Understanding Electrical Load Estimation

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Learning Objectives

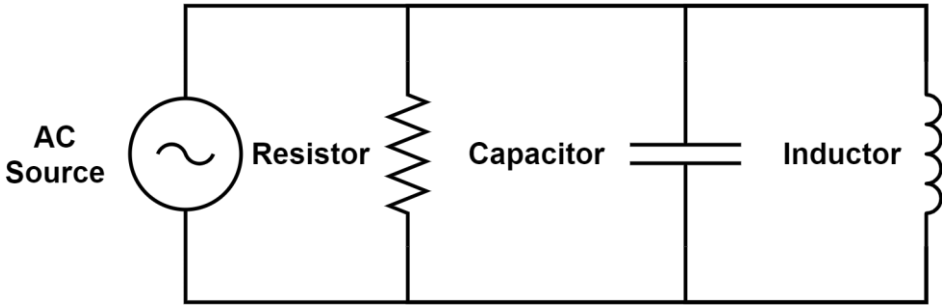
In this lesson, you will learn to:

- Analyze load shapes at different aggregation levels and time resolutions
- Compare load shapes of different customer sectors
- Understand how system-wide load profiles vary by region and time of year

Individual Loads

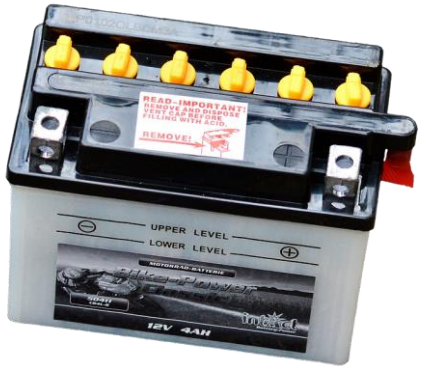
Electrical Load Basics

- An electrical load is a component or portion of a circuit that **consumes electric power**
- Examples include countless devices like lighting, appliances, and HVAC units



Electrical Load Basics

- Loads run on either **direct current (DC)** or **alternating current (AC)** supply
  - Most residential devices and industrial machines run on an AC supply
  - DC devices such as LED bulbs contain power electronics that let them run on AC



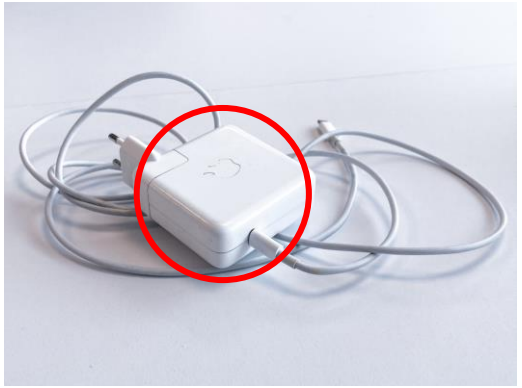
DC Loads

AC Loads

Electrical Load Basics

- **Some electronics have batteries** (laptops, cell phones, etc.), making them **DC loads**
- **Special power electronics on your charging cords** make it possible to power DC loads using AC power from your outlet!

DC Load



AC/DC Conversion

AC Power Source

Load Examples

Item	Voltage	Current (A)	Power (W)	Quantity	Category Total (W)
Refrigerator	120VAC	1.56	188	1	188
HVAC Unit	240VAC	14.17	3,401	2	6,802
LED Tubes	12VDC	1.58	19	8	152
Dryer	240VAC	12.97	3,112	1	3,112
Desktop Computer	120VAC	2.95	354	2	708

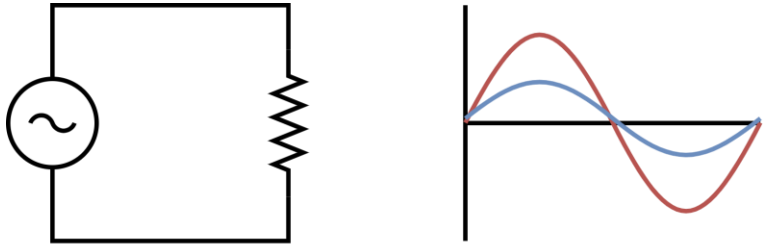
Total power consumed with all devices running: **10,962 watts**, or ~**11kW**

- Note that all the power consumption values can be added, as **wattage is a common metric**
- Even though the devices operate at different voltage levels, you can still compare and sum their power consumption using watts

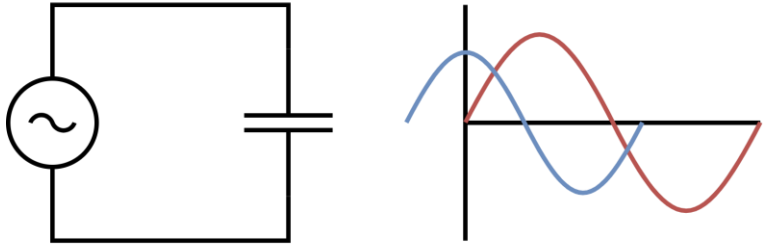
Why is it not a good idea to compare multiple device's power consumption values based on their amperage rating?

Three Types of AC Loads

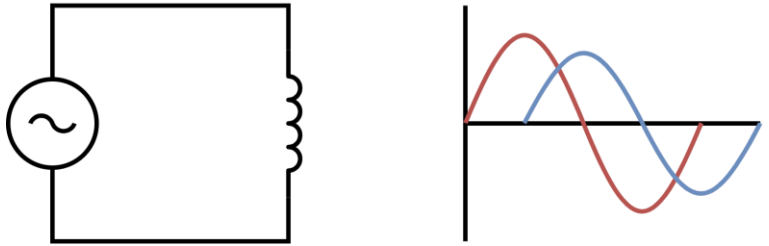
- Resistive (Resistance measured in **ohms**)
  - Current and voltage waves in phase
  - Electrical friction reduces current flow; **draws real power in Watts**
  - Power factor close to unity



- Capacitive (Capacitance measured in **farads**)
  - Current wave leads voltage wave
  - Dielectric material charges up; draws **reactive power in VARs** with opposite polarity
  - Power factor leads



- Inductive (Inductance measured in **Henrys**)
  - Current wave lags voltage wave
  - Magnetic fields; draws **reactive power in VARs**
  - Power factor lags



Load Profiles

Loads Over Time (Watt Hours, or Energy!)

- All of the previous examples consider **instantaneous power consumption -** Measurement of power consumption of a device at any one point in time

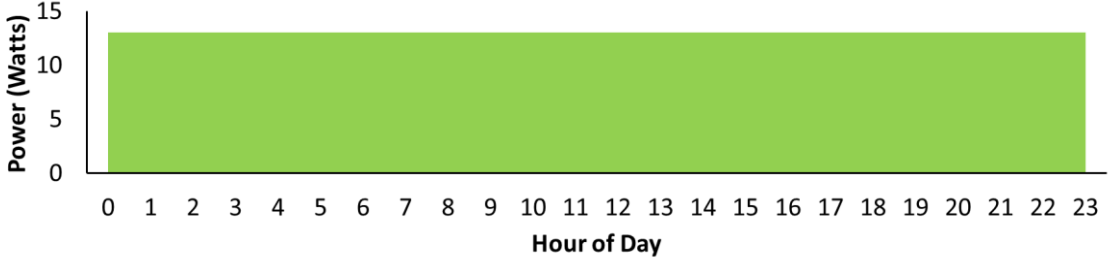
What happens when we use power over time?

- Power consumption (over a period of time) is called **energy:**

Example

An LED lightbulb, on for 24 hours/day:

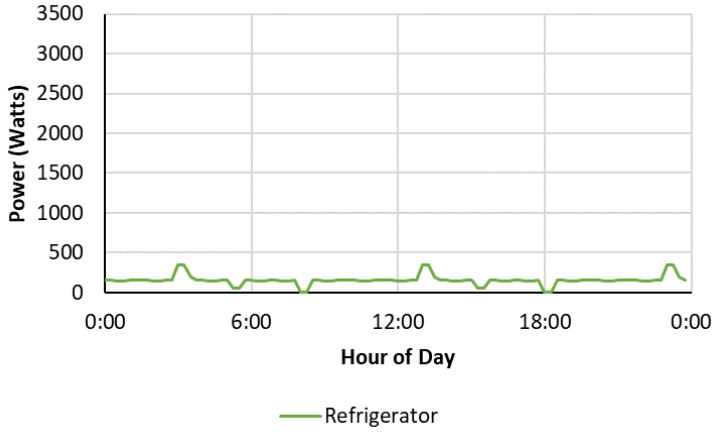
$$Power = 13\text{W}$$
$$Time = 24\ Hours$$
$$Energy = (Power * Time) = (13W * 24\ Hours)$$
$$= 312\ Watt\ Hours, or\ 312\ Wh$$

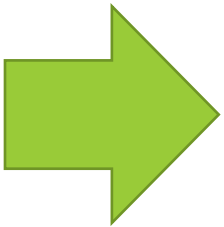


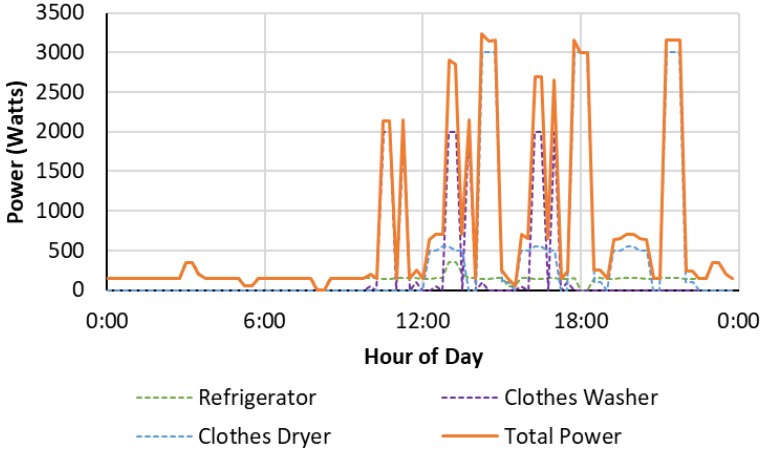
(Also equal to the total area under the curve of a power vs. time graph!)

Load Profiles

- **Load profiles** visually display electrical loads over time
- Can contain **individual loads or an aggregation of many loads**

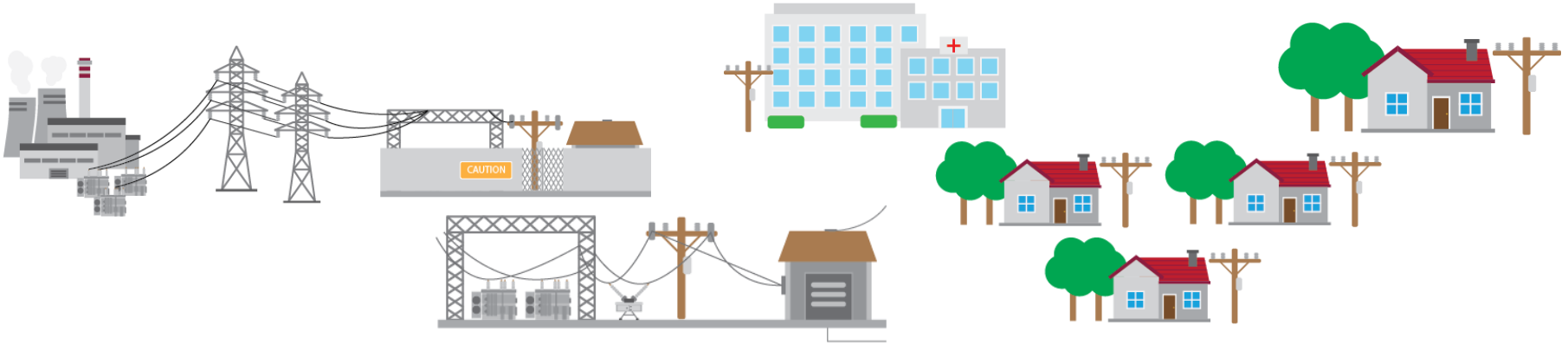






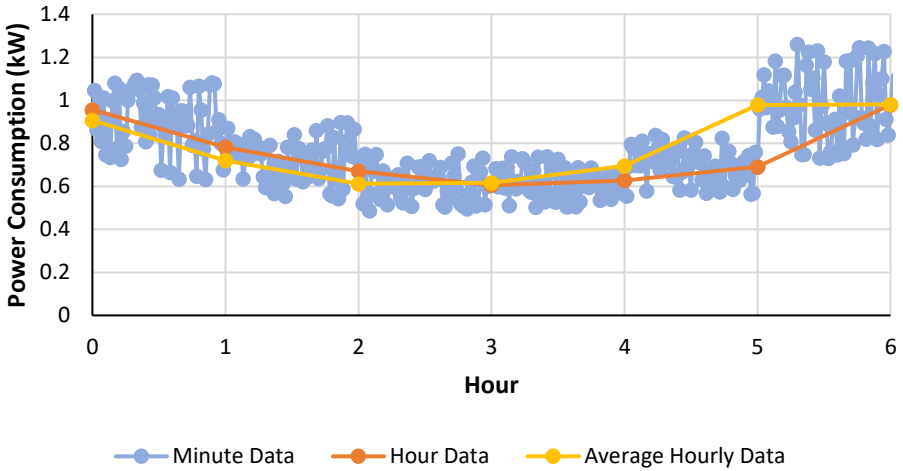
Load Profile Aggregation

- Load aggregation can occur at many levels
  - Individual loads
  - Breaker-panel
  - Building
  - Distribution network
  - Substations
  - Transmission network



Load Profile Resolution

- The **number of data points** collected and their **time interval** indicate the **time resolution** of the data
- **Higher resolution** is useful for understanding variability in power consumption behaviors and while **lower resolution** is helpful for finding summary information

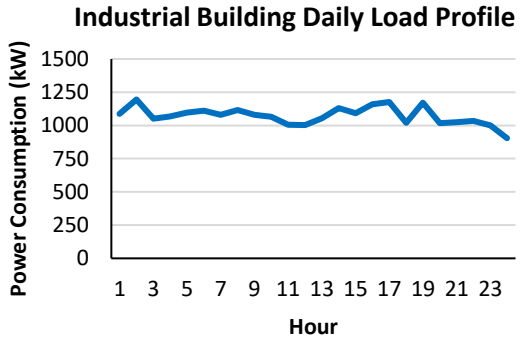


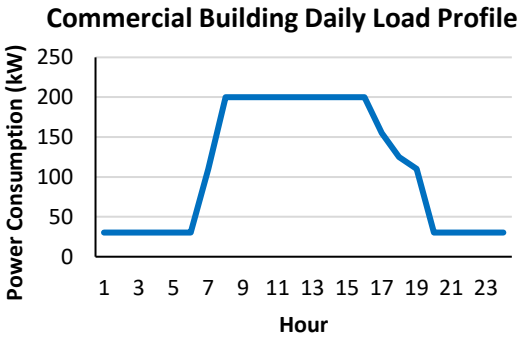
Load Profile Resolution

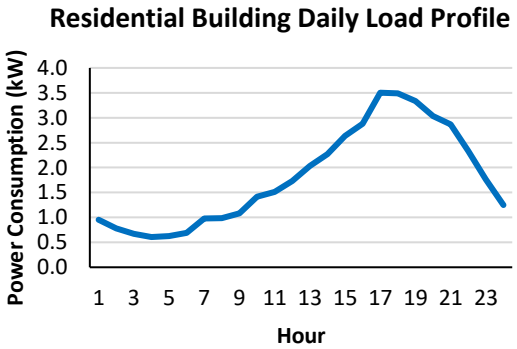
- **Collection rate**
  - Second
  - Minute
  - Hour
  - Weekly (usually total energy in time period rather than continuous time series collection)
  - Monthly (usually total energy in time period rather than continuous time series collection)
- **Measurement instruments**
  - Restricts collection rate/resolution
  - Limits aggregation level (by breaker panel, by device, etc.)
  - Limit type of data (voltage, current, frequency, power, power factor etc.)

Load Profiles by Economic Sector

- **Industrial**
  - Large buildings with large HVAC systems and industrial equipment
  - Largest base loads
  - Can be operating at all hours
- **Commercial**
  - Large buildings with large HVAC systems and many small loads (e.g. computers, kitchens, lighting)
  - Afternoon peak, usually 6am-5pm
- **Residential**
  - Small buildings with small HVAC systems and small loads
  - Evening peak, usually 4pm-8pm







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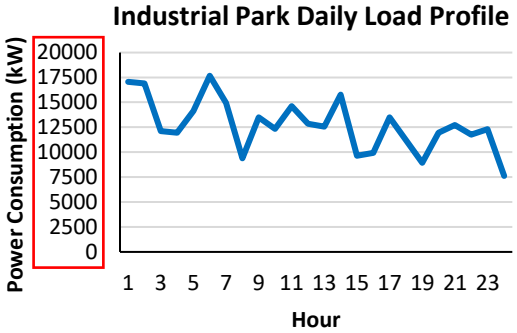
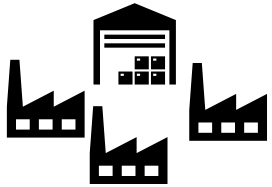
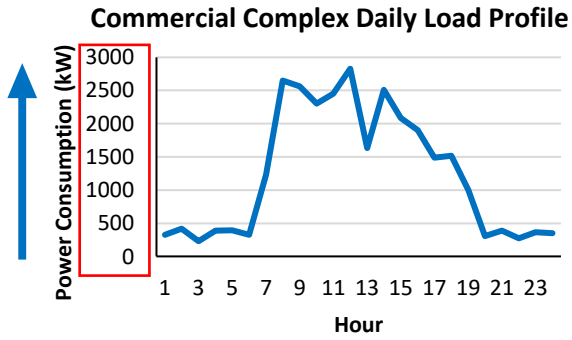
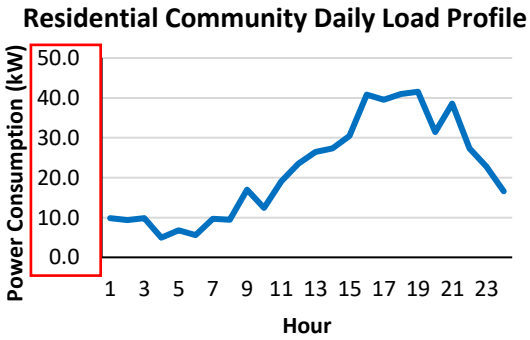
**Note how magnitude increases but shape stays relatively the same if similar building loads are aggregated together*



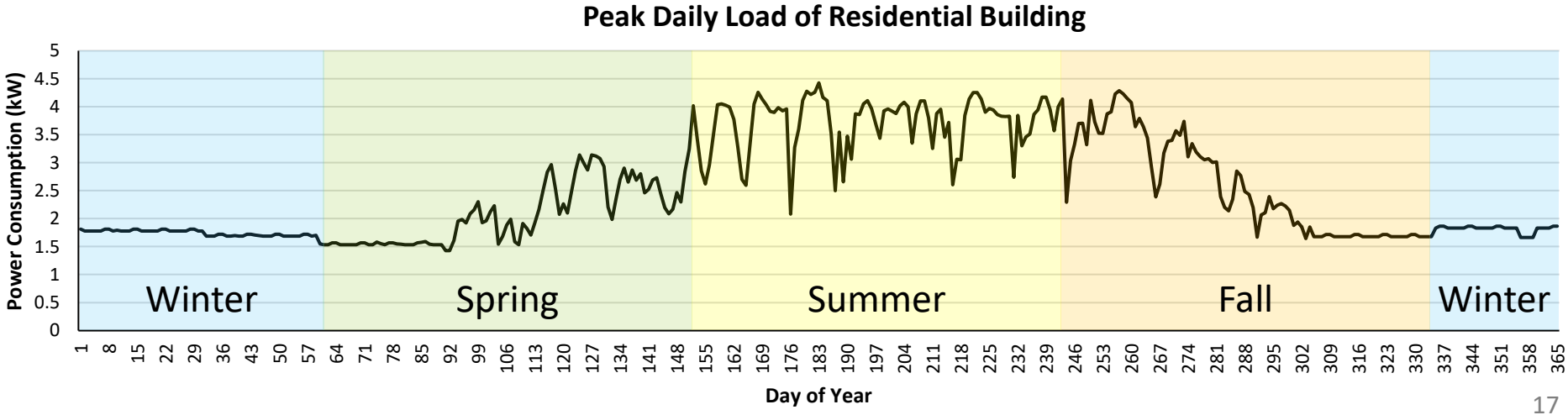






Regional and Seasonal Differences

- **Seasonal effects**
  - Temperature
    - HVAC loads
  - Daylight hours and time spent indoors
    - Lighting loads
    - Work hour loads



Load Profile Estimation

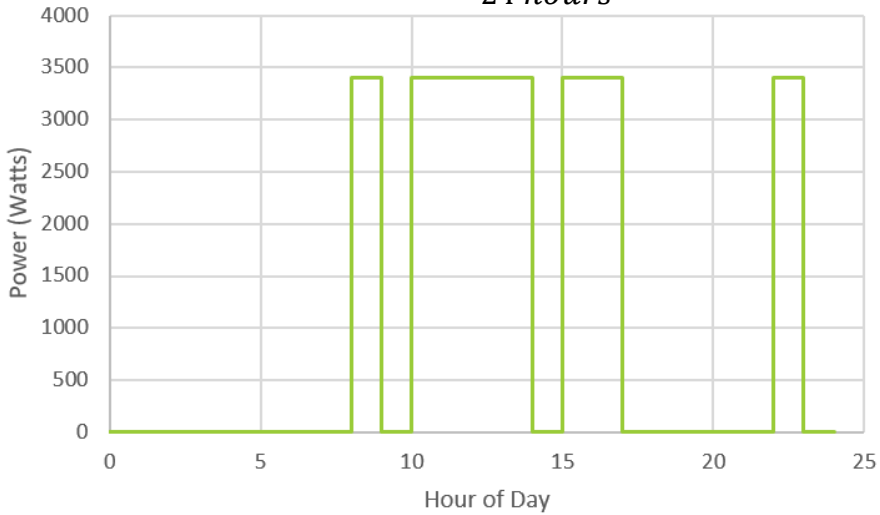
- **Load profiles** are **crucial when designing a power system** to ensure that all load is met
- **Sometimes, data cannot be collected** on expected load profile, and it **must be estimated**
- Techniques when estimating:
  - Summation of expected loads
    - Table of electrical loads and consumption
    - Averaging by time increment
    - Duty cycle
  - Scaling similar load shapes (use historical databases)

Load Profile Estimation Example

- Duty cycles can be used in combination with power requirements of a device to create a basic estimated load profile

$$Duty\ Cycle = \frac{On\ Time}{Total\ Time} \qquad Energy = (Power * Time * Duty\ Cycle)$$

$$Duty\ Cycle = \frac{8\ hours}{24\ hours} = 33\%$$



HVAC Example

$$Energy = (3.401kW * 24h\ * 0.33)$$

$$Energy = 26.94\ kWh\ (in\ a\ day)$$

OR:

$$\mathbf{26.94\ kWh/day}$$

Load Profile Estimation Example

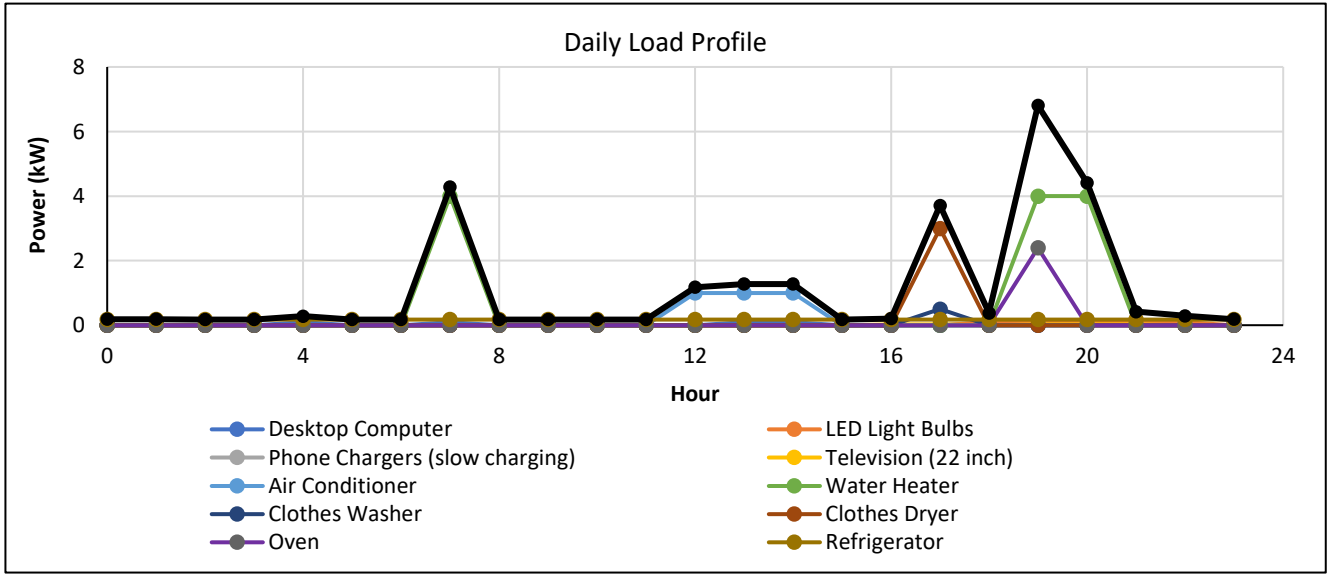
	User Input				
Device	Power Rating (W)	Quantity	Total Power (kW)	Duty Cycle (daily)	Estimated kWh/day
	N/A	N/A	Power Rating * Quantity / 1000	ON time/24 hours	Total Power * Duty Cycle
Desktop Computer	100	1	0.1	0.333333333	0.8
LED Light Bulbs	10	10	0.1	0.208333333	0.5
Phone Chargers (slow charging)	5	2	0.01	0.208333333	0.05
Television (22 inch)	30	1	0.03	0.208333333	0.15
Air Conditioner	1000	1	1	0.125	3
Water Heater	4000	1	4	0.125	12
Clothes Washer	500	1	0.5	0.041666667	0.5
Clothes Dryer	3000	1	3	0.041666667	3
Oven	2400	1	2.4	0.041666667	2.4
Refrigerator	180	1	0.18	1	4.32

	Hour of day (Device On =1, Device Off = 0)																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Desktop Computer	0	0	0	0	1	0	0	1	0	0	0	0	0	1	1	0	0	0	1	1	1	1	0	0
LED Light Bulbs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0
Phone Chargers	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Television	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0
Air Conditioner	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Water Heater	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Clothes Washer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Clothes Dryer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Oven	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Refrigerator	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Load Profile Estimation Example

Calculated Load Profile

	Hour of day																							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Desktop Computer	0	0	0	0	0.1	0	0	0.1	0	0	0	0	0	0.1	0.1	0	0	0	0.1	0.1	0.1	0.1	0	0
LED Light Bulbs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.1	0
Phone Chargers	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.01
Television	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.03	0	0.03	0.03	0.03	0	0
Air Conditioner	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Water Heater	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0
Clothes Washer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0
Clothes Dryer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Oven	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.4	0	0	0	0
Refrigerator	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Total	0.19	0.19	0.18	0.18	0.28	0.18	0.18	4.28	0.18	0.18	0.18	0.18	1.18	1.28	1.28	0.18	0.21	3.71	0.38	6.81	4.41	0.42	0.29	0.19



Historical Data Collection and Load Data Databases

Generated Load Profiles

- https://data.openei.org/submissions/153
- https://data.mendeley.com/datasets/rfnp2d3kjp/1

Recorded Data

- https://cm.asu.edu/
- https://www.appalachianpower.com/company/about/choice/csp/load-profiles
- https://ieee-dataport.org/open-access/8-years-hourly-heat-and-electricity-demand-residential-building#files
- https://www.peco.com/MyAccount/MyService/Pages/meteredhourlyloadbyclass.aspx

Open EI / OEDI database

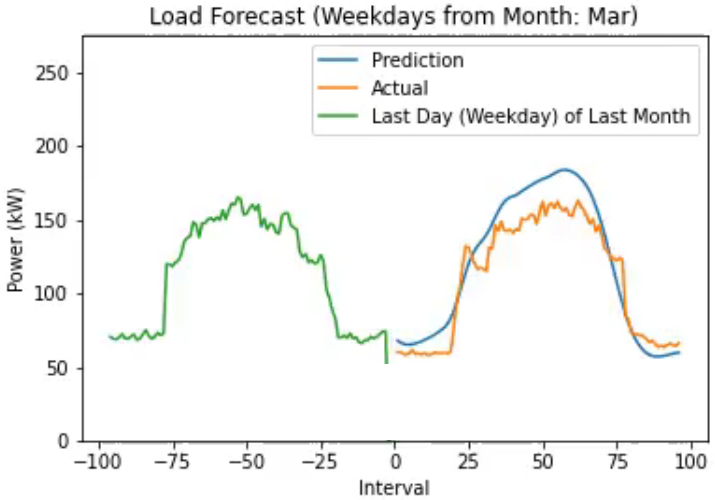
- https://data.openei.org/submissions/153
- OEDI: Commercial and Residential Hourly Load Profiles for all TMY3 Locations in the United States (openei.org)
- OEDI: Simulated load profiles for DOE commercial reference buildings (17 years using NSRD data) (openei.org)
- OEDI: AlphaBuilding - Synthetic Dataset (openei.org)

Historical ISO-level Data

- ERCOT: http://www.ercot.com/gridinfo/load/load_hist/
- CAISO: http://www.caiso.com/planning/Pages/ReliabilityRequirements/Default.aspx#Historical

Advanced Topic: Generating Synthetic Load Shapes

- Forecasting techniques
  - Short-term forecasting
    - Autoregressive Integrated Moving Average (ARIMA)
    - Seasonal Autoregressive Integrated Moving Average (SARIMA)
    - Support Vector Machines (SVMs)
  - Long-term forecasting
    - Multivariate Adaptive Regression Splines (MARS)
    - Artificial Neural Network (ANN)
    - Linear Regression (LR)



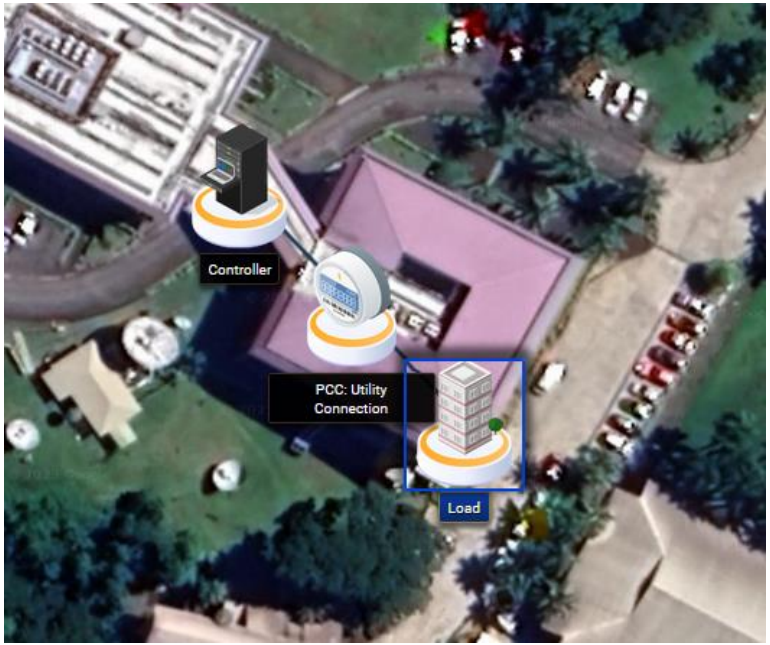
- Machine learning/software aid
  - MATLAB, Scikit-learn, TensorFlow

Activity - Create Load Profiles in XENDEE

Upload a Load Profile

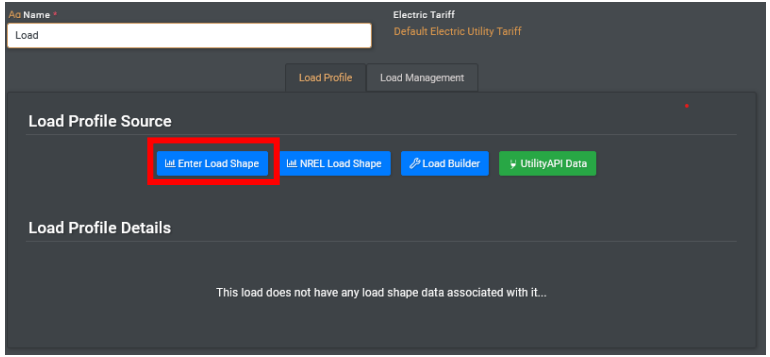
Open the previously create “Fiji Activities” project in your XENDEE account.

Navigate to the building icon labeled “Load” and double-click.

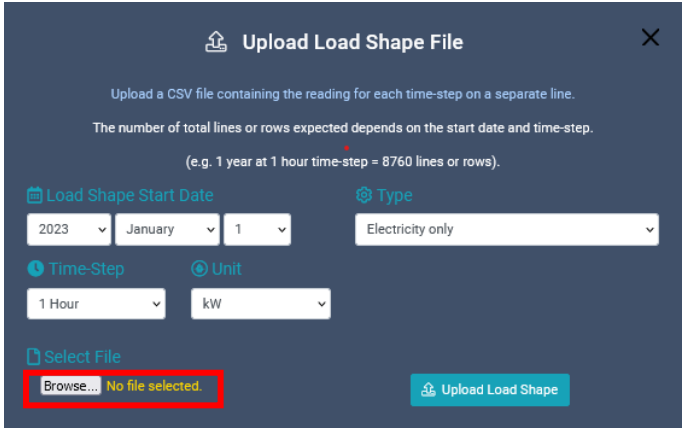


Upload a Load Profile

Select “Enter Load Shape”



Ensure the following inputs are defined and select the browse button under Select File.

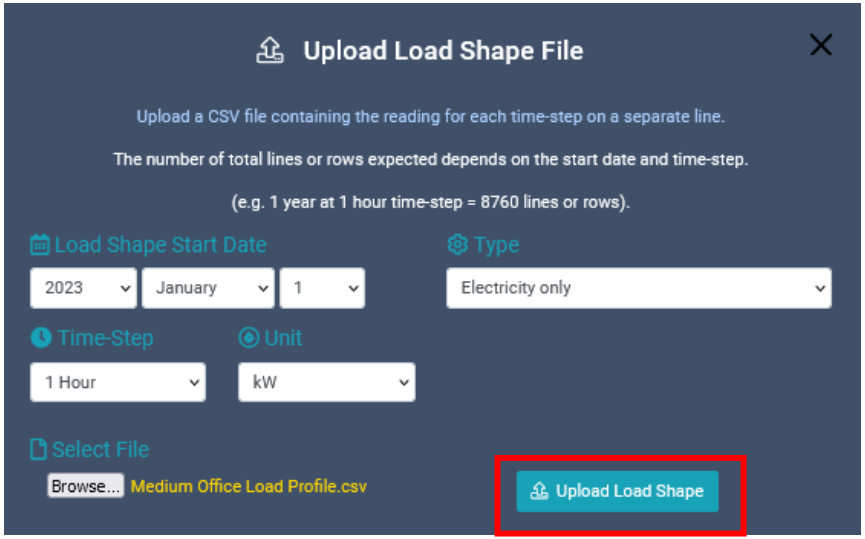


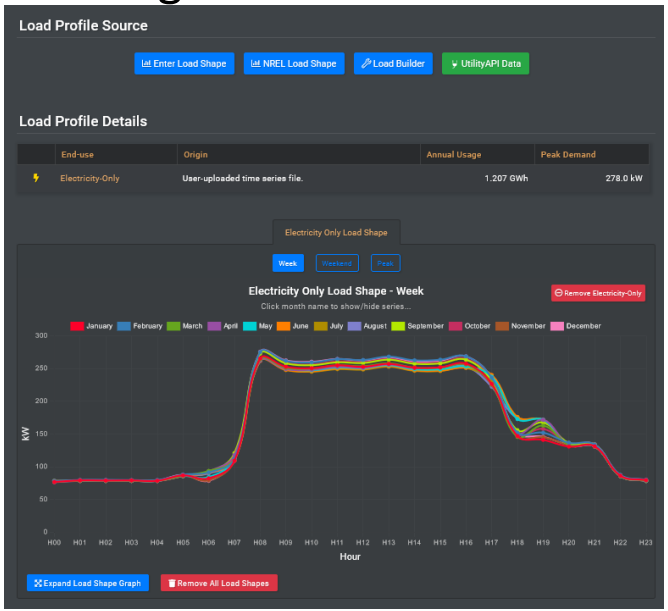
Upload a Load Profile

Navigate to the “Medium Office Load Profile.csv” file that was included in the course material downloads and select it.

Finish upload by selecting the “Upload Load Shape” button.

The final load profile should look like the image on the right.

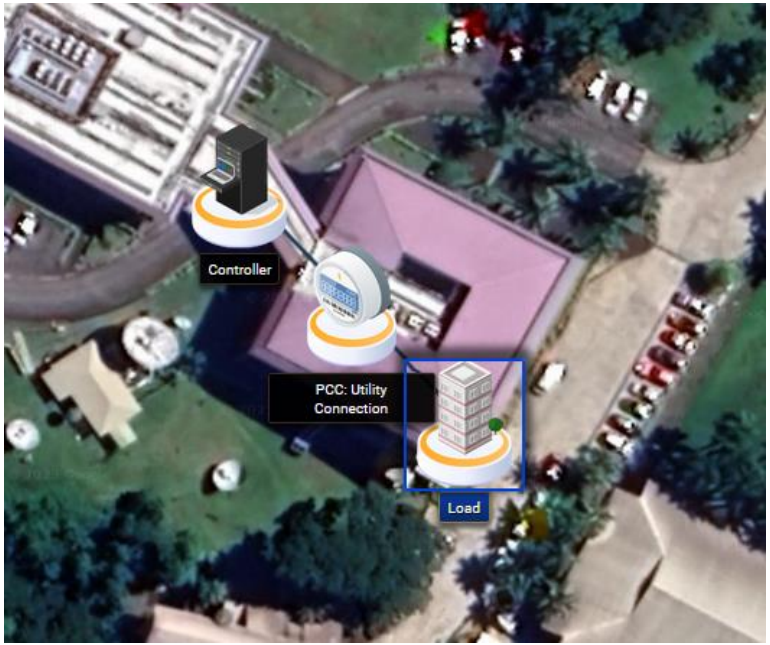




Create a Synthetic Load Profile

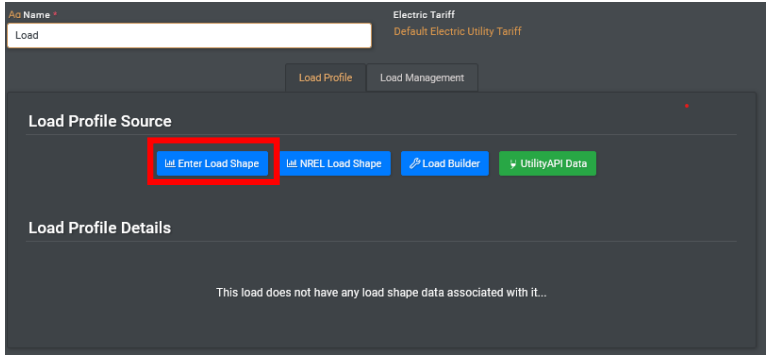
Open the previously create “Fiji Activities” project in your XENDEE account.

Navigate to the building icon labeled “Load” and double-click.

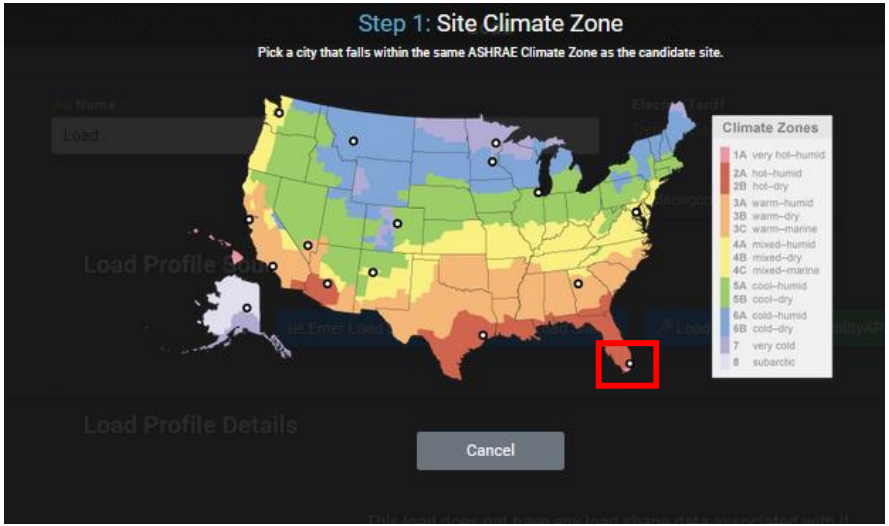


Create a Synthetic Load Profile

Select “NREL Load Shape”

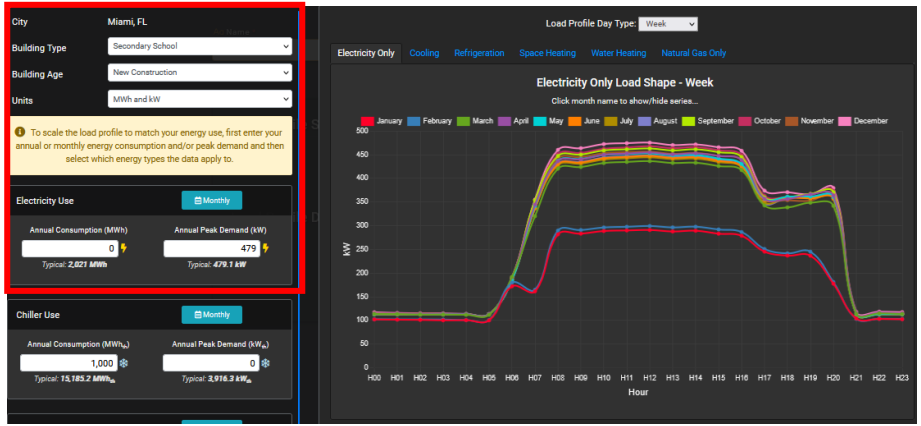


Select Miami, Florida on the map as it is probably the most similar environmental conditions to to Fiji.

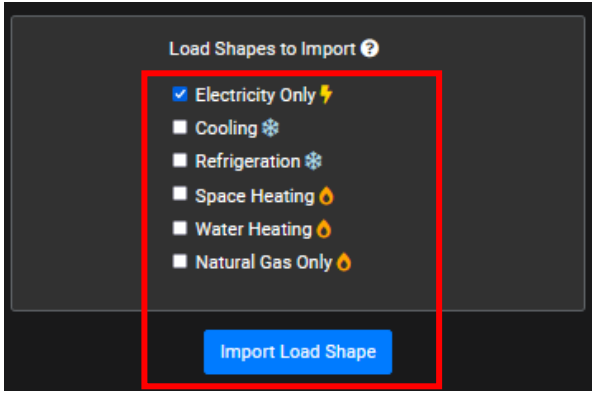


Create a Synthetic Load Profile

Ensure the following inputs are defined to model a newly constructed secondary school with a peak load of 479 kW.

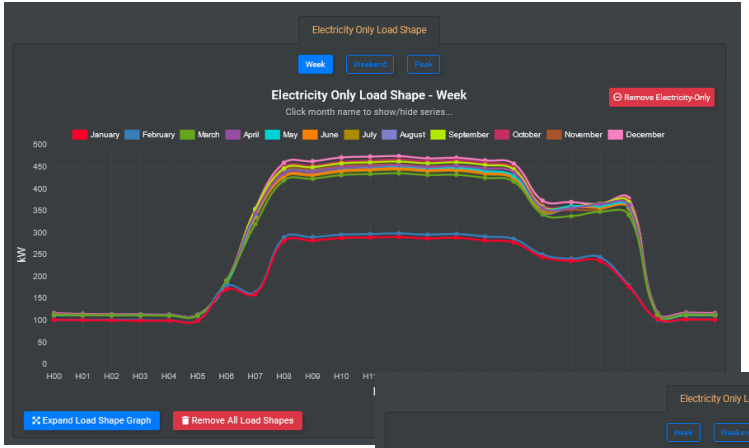


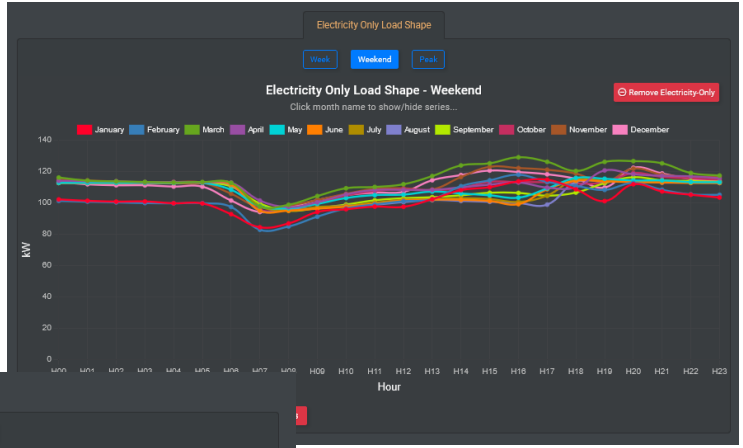
Disable all other load shapes as we are only interested in electricity for this model and select “Import Load Shape”

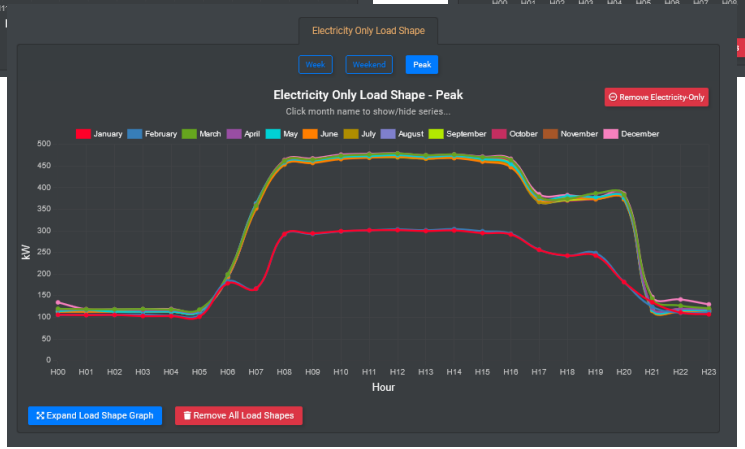


Create a Synthetic Load Profile

The final load profile(s) should look like following for weekdays, weekends, and peak days.







Lesson Summary

Lesson Summary

- What trends can load profiles show at different aggregation levels?
- What differentiates load shapes across economic sectors?
- How do load shapes change with seasons?
- What are some techniques for load profile estimation?