

A group of people are seated around a long table in a meeting room. They appear to be engaged in a discussion, with some looking at documents or laptops. The room has a whiteboard in the background and a patterned rug on the floor. The entire image is overlaid with a semi-transparent green filter.

17-Load Estimation & Characterization

Off-Grid Electrical Systems in Developing Countries

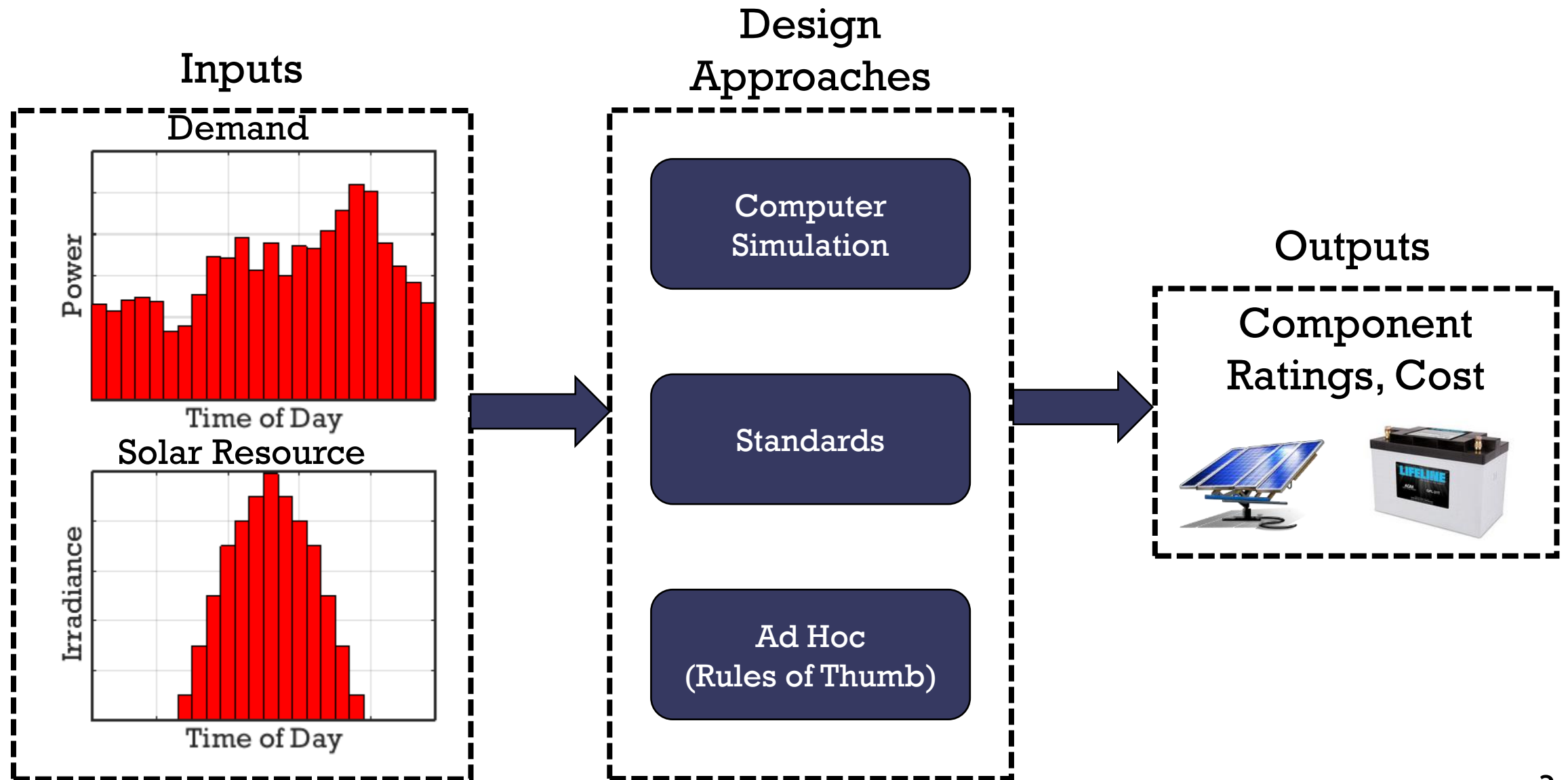
Chapter 11.1 to 11.3



Learning Outcomes

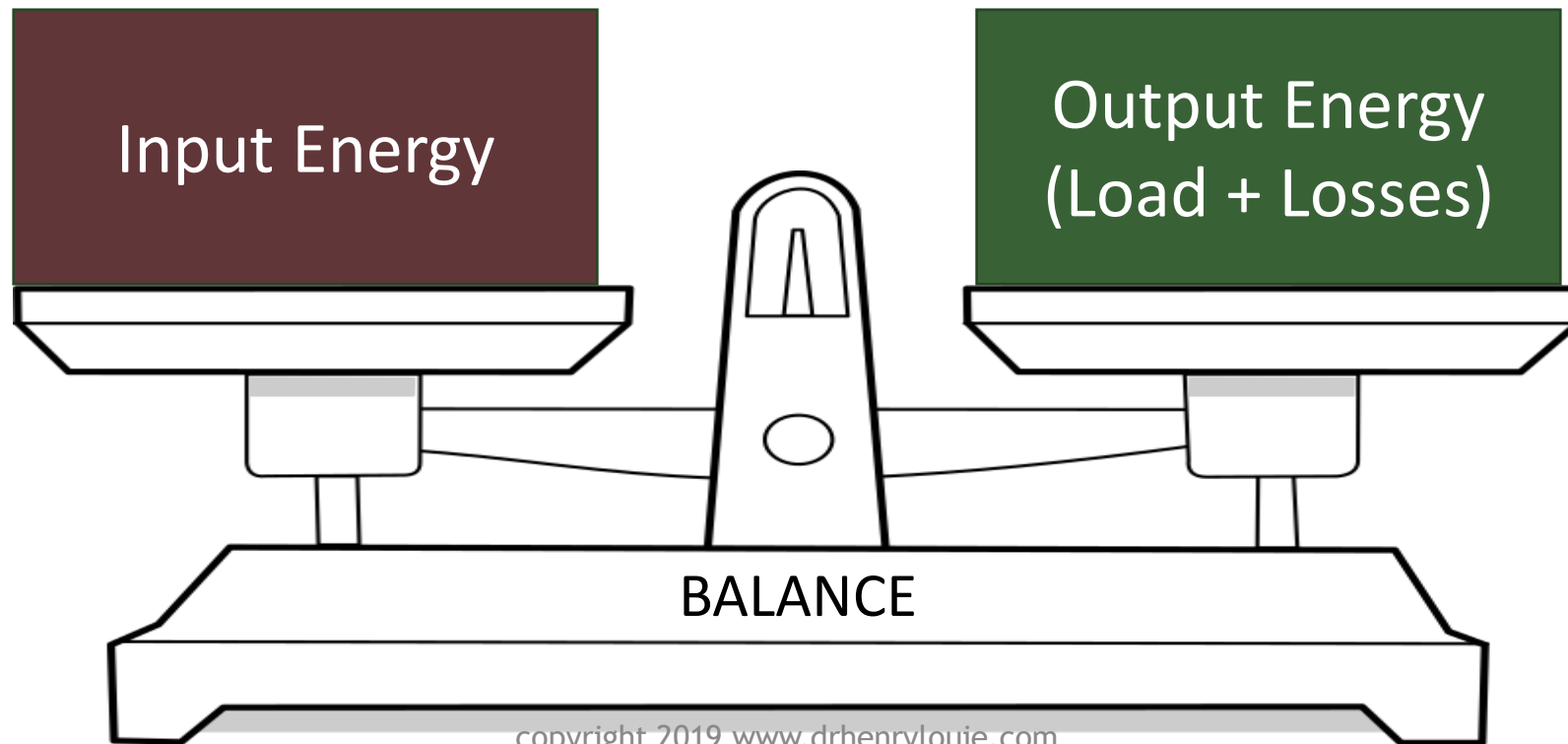
At the end of this lecture, you will be able to:

- ✓ describe the importance of load estimation in off-grid system design
- ✓ articulate the characteristics of the load that are important to designing off-grid systems
- ✓ calculate the average daily load, peak load, load factor, coincident factor of a group of users



A technically-appropriate design is one that...

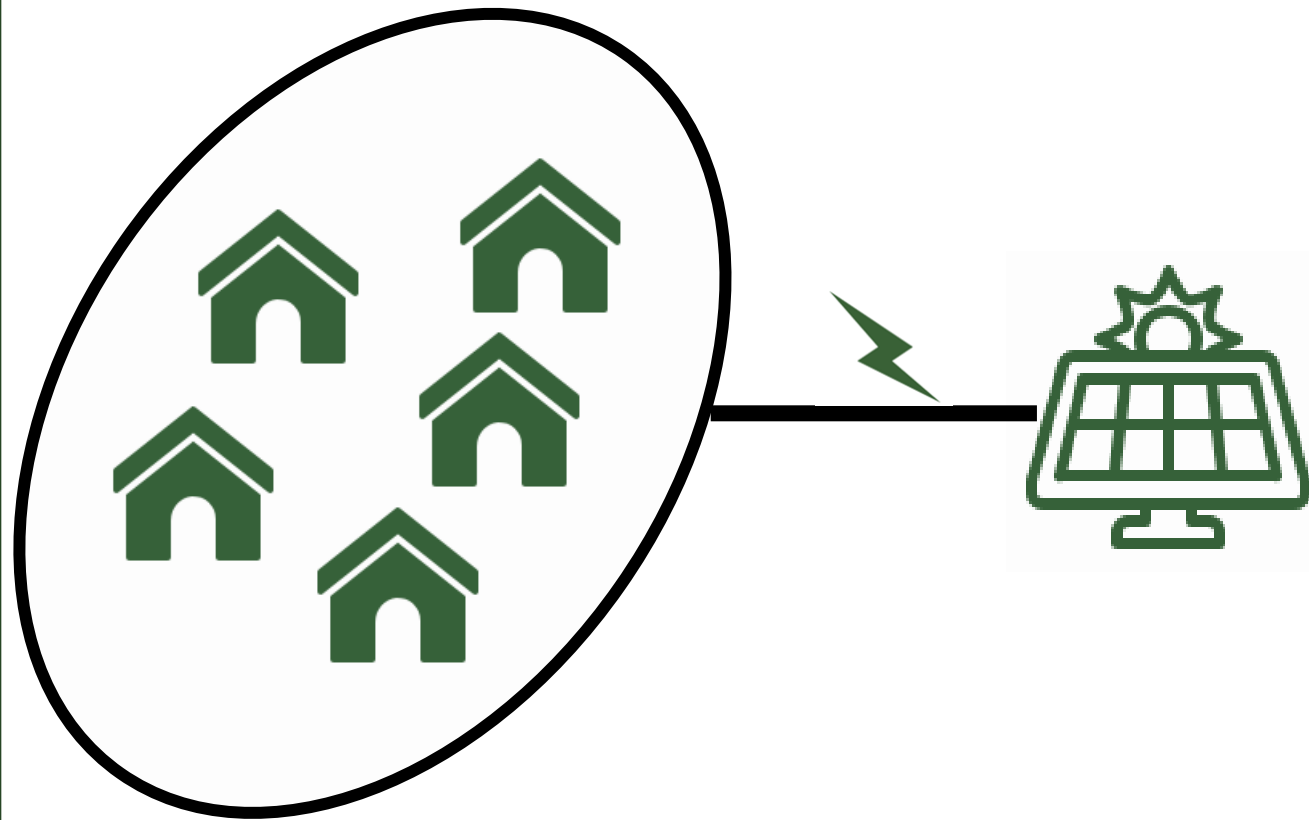
strikes a reasonable balance between the cost of implementing and operating the system with the ability of the system to reliably and safely meet the needs of its users



Load Characteristics

What do we need to know about the load to design our system?

- ✓ How much load (average daily load and peak)



Average Daily Load

- Energy consumption (watthours/day)
- Depends on user type: household, commercial, industrial
- Distribution of average daily load has a “long tail”
 - Most users use little energy, but a few use a lot
- Important for sizing energy production system and batteries

Representative Data

User Class	Avg. Daily Load (Wh)	Percent of Users (%)	Percent of Total Load (%)
Household (low)	35	75	15.5
Household (high)	250	20	29.6
Commercial (low)	1500	4.5	40.0
Commercial (high)	5000	0.5	14.8

Serving high-consumption users is critical to financial viability of off-grid systems

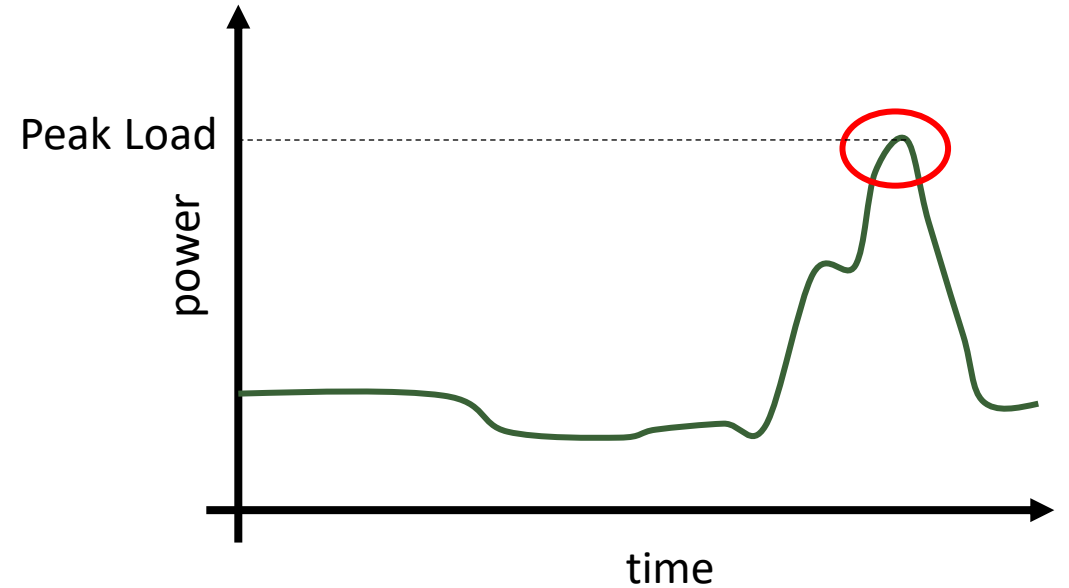
Average Daily Load

$$\bar{E} = \frac{\text{total energy consumed over } D \text{ days}}{D}$$

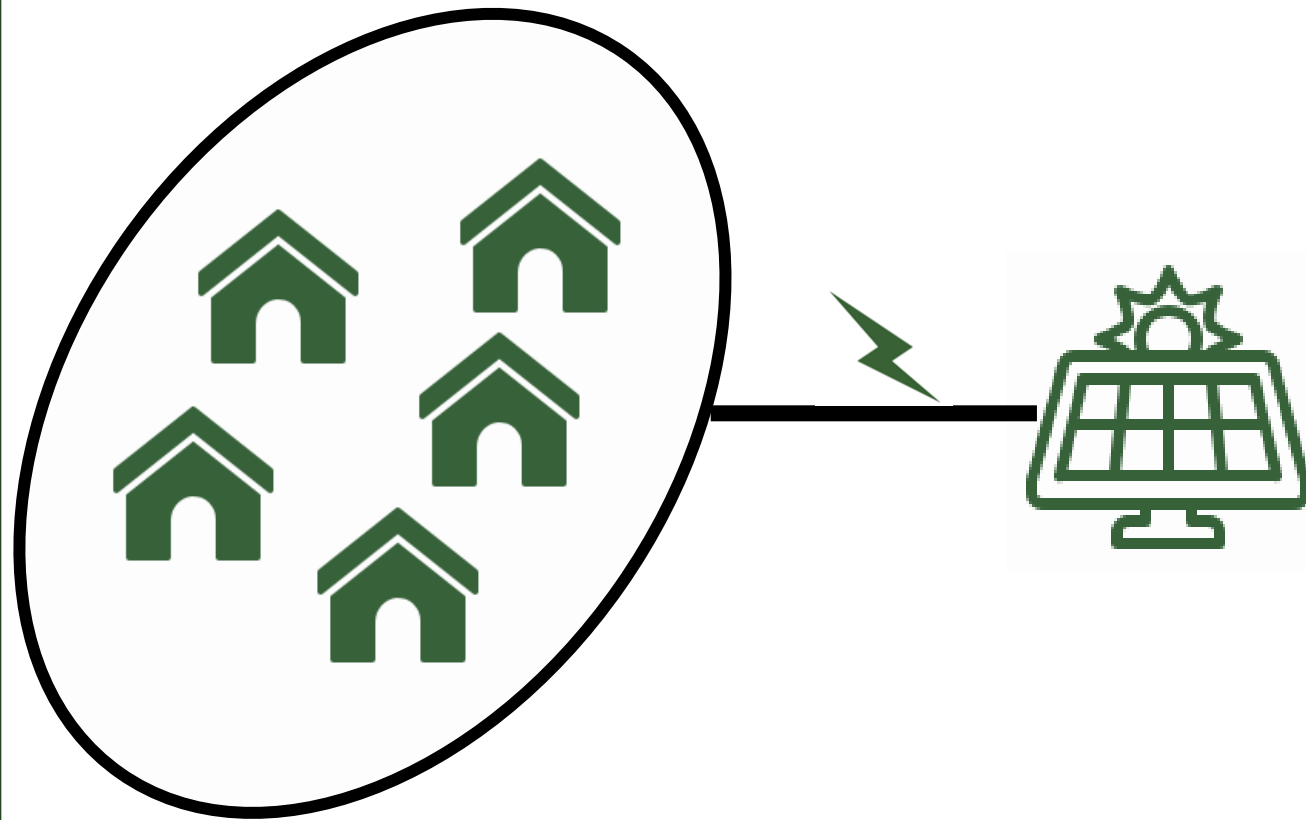
\bar{E} : Average daily load (kWh/day)
 D : number of days

Peak Load

- Power consumption (watts)
- Maximum power consumed
- Important for sizing inverters, generators, transformers, fuses, etc.



Load Characteristics

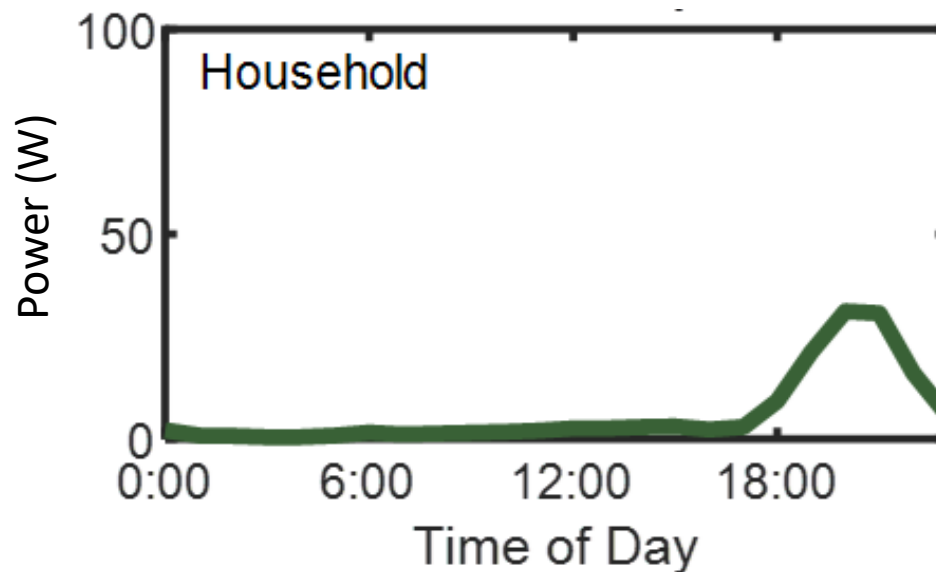


What do we need to know about the load to design our system?

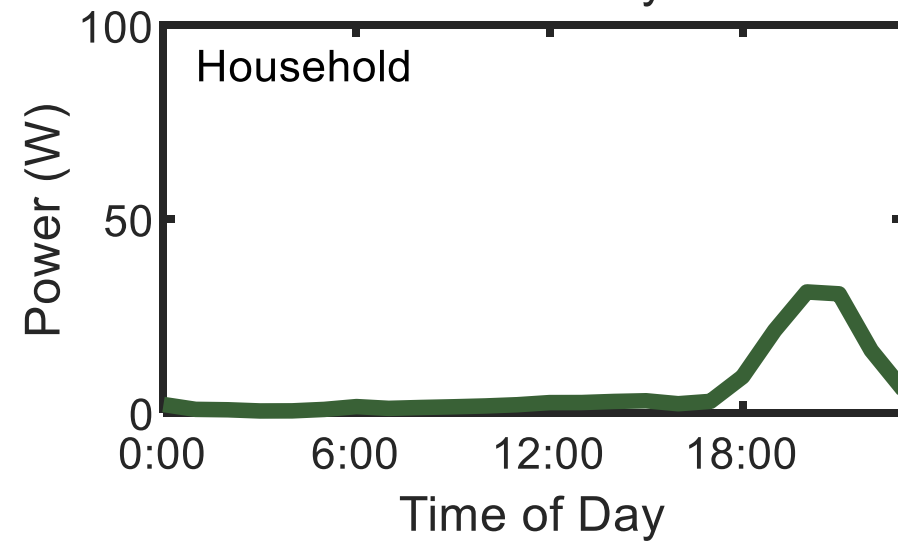
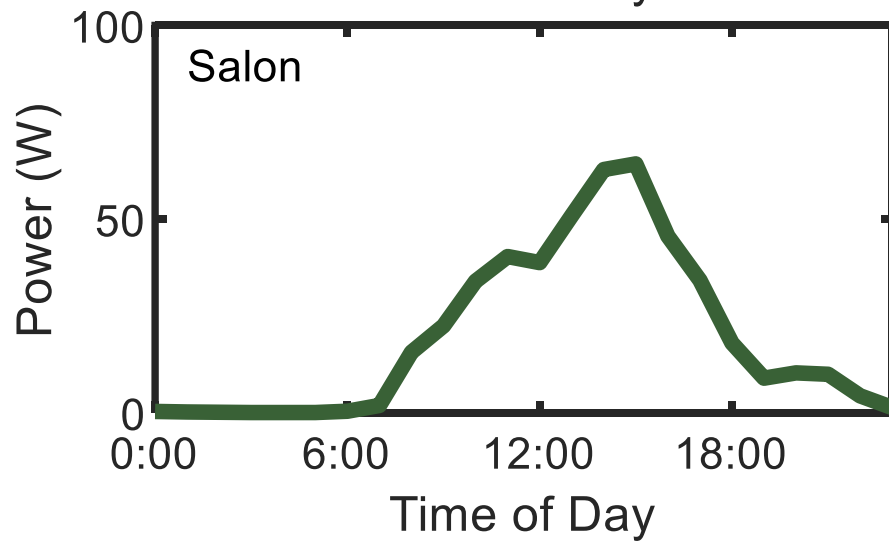
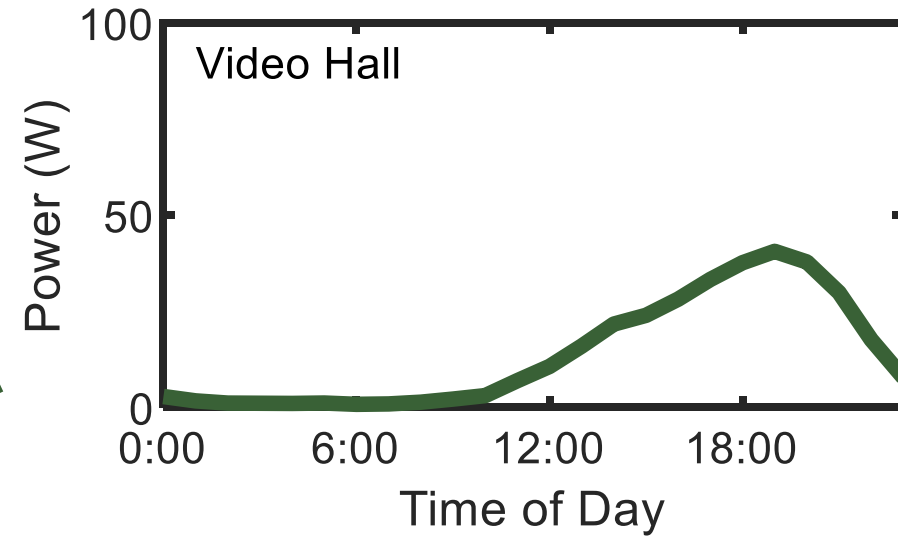
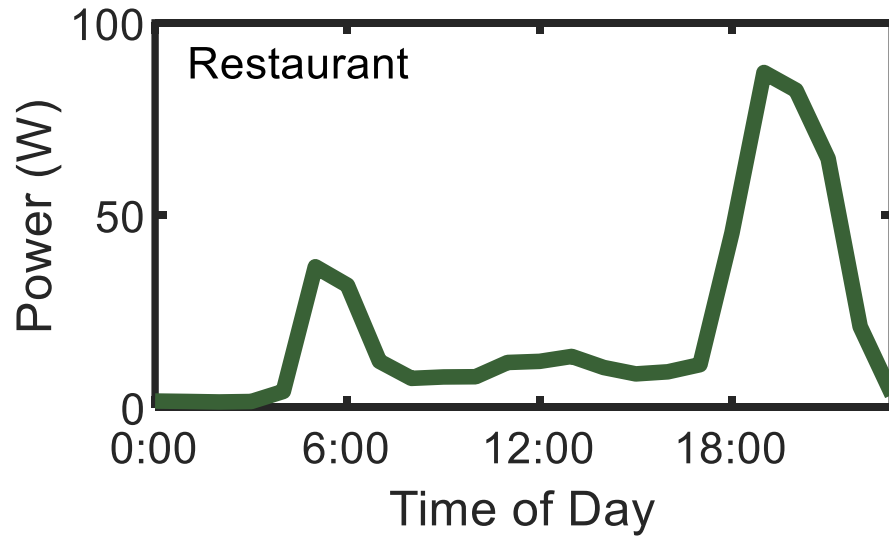
- ✓ How much load (average daily load and peak)
- ✓ When it is consumed (daily load profile)

Load Profile

- Load Profile: *average load over the course of the day*
- Total area under the Load Profile equals average daily consumption
- Timing of consumption is important
 - Load co-incident with generation is desirable
 - Night-peaking load profiles are a poor fit for solar-powered systems



Load Profiles

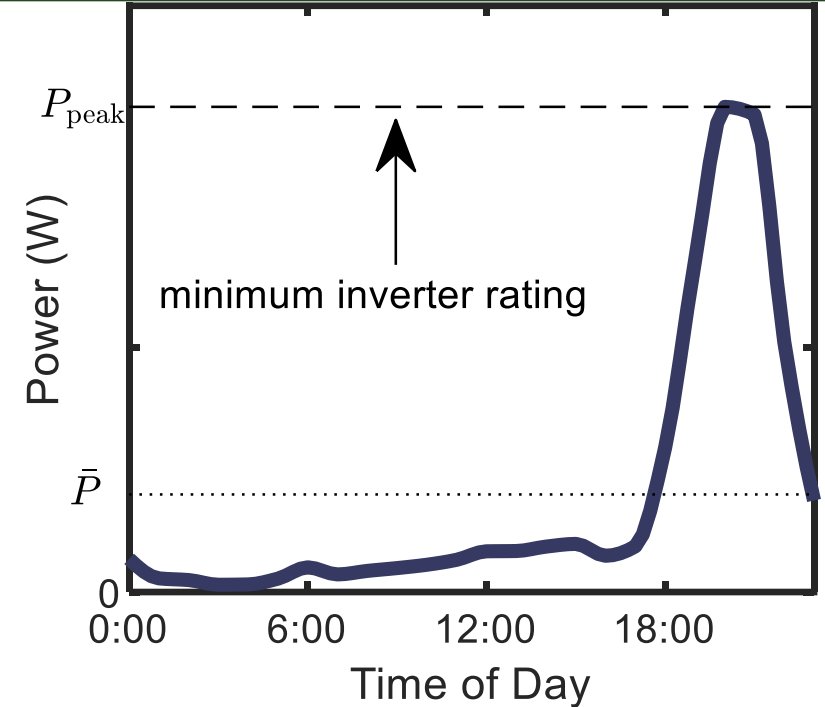


Load Factor (LF)

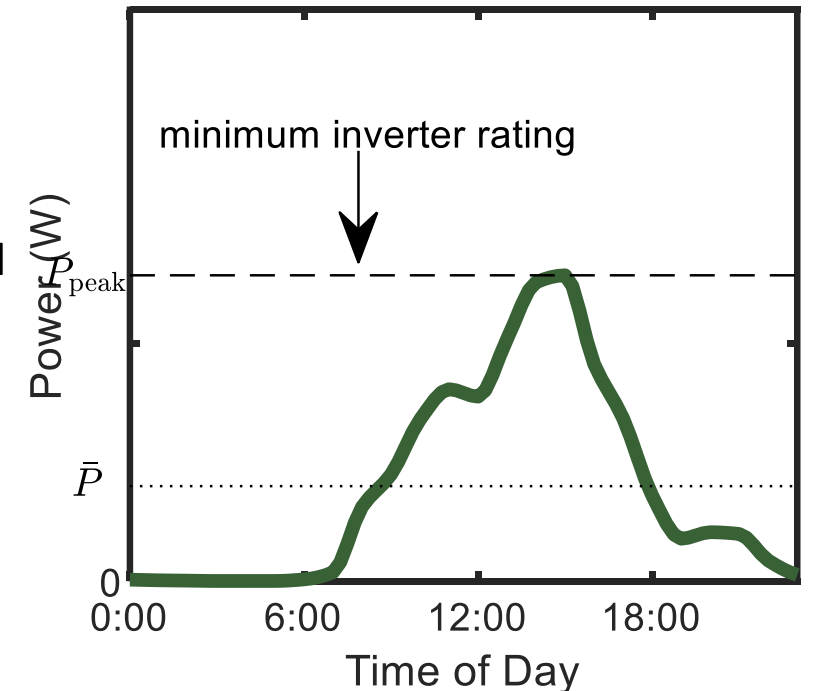
- Load Factor: *ratio of average power \bar{P} and peak load P_{peak}*
- Higher load factors are desirable
 - lower equipment power ratings needed

$$LF = \frac{\bar{P}}{P_{peak}} = \frac{\bar{E}}{24 \times P_{peak}}$$

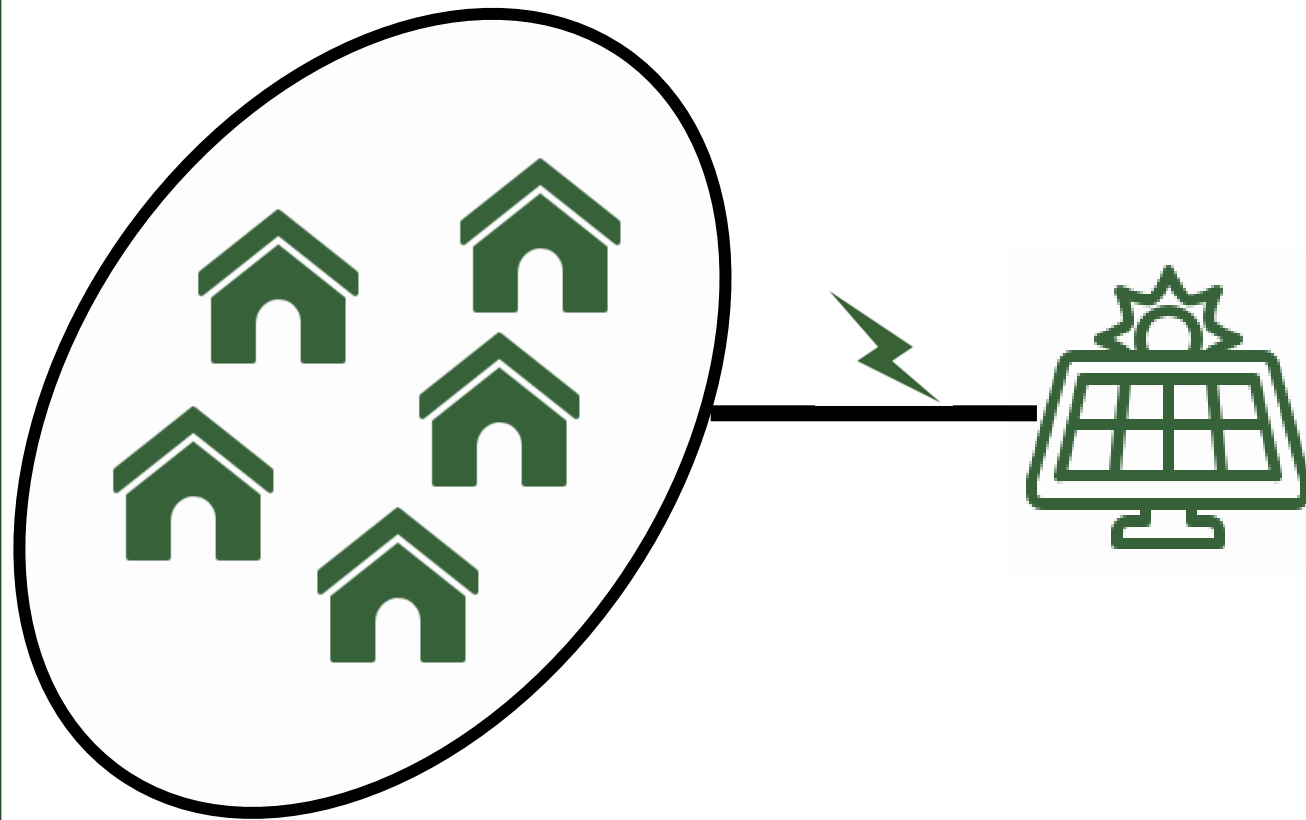
low load factor



high load factor



Load Characteristics

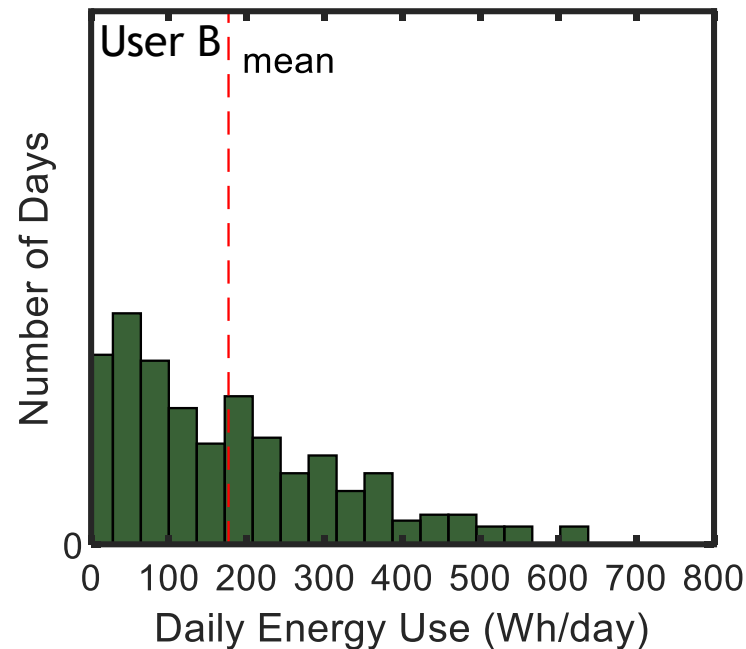
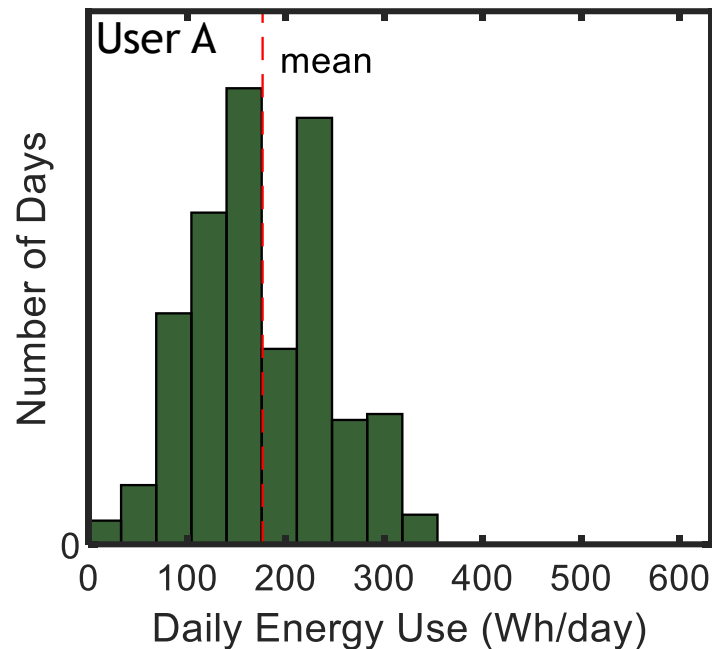


What do we need to know about the load to design our system?

- ✓ How much load (average daily load and peak)
- ✓ When it is consumed (daily load profile)
- ✓ How load varies over time (day-to-day and

Day-to-Day Variation

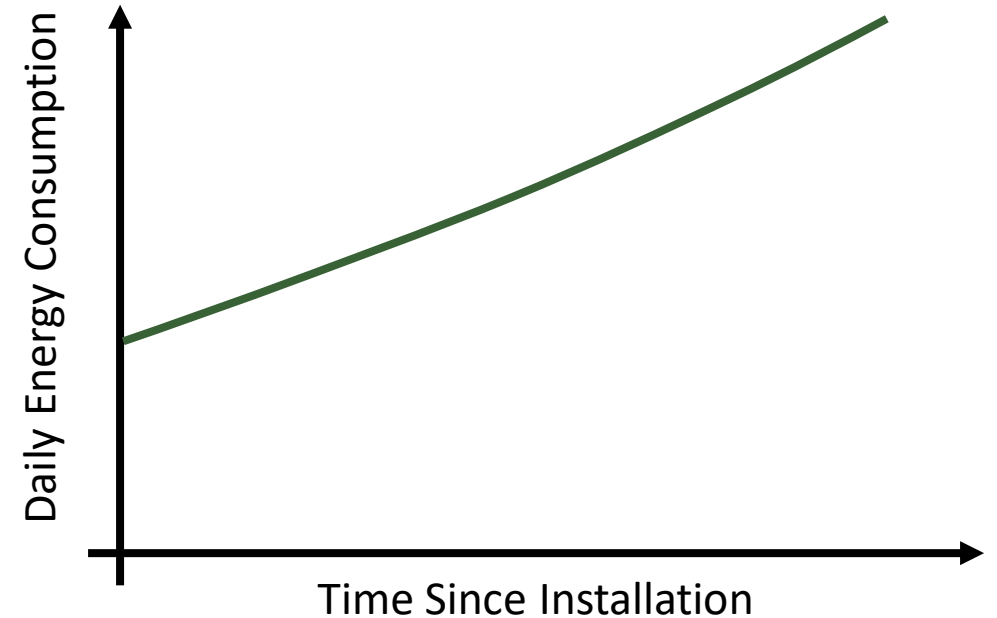
Reliability is dictated by extreme conditions, which is not captured by the average daily load



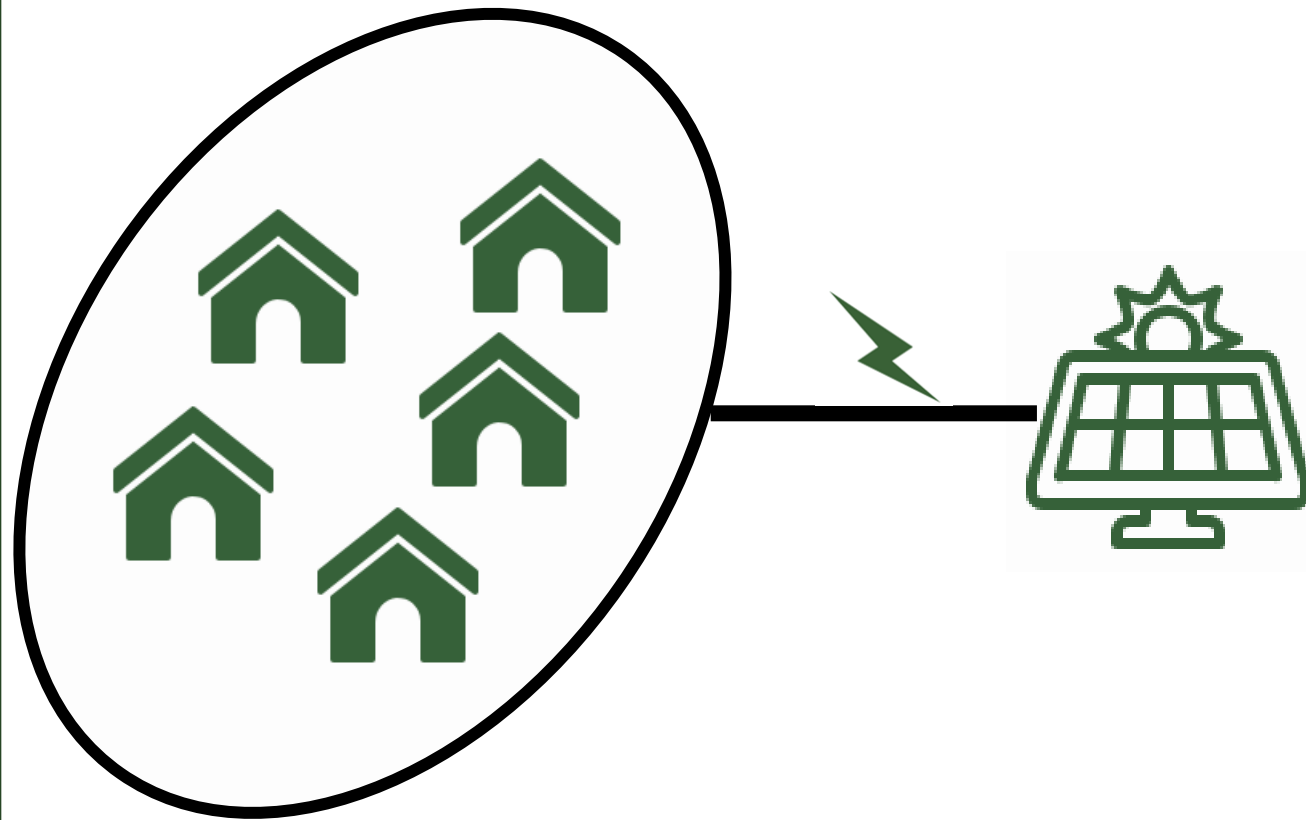
User A and B have same average daily consumption, but User B's consumption is more variable and requires a more expensive system to reliably serve

Year-to-Year Variation

- Consumption usually increases over time
 - 5-10% per year
- Load growth not consistent nor guaranteed
- Access to appliances a barrier
 - Appliance finance/leasing programs



Load Characteristics

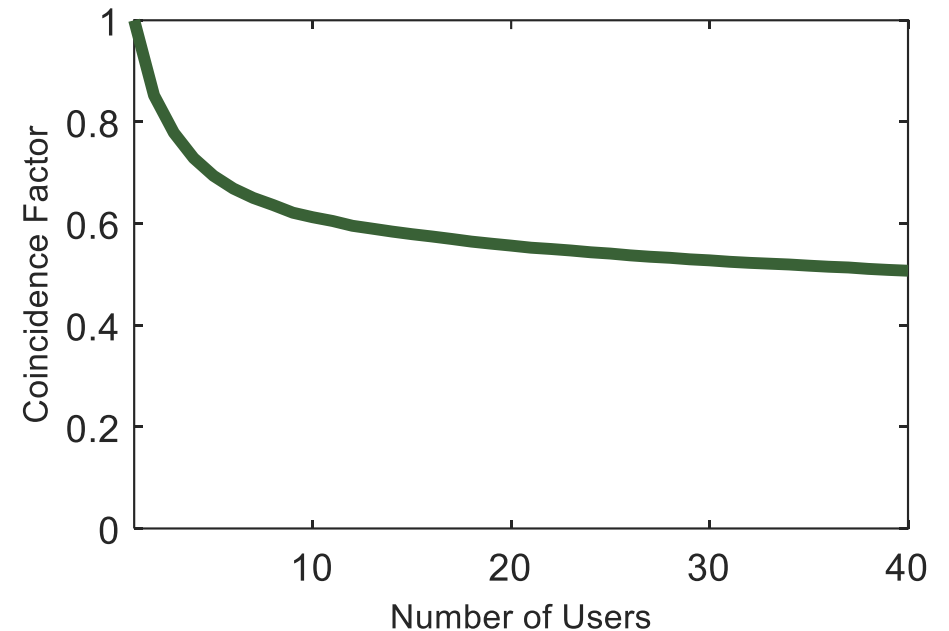


What do we need to know about the load to design our system?

- ✓ How much load (average daily load and peak)
- ✓ When it is consumed (daily load profile)
- ✓ How load varies over time (day-to-day and year-to-year)
- ✓ How load is coincident between users

Coincidence Factor (CF)

- Coincidence Factor: *ratio of the peak aggregate load to the sum of the individual peak loads*
- Less coincidence is desirable
- Households tend to exhibit high coincidence
- Inverse of CF is known as the *diversity factor*



Peak Load

50W



power

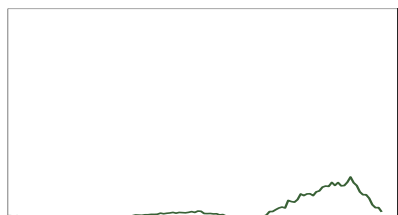


time

150W



power

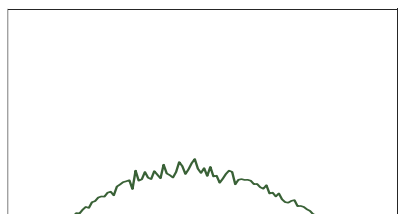


time

200W



power

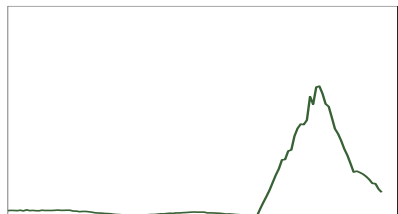


time

500W



power

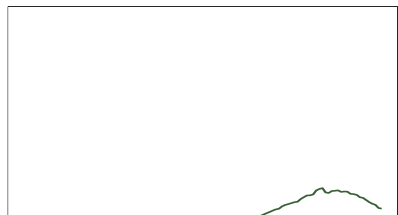


time

100W



power



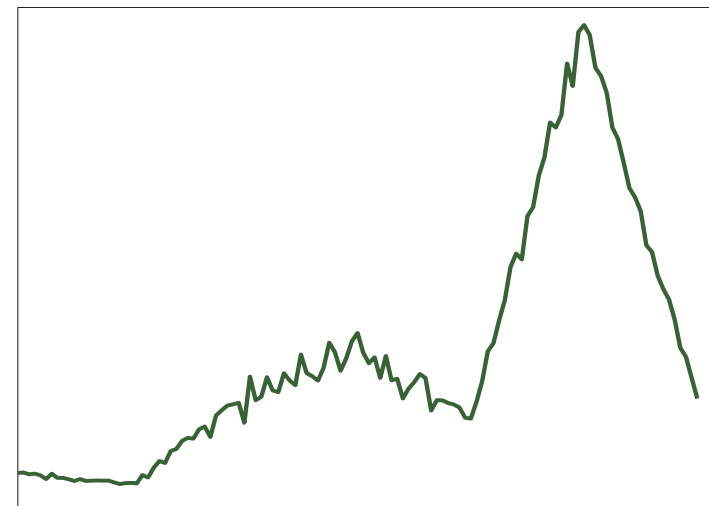
time

Aggregate Load

Aggregate Peak

780 W

power



time

Serving many, diverse users reduces the aggregate peak, increases the Load Factor and lowers the day-to-day variation

Coincidence Factor

$$CF = \frac{P_{\text{peak,agg}}}{\sum_{n=1}^N P_{\text{peak},n}}$$

$P_{\text{peak,agg}}$: peak of the aggregate load (W)

$P_{\text{peak},n}$: peak of the n th user

Preferable Load Characteristics

- ✓ High average daily load
- ✓ Load profile that is co-incident with production
- ✓ Load Factor near 1.0 (not peaked)
- ✓ Low day-to-day variation
- ✓ Predictable long-term growth
- ✓ Low Coincidence Factor

Load Estimation Approaches

- Bottom-up
- Survey
- Regression
- Data-driven



Bottom-Up Estimation

- Requires knowledge of appliances and load profile
- Only realistic in certain scenarios (e.g. lighting only, or when usage is controllable)
- Energy estimation of user n

$$\hat{E}_n = \sum_{a=1}^A p_a \times \frac{K_a}{100} \times T_a$$

P_a : rated power of appliance a , (W)
 T : average hours of use per day of appliance a , (h)
 K_a : loading percentage appliance a , (%)
 A : total number of appliances

Bottom-Up Estimation

Quantity x Rating (W) x Duration of Use/Day x Loading Percent = Energy Use/Day



$$5 \times 11\text{W} \times 4\text{hrs} \times 100/100 = 220 \text{ Wh}$$



$$1 \times 200\text{W} \times 24\text{hrs} \times 10/100 = 480 \text{ Wh}$$

700 Wh



Surveys

- Common method
- Estimate future energy use through surveys (door-to-door)
- Typical questions
 - What appliances do you expect to own?
 - What hours will you use them?
- Use bottom-up approach based on results
- Should be used with caution, as it is error-prone

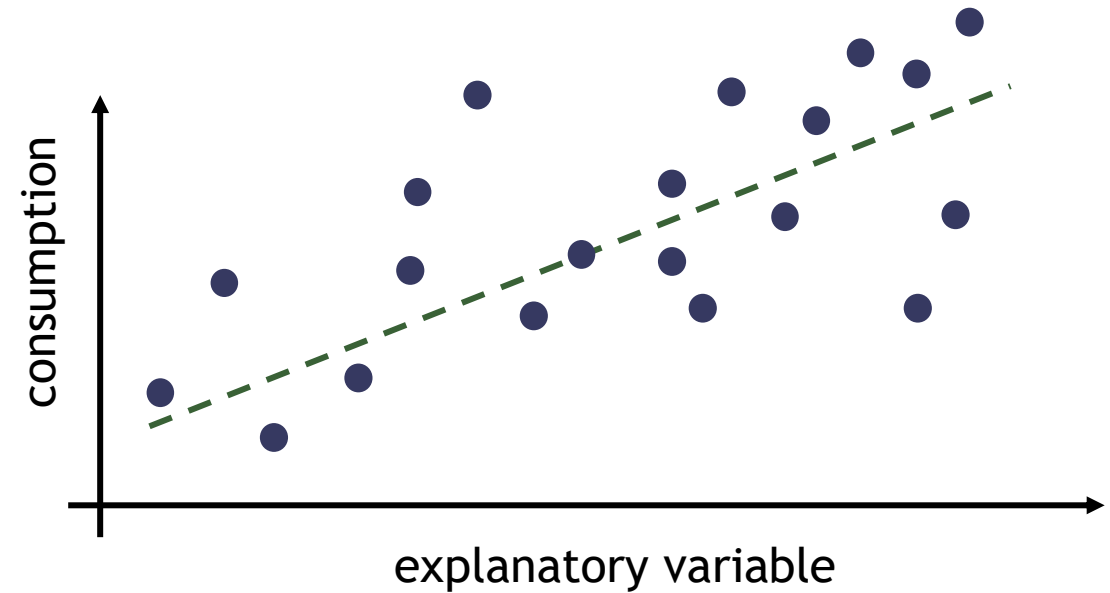
Sources of Error

- ✓ Appliance ownership is mostly speculative
 - Appliance cost can delay ownership
 - Appliances can be acquired over time
- ✓ Appliance usage is also speculative
 - How much use can they afford?
 - Intermittent use is hard to estimate
- ✓ Inaccuracy of power ratings and load percent
 - Many appliances do not consume constant power
 - How should stand-by power be accounted for?

Surveyor bias!

Regression

- Use mathematical model based on demographic/census data to estimate usage
- Several explanatory variables proposed [4,5]
 - Number of people living in house
 - Income
 - Distance to grid
 - Presence of a flushing toilet

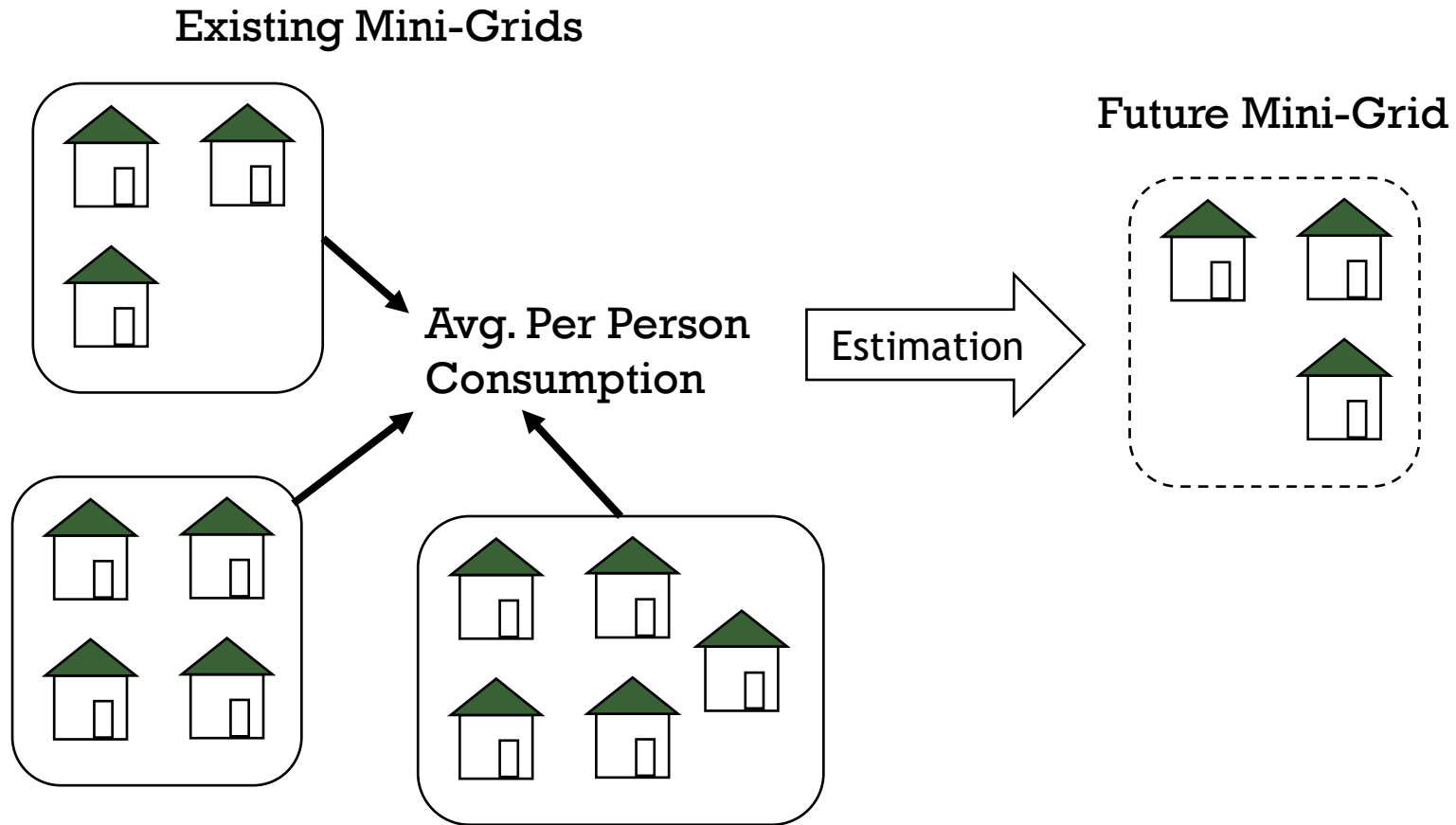


Data-Driven

- Use historical consumption data from similar mini-grids to predict consumption of new mini-grids
- Requires access to historical data from many mini-grids
- Requires a framework for determining which mini-grid projects are similar



Data-Driven Prediction



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