STATE OF THE ART: PLUG LOAD ENERGY EFFICIENCY AND MANAGEMENT STRATEGIES

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CALPLUG EARTH DAY WORKSHOP

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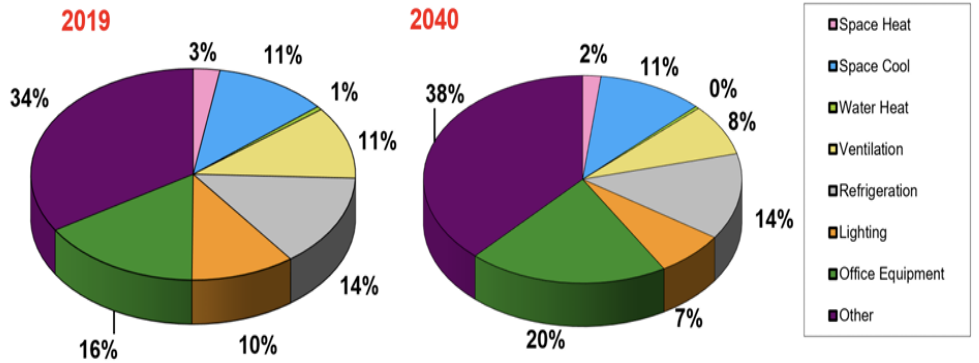
WHY PLUG LOADS?

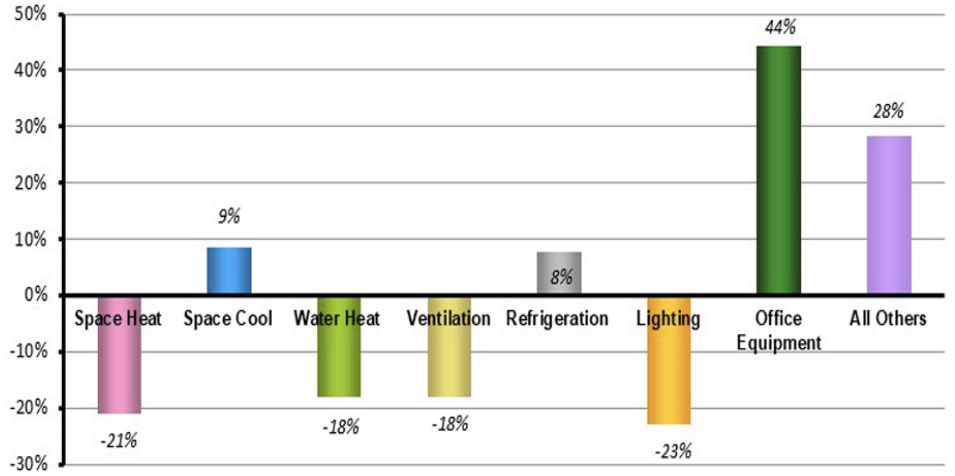
- In 2019, combined plug loads represented about 50% of end-use electricity consumption in commercial building
- According to US EIA data, office equipment energy consumption is expected to grow by 44% through 2040
- Other commercial building plug and process loads are expected to grow 28%

Figure 1: U.S. Commercial Building Electric Usage by End-Use Category



Source: Electric Power Research Institute, Inc.

Figure 2: Expected Change in Electricity Consumption of Major End Uses in U.S. Commercial Buildings from 2019 to 2040



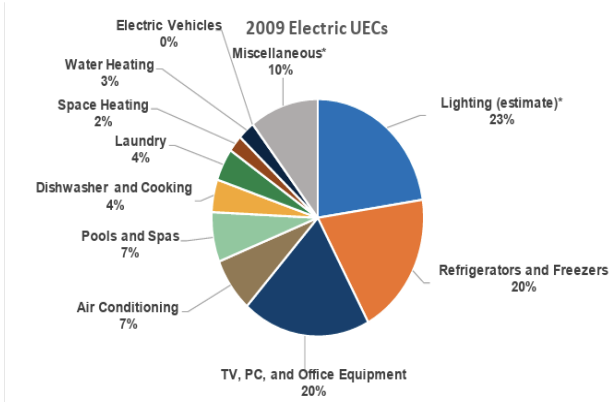
Source: Electric Power Research Institute, Inc.

WHY PLUG LOADS?

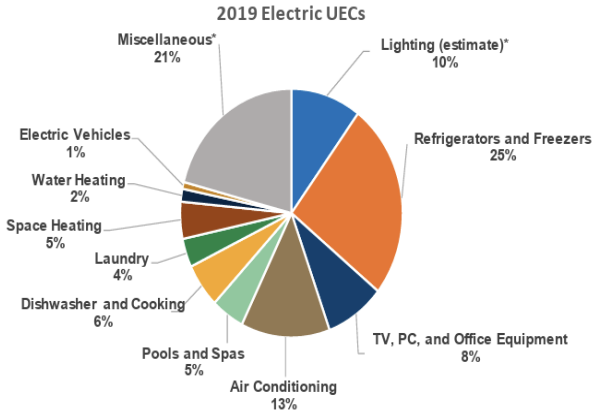
- According to California RASS survey of 2019, plug loads made up between half and two-thirds of residential electricity consumption (refrigeration, electronics, pool pumps, dishwasher and cooking, laundry, EV charging, and misc. process loads)
- While efficiencies in lighting (LEDs) have reduced end-use by >50% since 2009, trends in electrification have led to increased use of electricity for space heating and cooling (heat pumps)
- Necessary to continue EE efforts for plug loads

Figure ES-1: Statewide Electricity Consumption per Household

2009 RASS: 6,296 kWh per Household



2019 RASS: 6,174 kWh per Household



THE PROBLEM

Plug load control and energy consumption reduction remains a challenge:

- Variety of device types
- Various and irregular usage patterns
- Personal usage preferences and behavior

MITIGATION STRATEGIES

Plug Load Energy Management Systems (PLEMS)

Commercial Building Energy Management Systems (BEMs) and Integrated Plug Load and Lighting Controls

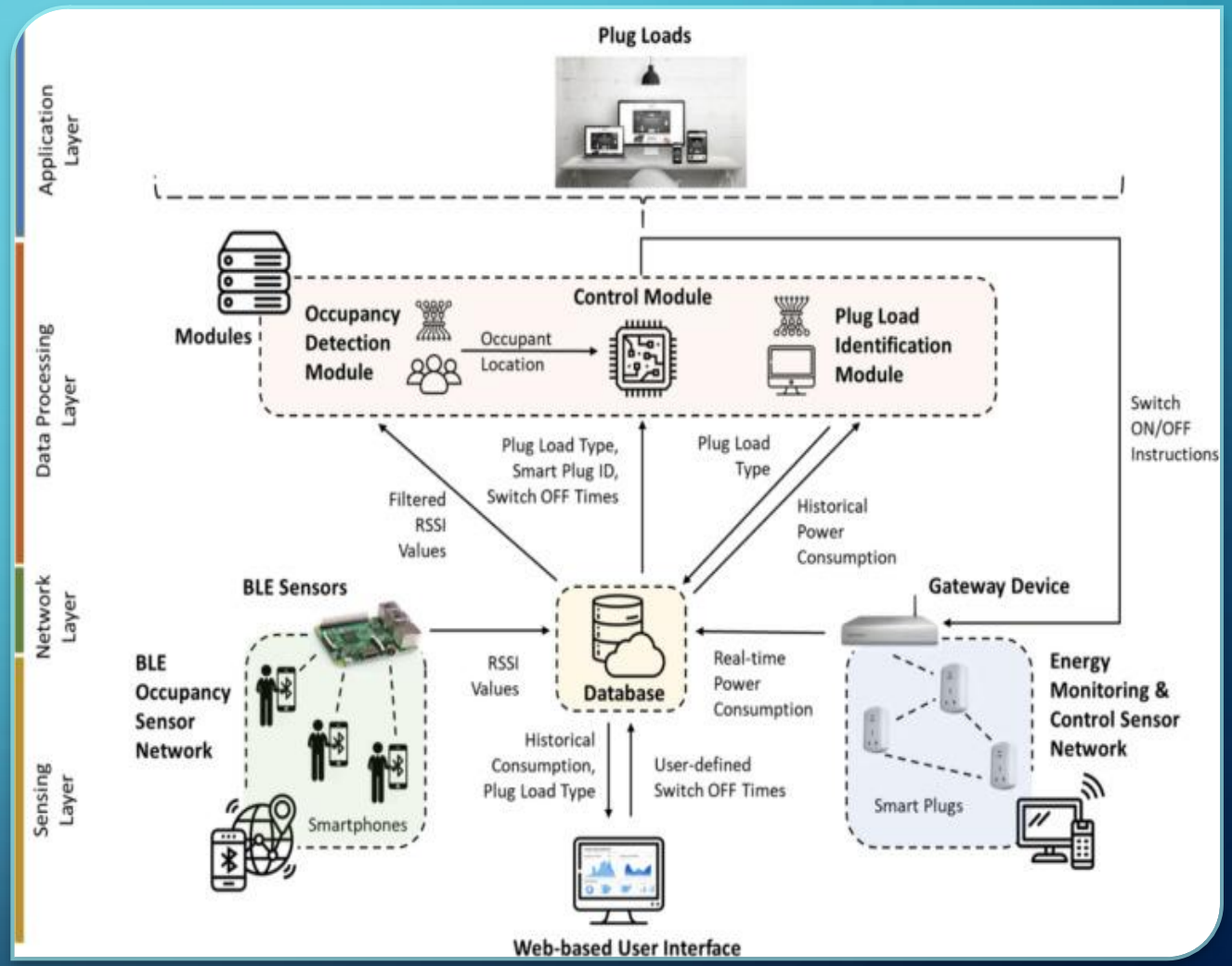
Smart Home/Home Energy Management Systems (HEMS)

Behavioral Interventions

Codes and Standards

PLEMS

- Central management of PLs (scheduling, sensor-based controls) via software platform connecting various hardware:
  - Occupancy sensors
  - Smart plugs
  - Advanced Power Strips



Source: Tekler et al, 2022

PLEMS CASE STUDY: FLEXIBLE CONTROL STRATEGIES FOR PLUG LOADS (EPRI 2023)

Pilot study of a PLEMS system in an office building, and a biology lab

Office Study (2 weeks):

- dAlchemy smart strip (Enmetrics Powerports) w/ four outlets for real time monitoring and automated switching operation of each outlet.
- Users can schedule devices on/off
- Detailed energy data collected; users can view historical and real time data via web app

Biology Lab Study (5 months)

- IBIS PLEMS
- Monitored energy usage and enabled automated switching of lab equipment plugged into smart device
- Tested for flexible load feasibility/ demand response event

Figure 4: Enmetric Smart Strip

Source: Electric Power Research Institute, Inc.

PLEMS CASE STUDY (CONT.)

Results:

Office Building Energy Savings (dAlchemy plug load energy-management system) :

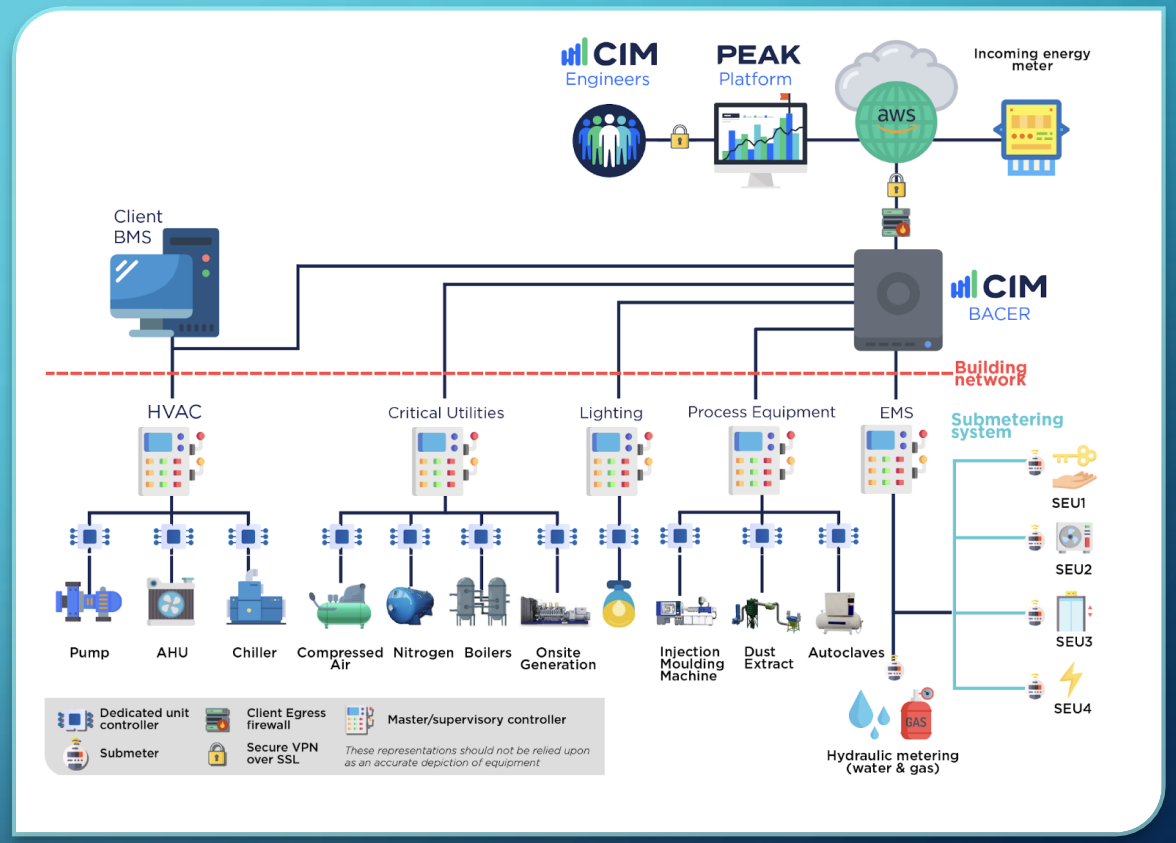
- 213 equipment pieces participated in the treatment period.
- 10.8% overall reduction in plug load energy consumption of the treatment group compared to baseline (2 weeks).
- Potential electricity savings of 684.7 GWh per year (2020)
- Potential customer bill savings of $143.8 million.
- Potential greenhouse gas avoidance of 293.7 mil.kg CO2e per year

Biology Lab Results (IBIS plug load management system):

- 21 equipment pieces chosen for the study
- 18% overall reduction in plug load energy consumption compared to baseline
- Potential electricity savings of 35.7 GWh/year in 2020.
- Potential utility customer bill savings of $7.5 million.
- Potential greenhouse-gas avoidance of 15.3 million kilograms CO2e in 2020.
- Demand response test successfully reduced 22% energy consumption during event; longer term testing necessary

BEMS

- Energy optimization and efficiency primary goal
- Real-time energy usage data
- Algorithm learns usage patterns, identifies problems, automatic controls of wasteful energy usage
- Fault detection and preventative maintenance
- Typically reduces 10-30% of building energy usage
- Major suppliers: Siemens, Schneider Electric, Johnson Controls, IBM



Source: cim.io

BEMS CASE STUDY: PLUG LOAD MANAGEMENT USING A BUILDING ENERGY MANAGEMENT SYSTEM (UCSD)

- Demonstrated integration of smart outlets into building automation system
- Recorded baseline data
- Configured BAS to turn smart outlets on and off on set schedule
- 800 plug load controllers across 14 UCSD campus buildings
- 3 levels of control (static, schedule tightening, usage optimized)

Sample Result:

Global Policy School (Robinson Hall)

- 25 plug loads
- ON 7am-6pm M-F; OFF weekends
- 1 week used 67.4 kWh (66%) less energy than baseline; Estimated annual savings: $1,192

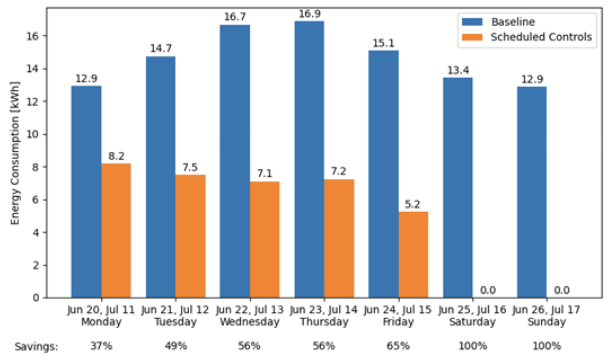


Figure 1: One week of controls consumed 66% less energy than the baseline week.

Source: UCSD

HEMS

- Digital system (cloud based) that controls and monitors energy generation, storage and consumption in a household
- Communicates between PV, battery storage, EV charger, smart meter, and end use (heat pumps, appliances, smart speakers)
- Use cases:
  - Monitor
  - Optimize for energy/cost savings and emissions reductions
  - TOU signals
  - Prosumer sale to grid
  - VPP

- Major suppliers: Schneider Home, Honeywell Home, Siemens LOGO

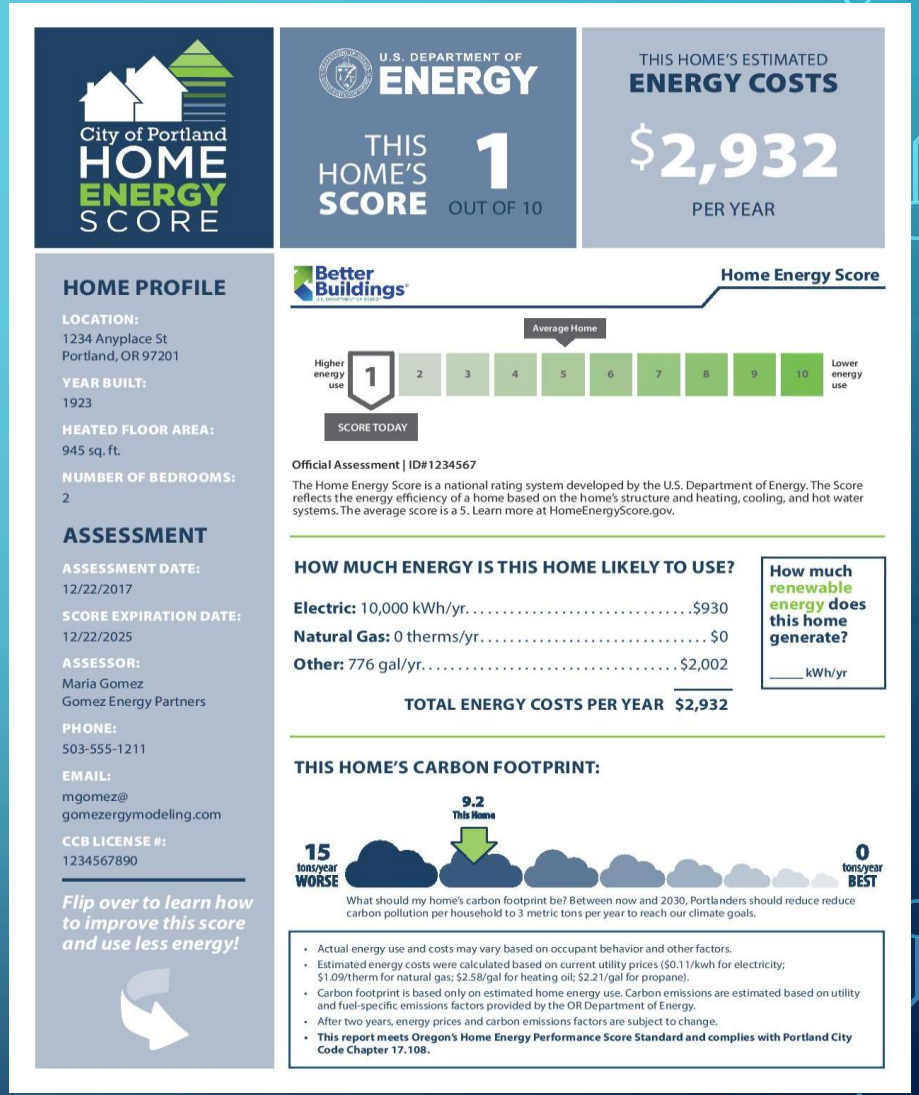
Source: Mahapatra & Nayyar 2002

HEMS CASE STUDY: LOAD PREDICTION AND SCHEDULING USING AI

- HEMS is a mature technology
- New frontier is using AI/ML to schedule loads and predict demand
- Haq et al (2021): Demonstrated reduction in electricity usage/cost using reinforcement learning algorithm. AI agents for household electric appliance and storage system acquire behaviors separately by interacting with environment until average goals are maximized
- Ali et al (2024): Demonstrated Optimized Smart HEMS algorithm that could identify and incorporate real-time pricing tariffs (e.g. TOU) to manage appliance and energy storage schedule. Results showed 46.6% decrease in grid reliance, and 57.7% reduction in energy costs compared to non-scheduled scenarios

BEHAVIORAL INTERVENTIONS

- Proper user training is key to success for maintaining energy savings using BEMS and HEMs
- UCSD study acknowledged that Level 2 and Level 3 scheduling (requiring human interaction) were more difficult to maintain due to perception of workflow interruption
- Home Energy Reports (HERS), visual displays/ real-time feedback, and targeted prompts and tips can be influential in changing behaviors, especially at home
- Tariffs/incentives for peak consumption reduction are important behavioral nudging tools for utilities



Source: Enerstructa

CODES AND STANDARDS

Codes:

- CA Title 24: Regulates minimum efficiency on electronics not covered by federal law, including TVs and computer monitors
- ASHRAE 90.1: 50% of outlets in offices, open office spaces, classrooms, etc. must be controlled receptacles

Standards:

- ISO 50001: Framework for implementing BEMS
- CTA 2045: HPWH integration with HEMS; foundation for additional appliance integration

BEMS/HEMS Protocols:

- BACNET; Modbus; LonWorks: Commercial building communications
- Matter: Smart speaker/smart home

EMERGING AREAS OF INTEREST

- Data centers – Projected to consume 10% of US primary electricity usage by 2030
- Building electrification – Switching to electric HVAC and cooking requires more grid resources and reliability – increasing plug load efficiency can help lighten the load
- Integration of home appliances into load flexibility programs/ MIDAS-based flexible rates
- Home health energy consumption – Aging population; home breathing machines, dialysis, O2/heart monitors, require uninterrupted power supply
- Robotics – Commercial and residential robotic cleaning machines/vacuums, personal assistants, etc.

THANK YOU!

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