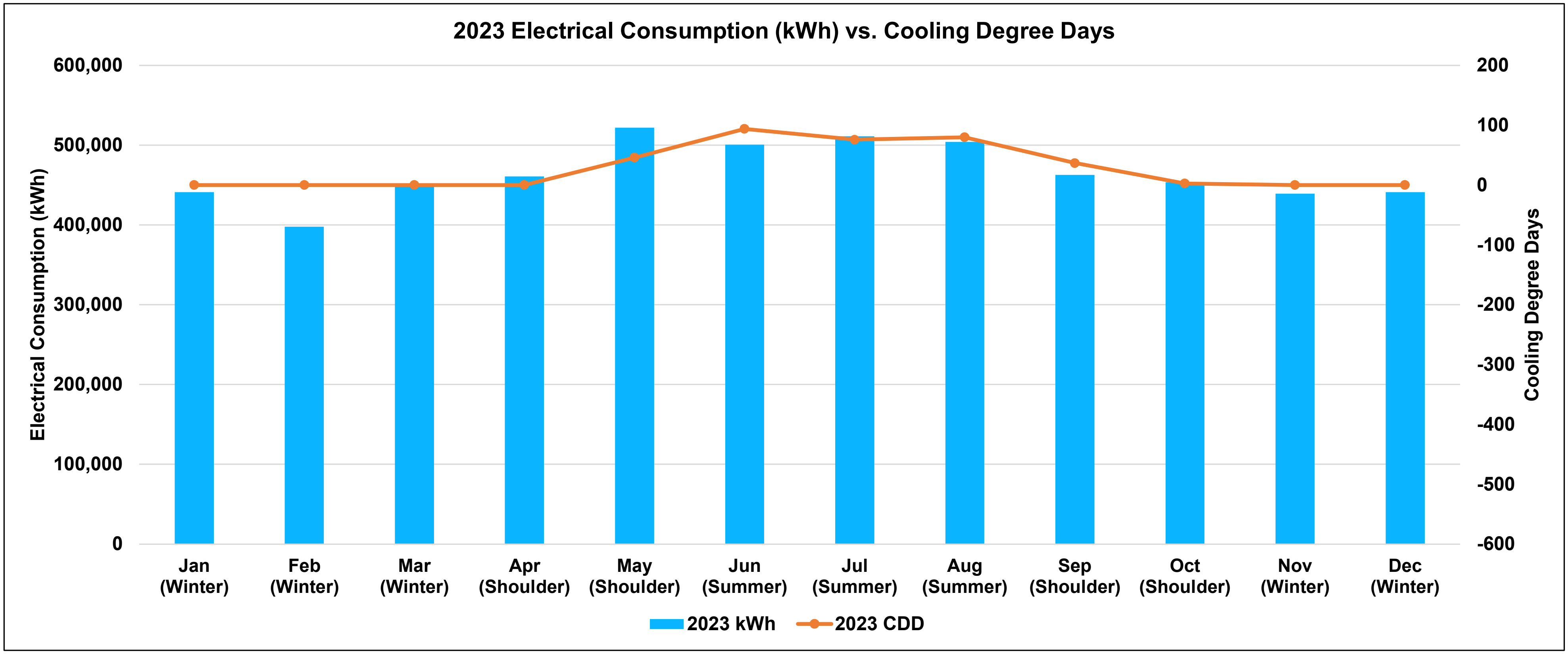
  Hourly CDD=if(OAT>TBT, (TBT-OAT)/24,0)

  TBT = Thermal Balance Temperature (64.4F, 18C)
  OAT = hourly Outdoor Air Temperature

Compare Gas to Heating Degree Days



Compare Electrical to Cooling Degree Days

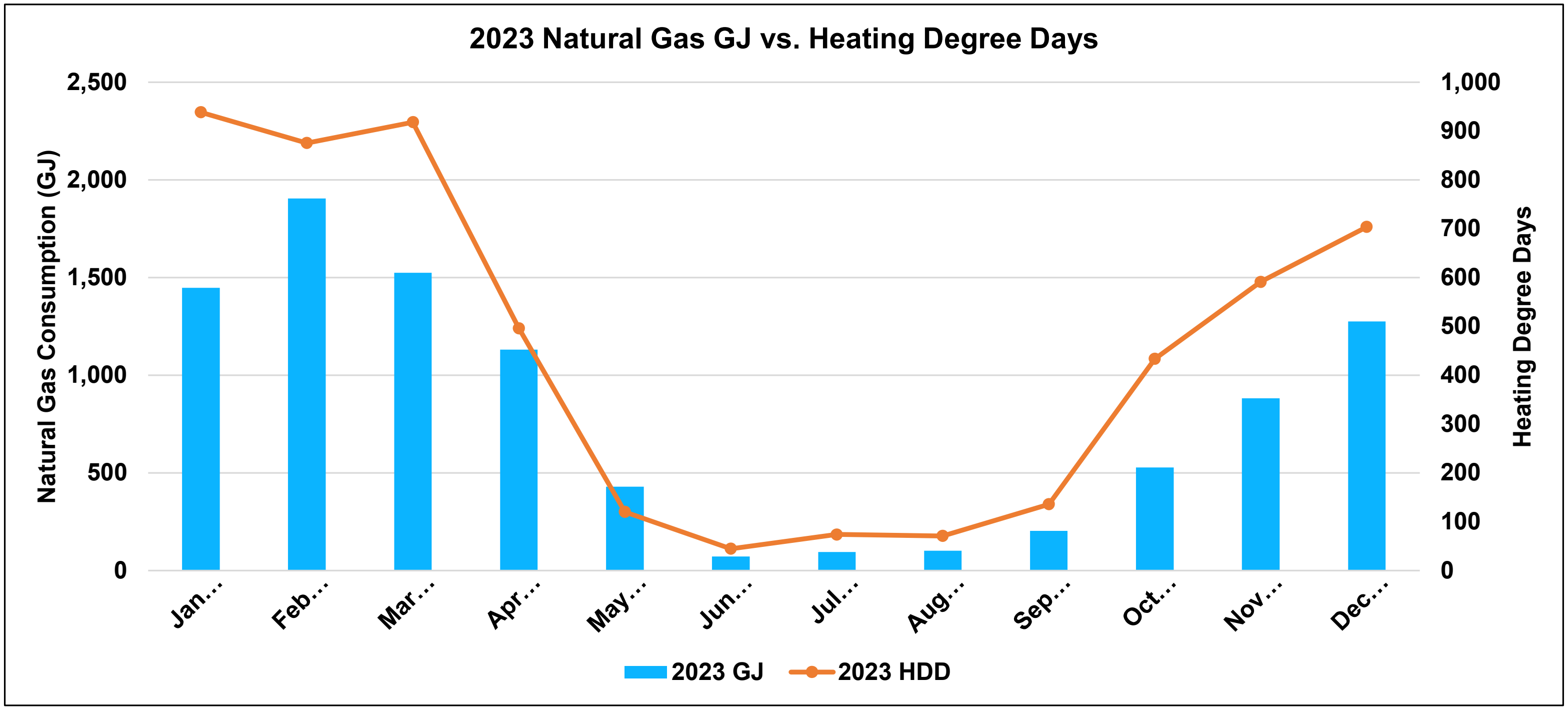


Utility Analysis Tip

- Plot HDD and CDD on the secondary axis (right side)
- Ensure HDD and CDD match the year of energy data you are using (in this example, 2023)
- Choose a baseline year to compare multiple years of data to (in this example, 2017 was used as it was the first available year of a full energy data bills)

Look for patterns in the energy data

- From the Gas vs. HDD data, what do we see?

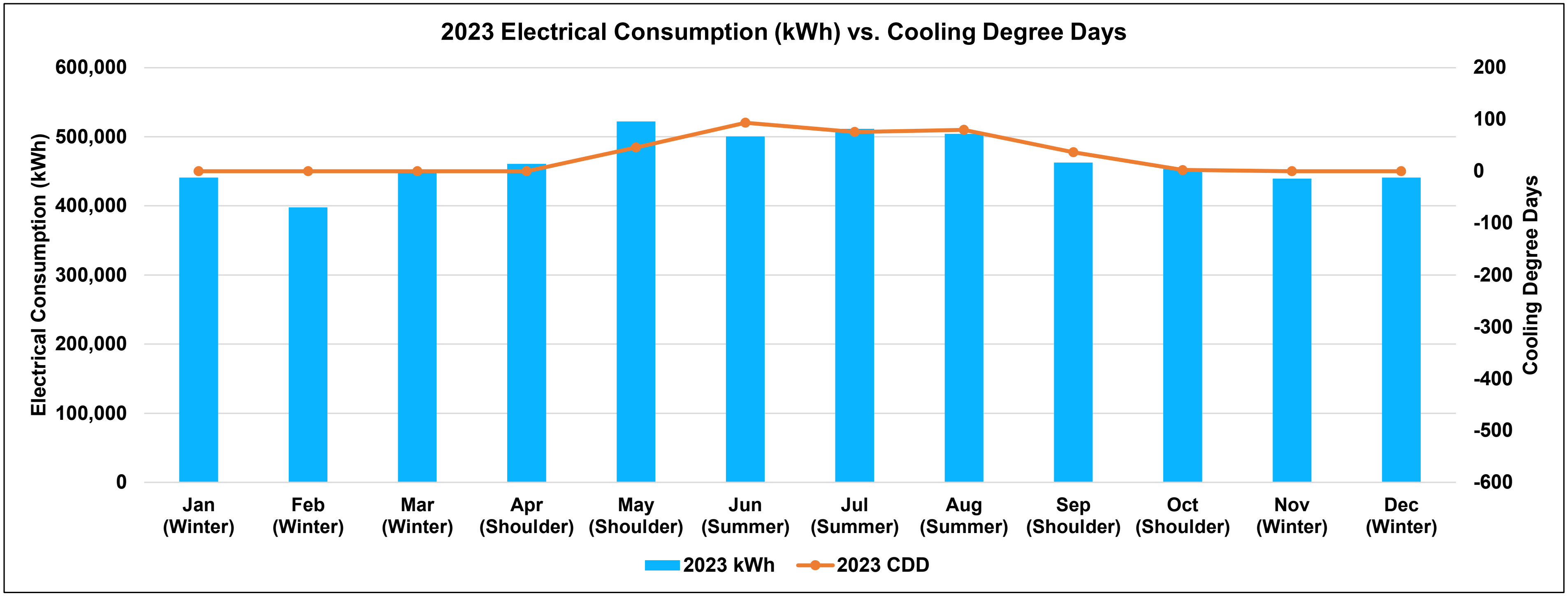


Compare Gas to Heating Degree Days

- Gas consumption varies with the # of HDD
- When HDDs are at a minimum, gas consumption is at a minimum
- In colder climate zones, the summer season gas consumption is usually the Domestic Hot Water (DHW) consumption (could also have a component of pool heating if you were conducting your audit on an MURB (Multi-Unit Residential Building).

Look for patterns in the energy data

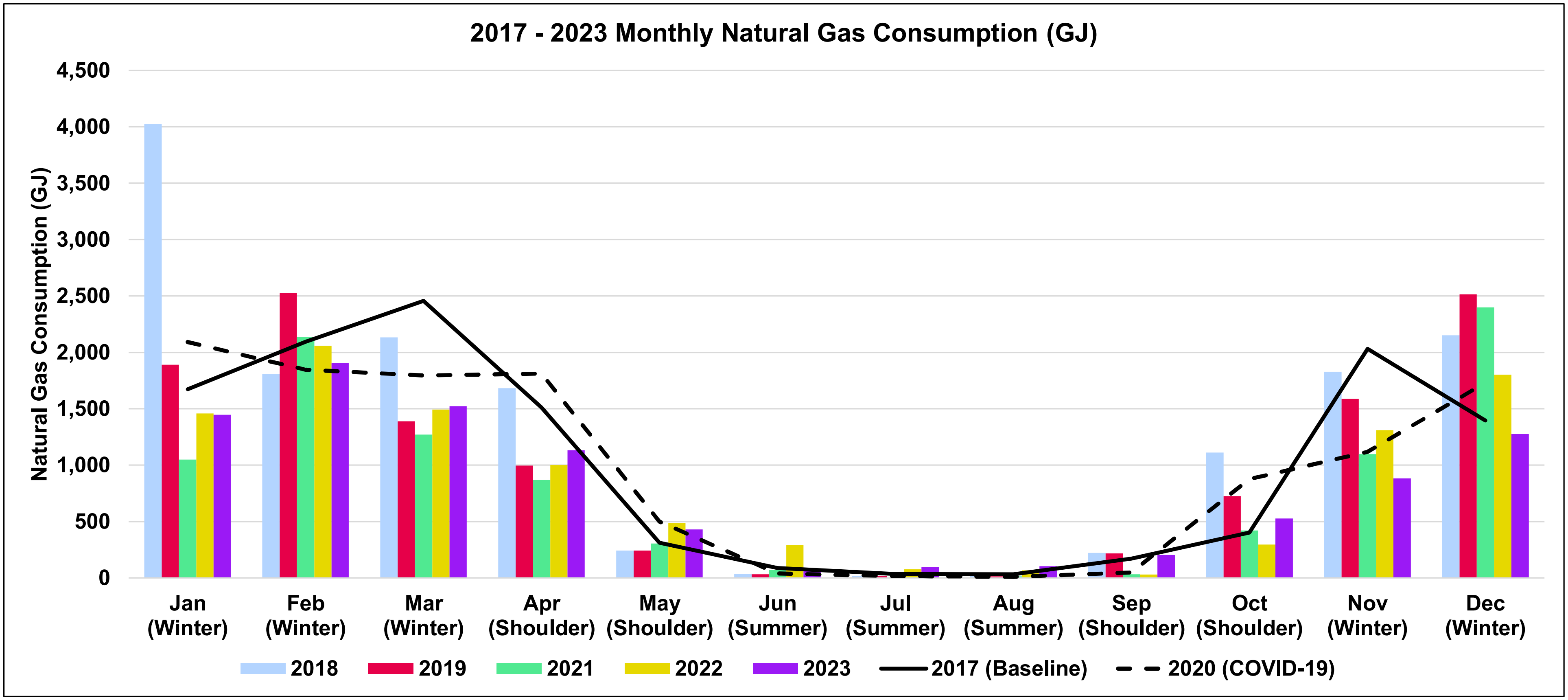
- From the Electrical vs. CDD data, what do we see?



Compare Electrical to Cooling Degree Days

- Electrical consumption varies minimally compared to CDDs
- When CDDs are at a maximum, electrical consumption is at a maximum
- In colder climate zones, the summer season electrical consumption is usually associated with the cooling system consumption
- In the example, there is a significant baseline cooling load. This is from a refrigerated warehouse (so not a surprise). A data centre would be similar.

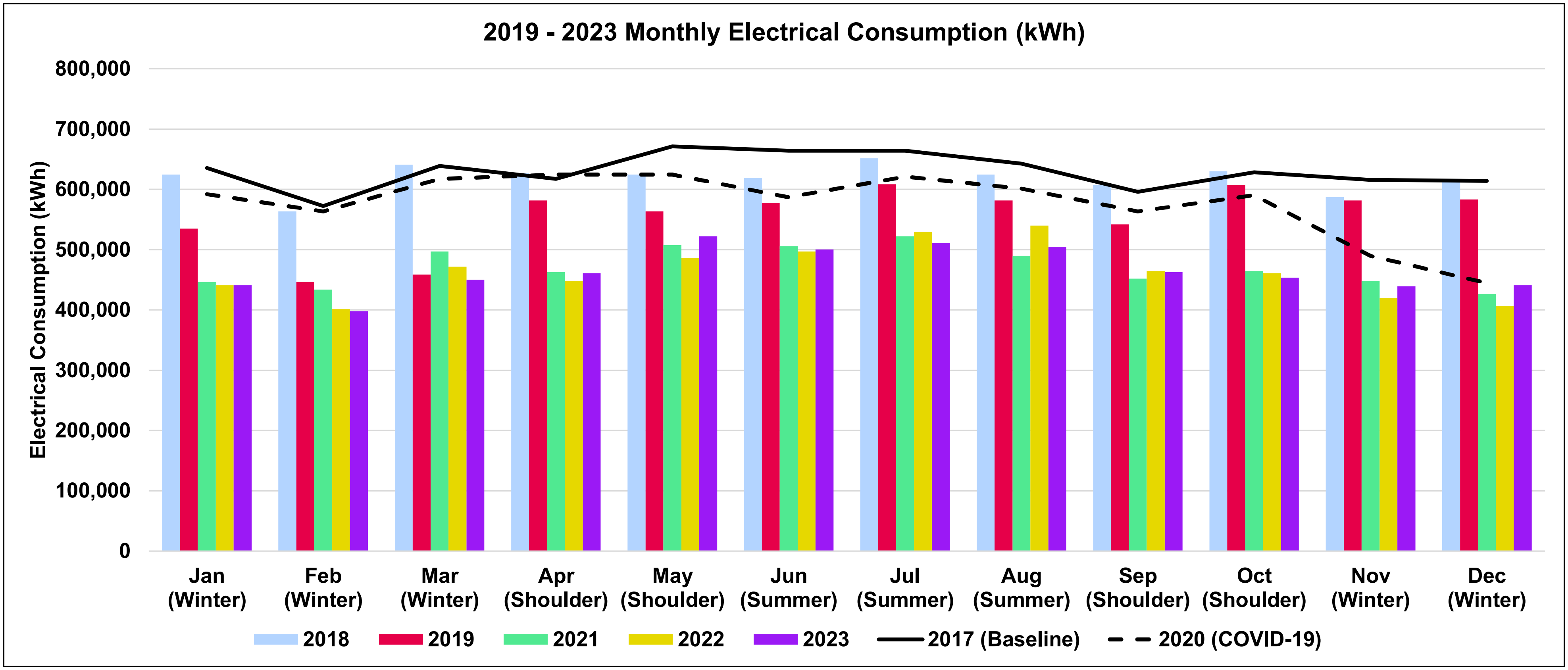
What can we observe from the monthly plots



What can we observe from the monthly plots

- 2018 monthly consumption was the highest
- 2019 sees a reduction from 2018
- Fairly consistent consumption from 2021-2023 in the Jan – Apr range; definite reductions in the Oct – Dec range
- Why? In the interview with the operations personnel
  - Heat recovery added to the refrigeration plant
  - Heat used to offset the heating of outdoor air on 3 Make-up Air Units (MUAs)
  - 4 Air Handling Units (AHUs) that provide heating were replaced

What can we observe from the monthly plots



What can we observe from the monthly plots

- Baseline year (2017) had highest consumption
- 2018 also very high
- Significant reductions from 2019-2023
- Why? In the interview with the operations personnel
  - Refrigeration plant was upgraded
  - 6 old AHUs replaced with more efficient units
  - Facility converted to LED lighting

Benchmarking (normalizing to Weather)

- Variations month-by-month or year-by-year can have a significant impact on energy consumption
- Normalizing to the baseline year can provide insight on energy consumption; for example:
  - Jan 2017 – Saskatoon – 950 HDD
  - Jan 2023 – Saskatoon – 938 HDD
  - Normalizing to 2017 = Jan 2017 consumption x (938/950)
  - We would expect lower consumption in Jan 2023 (if there had been on ECMs implemented)

Benchmarking (normalizing to Weather)

- Annual Variations

	2017	2018	2019	2020	2021	2022	2023
NG Consumption (GJ)	12,203	15,288	12,145	11,884	9,662	10,371	9,597
Comparison to 2017	N/A	25.3%	-0.5%	-2.6%	-20.8%	-15.0%	-21.4%
Heating Degree Days (HDD)	5,615	6,126	6,191	5,944	5,693	6,081	5,401
Comparison to 2017	N/A	9.1%	10.3%	5.9%	1.4%	8.3%	-3.8%
Gas Consumption per HDD (GJ/HDD)	2.17	2.50	1.96	2.00	1.70	1.71	1.78
Comparison to 2017	N/A	14.8%	-9.7%	-8.0%	-21.9%	-21.5%	-18.2%

EnergyStar Portfolio Manager (ESPM)

- Free to use
- www.portfoliomanager.energystar.gov
- Enter utility bills for each meter
- Enter type of facility (office, lab, etc.)
- Enter details such as ft^2, number of shifts, occupied hours, etc. ESPM will walk you through the questions.

EnergyStar Portfolio Manager (ESPM)

- Baseline will be your first year of data and compares to your most recent year of data (selectable)
- ES score – higher is better
- Site EUI is normalized to location – lower is better

Metrics Summary

Metric	Dec 2017 (Energy Baseline)	Dec 2023 (Other)	Change
ENERGY STAR Score (1-100)	73	91	18.00 (24.70%)
Source EUI (GJ/m^2)	1.47	1.10	-0.37 (-25.20%)
Site EUI (GJ/m^2)	0.92	0.70	-0.22 (-23.90%)
Energy Cost ($)	Not Available	Not Available	N/A
Total (Location-Based) GHG Emissions Intensity ($kgCO2e/m^2$)	141.7	92.4	-49.30 (-34.80%)
Water Use (All Water Sources) (m^3)	Not Available	Not Available	N/A
Total Waste (Disposed and Diverted) (Metric Tons)	Not Available	Not Available	N/A

What is Energy Use Intensity (EUI)

- EUI involves converting your utility data to a common unit (i.e., Gigajoules, GJ) and dividing by the square footage of the facility.
- Comparing annual EUI provides a snapshot as to how a building is tracking in its energy performance.

Electrical: kWh * 0.0036 = GJ

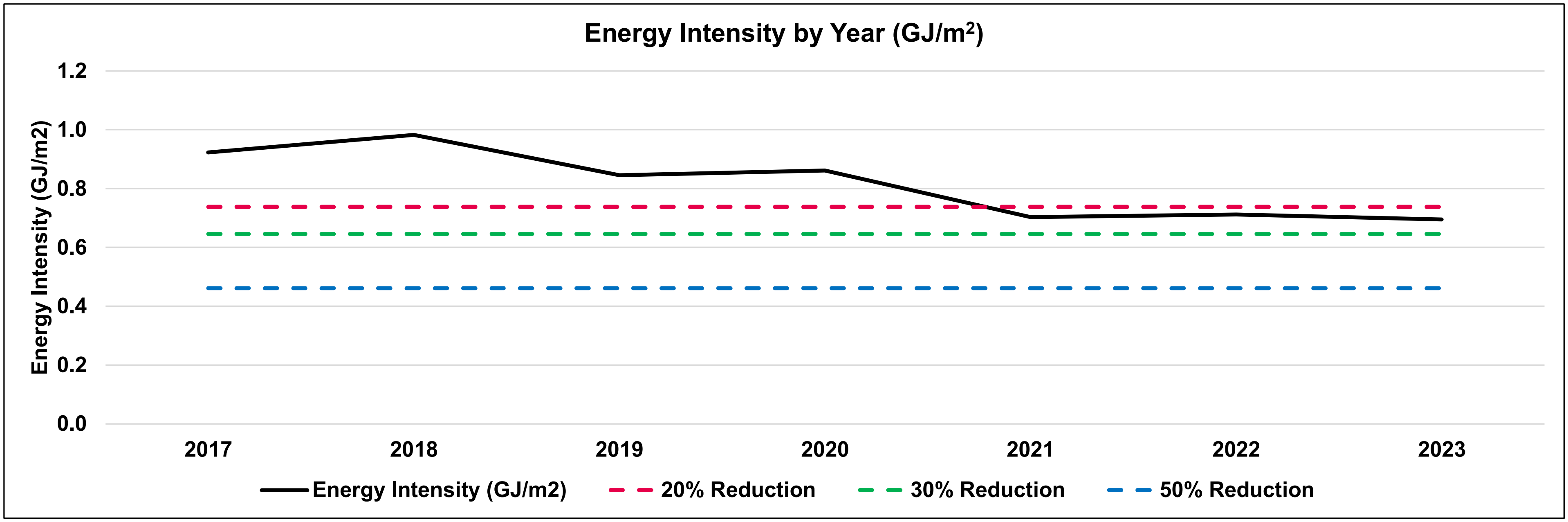
Gas: cubic meters / 26.137 = GJ

What is Energy Use Intensity (EUI)

	2017	2018	2019	2020	2021	2022	2023
Energy Intensity (GJ/m^2)	0.92	0.98	0.85	0.86	0.70	0.71	0.69
Comparison to 2017	N/A	6.5%	-8.3%	-6.7%	-23.8%	-22.9%	-24.7%

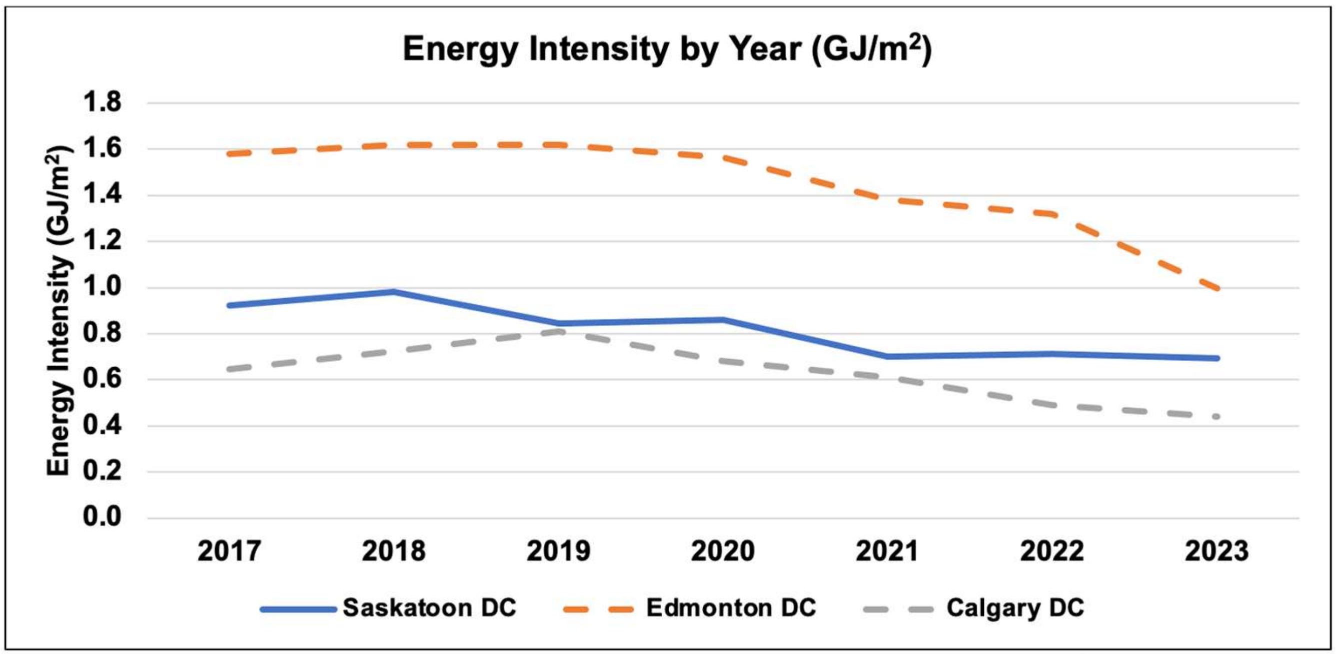
- Look for trends, plot the EUIs, set goals (with the owner)
- Compare to the baseline year (2017) and look for the trend of increasing or decreasing EUI. In this case, a reduction on an annual basis.

What is Energy Use Intensity (EUI)



- Trend is between a 20-30% reduction from baseline year
- Owner should have no problem eclipsing 30%
- Might set an aggressive goal of 50%

Compare EUI to other buildings



- Foor warehouses; Saskatoon & Edmonton – refrigerated
- Big differences in EUI for very similar buildings

Spot the Energy Saving

- Spotting potential Energy Conservation Measures (ECMs)
  - Walkthrough with Operations Staff
    - Fans running 24/7
    - Fans without VFDs
    - Fans that can be replaced with ”Fan Walls” [33%]
    - Changes in functional use of spaces (i.e., hospital rooms to office space) can reduce required air changes per hour
  - Building Automation System (BAS)
    - Graphics
    - Sequences
    - Setpoint Schedules

Steps to Calculating Baseline Consumption

- Calculate the baseline energy consumption for the ECM
  - Single duct, heating and cooling
  - Calculate the heating load
  - Calculate the cooling load
  - Calculate the fan motor consumption

Supply Fan – Baseline Calculation

- 100 HP fan motor, Load Factor = 80%, Efficiency = 85%
- Run hours = 24/7 = 8,760 per year
- Fan kWh = ((HP x 0.746) x Load Factor / Motor Eff) x Run Hours

Energy Conservation Measure (ECM)

- Fan Motor Efficiency
  - 100 HP, 85% efficient, Load Factor = 80%, operating 24/7
  - Formula:
    - kW = HP * 0.746 * Load Factor / Motor Efficiency
    - kW = 100 * 0.746 * 80% / 85%
    - kW = 70.2

<u>Baseline</u>

- kWh = 70.2 * 8,760 hours / year
- kWh = 615,055 kWh
- Average cost of electricity = $0.10/kWh
- Cost to operate the fan motor = $61,506 / year

ECM -1 Replace the motor

- Fan Motor Replacement
  - Baseline motor consumption = 615,055 kWh
  - New fan motor = 93% efficient
  - ECM 1 consumption = baseline * (baseline eff / new eff)

  - kWh = 615,055 * (85%/93%)
  - kWh = 562,147

  - Savings = 52,907 kWh
  - Savings = $5,291
  - Cost of a 100 HP motor = $50,000 (supply, install, electrical, mark-up)
  - Payback = cost / ECM savings = 9.5 years

ECM -2 Fan speed reduction - Unoccupied

- Unoccupied hours – 12 hours / day (CFM reduced 50%)
  - Baseline motor consumption = 615,055 kWh
  - Add a VFD to the supply fan (Supply fan only for this example)
  - ECM 2 consumption = hours unoccupied * (VFD speed)^2.5

    - kWh occupied = 615,055/2 = 307,527.5 kWh
    - kWh unoccupied = 307,527.5 * (50%)^2.5 = 56,232.6 kWh

    - Savings = (307,527.5 - 56,232.6) kWh = 240,723 kWh
    - Savings = $24,072
    - Cost of a 100 HP VFD (supply, install, electrical) = $35,000
    - Payback = cost / ECM savings = 1.45 years [VFD only]
    - Payback =($50k + $35k)/($24,072 + $5,291) = 2.9 years [VFD and motor]

ECM -2 Fan speed reduction – What else?

- Unoccupied hours – 12 hours / day (CFM reduced 50%)
  - Heating Savings
  - Cooling Savings
  - In Canada, Carbon Tax Savings

- Calculate the hourly heating and cooling loads
- This is why the hourly weather data is so important
- Don’t settle for estimates based on annual or monthly HDD formulas or average monthly temperatures

ECM -2 Fan speed reduction – What else?

- What do you need to make these calculations?
  - Supply Air Temperature Reset Schedule
  - Return Air Temperature (RAT)
  - Outdoor Air Damper %
    - Fixed minimum or allowed to modulate to 100%?

- Assumptions
    - RAT is constant (73.4F)
    - SAT reset based on OAT
    - Mixed Air Temp (MAT) = (OAT * %OA

Supply Air Temperature Setpoint				
SAT Maximum	81	@	41	°F OAT
SAT Minimum	48	@	72	°F OAT

Baseline

- Calculate slope and intercept
- Calculate SAT_SP based on OAT
  - Excel formula=if(OAT>=72,48,if(OAT<=41,81,mx+b)) [deg F]

- To calculate the heating load or cooling load
  - SAT_SP – MAT = delta-T
  - If delta-T > 0 = heating; if delta-T is <0, cooling
  - Load = 1.08 * CFM * delta-T

Heating and Cooling Load

- Fan system is 100,000 CFM with a minimum 20% Outdoor Air (OA) and no Heat Recovery (HR)
- Mixed Air Temperature (MAT)
  - MAT = (%OA * OAT) + (1-%OA)*RAT
    - OAT = Outdoor Air Temperature
      - Obtain hourly weather data for your location
    - RAT = Return Air Temperature
      - Obtain from BAS trends or from the Operations Staff (monthly profiles are preferred)

ECM -2 Heating/Cooling Estimates

- Delta-T = (SAT_SP – MAT)
  - If positive = heating
  - If negative = cooling

- Heating/Cooling Loads = 1.08 * CFM * delta-T
- Units are BTU per hour (BTUH)
- For cooling, divide BTUH/3,412 = kWh
- Chiller consumption = Cooling load / COP

Baseline Utility Costs

- Gas consumption = Heating Load/boiler efficiency
- Gas Load * $/GJ = Gas Cost

- Chiller consumption (kWh) = Cooling load / COP
- Electrical Load * $/kWh = Electrical Cost

ECM -2 Heating/Cooling Estimates

- From the hourly calculations:

Saskatoon		
Baseline Fan Consumption	614,952	kWh
Baseline Heating Consumption	11,837	GJ
Baseline Cooling Consumption	560,574	kWh

Las Vegas		
Baseline Fan Consumption	614,952	kWh
Baseline Heating Consumption	2,137	GJ
Baseline Cooling Consumption	2,043,496	kWh

Post ECM -2 Heating/Cooling Estimates

- From the hourly calculations:

Saskatoon		
Post ECM 2 Fan Consumption	361,831	kWh
Post ECM 2 Heating Consumption	8,659	GJ
Post ECM 2 Cooling Consumption	420,232	kWh

Las Vegas		
Post ECM 2 Fan Consumption	361,831	kWh
Post ECM 2 Heating Consumption	1,352	GJ
Post ECM 2 Cooling Consumption	1,027,555	kWh

Post ECM -2 Heating/Cooling Savings Estimates

- From the hourly calculations:

Saskatoon - ECM 2 Savings		
Post ECM 2 Fan Consumption	253,121	kWh
Post ECM 2 Heating Consumption	3,178	GJ
Post ECM 2 Cooling Consumption	140,342	kWh

Las Vegas - ECM 2 Savings		
Post ECM 2 Fan Savings	253,121	kWh
Post ECM 2 Gas Heating Savings	785	GJ
Post ECM 2 Cooling Electrical Savings	1,015,941	kWh

Post ECM -2 GHG Savings Estimates

- From the hourly calculations:

Saskatoon - ECM 2 Savings (t CO2e)		
Post ECM 2 Fan Consumption	104	t CO2e
Post ECM 2 Heating Consumption	150	t CO2e
Post ECM 2 Cooling Consumption	58	t CO2e
Post ECM 2 GHG Savings	312	t CO2e

Las Vegas - ECM 2 Savings (t CO2e)		
Post ECM 2 Fan Consumption	104	t CO2e
Post ECM 2 Heating Consumption	37	t CO2e
Post ECM 2 Cooling Consumption	418	t CO2e
Post ECM 2 GHG Savings	559	t CO2e

Post ECM -2 $ Savings Estimates

Saskatoon - ECM 2 Savings (Utilities and Carbon Tax)		
Post ECM 2 Fan Consumption	$25,312	kWh
Post ECM 2 Heating Consumption	$30,416	GJ
Post ECM 2 Cooling Consumption	$14,034	kWh
Post ECM 2 GHG Savings ($84/tonne)	$26,191	2024
Post ECM 2 GHG Savings ($178.50/tonne)	$55,657	2030
Total Estimated Savings (no Carbon Tax)	$69,762	
Total Estimated Savings (with 2024 Carbon Tax)	$95,953	
Total Estimated Savings (with 2030 Carbon Tax)	$125,419	

Las Vegas - ECM 2 Savings (Utilities and Carbon Tax)		
Post ECM 2 Fan Consumption	$25,312	kWh
Post ECM 2 Heating Consumption	$7,515	GJ
Post ECM 2 Cooling Consumption	$101,594	kWh
Post ECM 2 GHG Savings	$46,987	2024
Post ECM 2 GHG Savings	$99,848	2030
Total Estimated Savings (no Carbon Tax)	$134,422	
Total Estimated Savings (with 2024 Carbon Tax)	$181,409	
Total Estimated Savings (with 2030 Carbon Tax)	$234,270	

ECM 3 – Replace Boilers (High Cost ECM)

- Existing Boiler Efficiency = 85%
- New Boiler Efficiency = 95%
- Post boiler retrofit gas consumption = 25,000 GJ * (85%/95%) = 22,368 GJ
- Savings = 25,000 – 22,368 GJ = 2,631 GJ
- Savings = 2,631 GJ x $9.57/GJ = $25,184
- Estimated cost of a boiler replacement = $500,000
- Payback = 19.9 years
- 20-year carbon tax savings = $401,922

Saskatoon		
Baseline Heating Consumption	25,000	GJ

ECM 4 – Replace Chiller (high cost ECM)

- Existing Chiller COP = 2
- New Chiller COP = 4
- Post chiller replacement electrical consumption = 2,043,496 kWh * (2/4) = 1,021,748 kWh
- Savings = 2,043,496 – 1,021,748 = 1,021,748 kWh
- Savings = 1,021,748 kWh x $0.10/kWh = $102,175
- Estimated cost of a chiller replacement = $500,000
- Payback = 4.9 years

Las Vegas		
Baseline Cooling Consumption	2,043,496	kWh

Other Examples

Fan Power Consumption

The ideal power consumption for a fan (without losses) can be expressed as

$$P_i = dp\ q \qquad (1)$$

where

P_i = *ideal power consumption (W)*

dp = *total pressure increase in the fan (Pa, N/m²)*

q = *air volume flow delivered by the fan (m³/s)*

- Replace filters
  - 1” w.c. increase
  - = 248.8 Pa
  - 100,000 CFM unit
  - =47.2 m^3/s
  - 8,760 hours per year
  - Increased power = 248.8 Pa x 47.2 m^3/s = 11.7 kW
  - Energy penalty = 11.7 kW x 8,760 hrs/year * motor eff/fan eff
  - Energy penalty = 11.7 kW x 8,760 hrs/year * (93%/60%)
  - Energy penalty = 158,863 kWh = $15,886
  - Also applicable to increased pressure drop across dirty coil surfaces

Other Examples – Heat Recovery Coil (HRC)

- Add a glycol runaround loop (max efficiency = 40%)
- Post HRC gas consumption = 11,837 GJ * (1-40%) = 7,102 GJ
- Savings = 11,837 GJ – 7,102 GJ = 4,735 GJ
- Savings = 4,735 GJ x $9.57/GJ = $45,312
- Estimated cost of the HRC retrofit = $100,000
- Payback = 2.2 years
- Carbon Tax savings = $18,753 (2024); $39,851 (2030)

Other Examples – Heat Recovery Coil (HRC)

- You may think that is a great payback so let's do it.
- Caution: you are adding heat recovery coils in the air streams. This can easily lead to an extra delta-P of 1" w.c.
- From filter replacement example, this has an electrical energy penalty of $15,886
- There is a pump to circulate the fluid; another penalty of $2,000-$4,000 depending on the horsepower
- Payback drops to approximately 4 years
- However, carbon tax savings make this very attractive.

Speaker: Kevin Thurston, P. Eng., CEM, CMVP, CCP

kthurston@teservices.ca

(306) 220-1998

Thurston Engineering Services, CCF

Thurston
Engineering Services