Assessing and Reducing Plug and Process Loads in Office Buildings

Introduction

Plug and process loads (PPLs) account for 47% of U.S. commercial building energy consumption (EIA 2020) (see Figure 1). Minimizing these loads is a significant challenge for energy-efficient building design and operation.

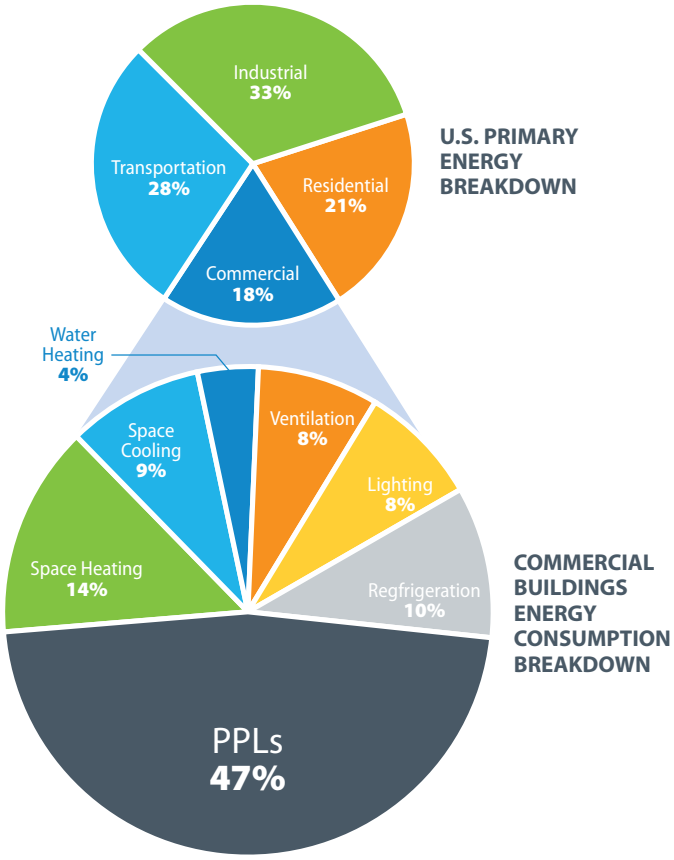

Figure 1. Plug and process loads account for 47% of commercial building energy consumption. *Graph by Kristi Maisha, NREL; Data source: EIA (2020)*

Langner and Trenbath (2019) define PPLs as all plug-in and hardwired loads in a building that are not associated with heating, ventilating, and air conditioning (HVAC), lighting, water heating, or other major equipment needed for basic building operation. This includes all plug-in equipment and appliances, as well as processes for cooking, computing, and internal transportation. The percentage of total building energy use from PPLs is increasing; by 2029 the percentage of PPL energy consumption is anticipated to increase to 51% (EIA 2020). The commercial sector is making strides increasing energy efficiency in other end uses, such as HVAC and lighting, but to continue the trend of reducing whole-building energy consumption, PPLs must be targeted as well.

Using similar processes and strategies as those in this resource, the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) was able to reduce its PPL energy use in the Research Support Facility by 43%, resulting in an annual cost saving of $58,000 (see Figure 2).

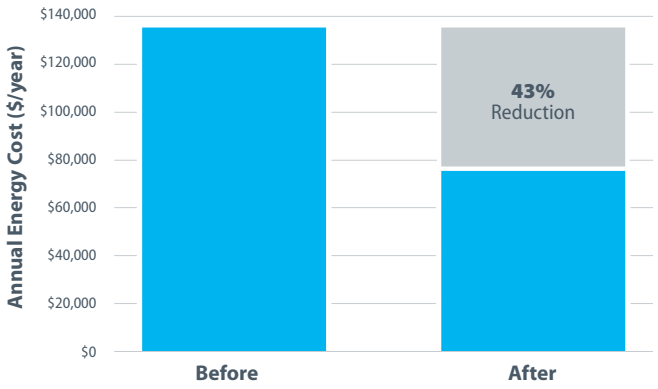

Figure 2. A 43% reduction in PPL energy use saves $58,000 annually. *Graph by Chad Lobato, NREL*

This "quick start guide" will help building owners and energy managers reduce PPL energy use in their facilities. It packages extensive PPL research into an easy-to-use set of instructions and provides quick references to useful tools, websites, and databases. It is also intended to guide the procurement of new equipment that incorporates strategies and technologies to significantly reduce energy consumption.

Steps for Establishing a Plug and Process Load Reduction Strategy

This section describes the actions that building owners and energy managers should take to develop a PPL control strategy.

Step 1: Establish a Plug and Process Load Champion

The first step in addressing PPLs is to establish a PPL champion (or a team of champions) to initiate and help with the process. This person or team needs to understand basic energy efficiency design strategies and be able to apply cost justifications. They must also have the skills to critically evaluate, address, and influence the building's operations, institutional policies, and procurement processes. PPLs are often specified by multiple parties, so equipment and efficiency strategies are rarely handled by one decision maker. The champion will make sure that all decision makers (such as the information technology and audiovisual teams) are on the same page about PPLs and that their decisions save energy and integrate well with other building systems. The PPL champion must be involved in selecting the control strategy, understand it thoroughly, and monitor the dashboard and energy use data.

PPLs are often treated as an end use to which energy efficiency measures cannot be applied. There are, however, huge opportunities in understanding and managing these loads, and the PPL champion plays an integral role in taking advantage of them.

Step 2: Institutionalize Plug and Process Load Measures

The day-to-day energy efficiency of any building depends largely on the decisions of employees, facility managers, and owners, all of whom play key roles in whole-building energy consumption. Therefore, one key step in reducing PPL energy use is to institutionalize PPL measures. The champion must work with decision makers to incorporate energy-saving tactics into building policy, such as purchasing only energy-efficient equipment or requiring the use of low-energy states whenever possible. Particularly, they should work with information technology and audiovisual teams to turn off equipment and time technology updates to allow for device shutoff during nonbusiness hours.

It is also crucial that the champion facilitate regular communication between decision makers from these teams and the building facilities staff to maintain the PPL control strategies. For long-term success, the building must have a plan for building occupant turnover. When there are changes in management and employees, steps must be taken to ensure that all occupants are aware of and trained in best practices for using the control strategy.

Step 3: Benchmark Current Equipment and Operations With a Walkthrough

The building benchmarking process provides an estimate for the current status of PPL energy usage in a building. It can help occupants better understand the needs of the building and identify the changes that can be made. The process should begin with a walkthrough of the building to take inventory of all PPL devices. The goal of the walkthrough is to determine device usage, the schedule that the building and devices follow, and device attributes (e.g., how many devices are in the building, the purpose the devices serve for occupants, and the ages of the devices). You can use the NREL PPL reduction workbook to assist in these tasks. The inventory page of the workbook lists the information to be collected during the walkthrough.

If you desire a more detailed and precise audit, you can use metering devices to establish the baseline energy usage. For this process, you need a plug load power meter that can wirelessly transmit data collected in 30-second to 1-minute intervals, has an internal clock, and can measure loads from 0 to 1,800 W. After installing the meters, collect plug load data for at least 1 week, longer if possible. A similar benchmarking process is described in Gentile-Polese et al. (2014).

Whether you choose to meter at this stage or not, if the building has sections that are similar, you can use a scalable methodology. This involves auditing one of the sections and then using that information to extrapolate the energy usage of similar sections. See Doherty and Trenbath (2019) for more about this process. The goal is to have the information needed to make decisions about which devices should be targeted and which control strategies are most appropriate.

Step 4: Develop a Business Case for Addressing Plug and Process Loads

To achieve buy-in from all parties involved, the champion must develop a business case that justifies measures to reduce PPLs. Based on the building and occupant needs and PPL energy usage, decide on the PPL reduction goals. For example, you may find that

given the number of loads, it would be beneficial to control all plug-in devices and have constant energy-use monitoring. Or you may find that specific devices are consuming significant energy and target only those devices for controls.

After determining the goals, select the relevant control strategies, many of which are listed in this guide. When considering each strategy, check that the information/data transmission needs match the building's cybersecurity requirements (Langner and Christensen 2018). Control strategies will vary in terms of associated costs, energy savings, and payback periods. The initial business case is based on energy cost savings. Use the PPL calculator in the workbook and the PPL Utility Incentives listed under Policies and Incentives (NREL n.d.-a) to help determine potential financial savings.

Beyond energy savings, there are many nonenergy benefits to incorporating PPL controls. Consolidating loads and reducing the active times of several devices, such as copiers, reduces building air pollutants, improving air quality and the health of building occupants. Constant data production exposes the appliances that are nearing failure or performing incorrectly, allowing for timely maintenance and repairs. The data collection also allows for asset management and occupancy monitoring. You can better understand how the building is being used, which locations in the building are used the most, what equipment should or should not be purchased, and how the occupants behave. PPL reduction strategies can improve whole-building functionality and the business case can clearly demonstrate how.

General Plug and Process Load Reduction Strategies

Refer to the Decision Guides for PPL Controls (NREL n.d.-b) to view several strategies for reducing PPL energy usage that do not require infrastructure or system changes and can be implemented along with control strategies to maximize energy savings. Some of these strategies include:

- **Replace inefficient appliances.** Older models can use more energy, so replacing them with their ENERGY STAR®- (ENERGY STAR n.d.) or EPEAT- (EPEAT n.d.) approved equivalent can provide energy savings.
- **Incorporate low power/power off settings.** Many devices have sleep settings or can be manually powered off without affecting the building functionality—computers, for example.
- **Consolidate loads.** Replace redundant loads with one larger load, such as purchasing a large shared printer rather than having individual printers.
- **Time software updates.** Ensure that updates occur at times close to business hours to allow equipment to be shut off during nonbusiness hours.

Plug and Process Load Education and Awareness

A crucial step in reducing PPL energy use is to facilitate employee education and promote employee awareness of efficiency measures and best practices. In order to take full advantage of all the benefits offered by plug load meters and controls, employees must be aware of what PPL reduction strategies have been implemented in the building, including:

- How the system (meters, controls, power strip) will help save energy in the office
- What actions need to be taken to save energy (putting appliances in low power mode, monitoring the dashboard, etc.)
- How to reset or adjust the controls in the event of a malfunction or schedule change.

Case studies have shown that without the education and awareness, there is a high likelihood for employees to unplug or choose to forgo the control system (Metzger et al. 2012; Kandt and Langner 2019). To realize the full potential and savings of PPL meters and controls, this step is necessary and should be reinforced throughout the lifetime of the control system. Figure 3 is an example of a sticker that could be placed on computers and monitors to remind employees to turn off their equipment when it is not being used. Other employee awareness strategies include:

- Training
- Emails
- Competitions among employees
- Signage
- Videos
- Periodic reminders or updates.

Figure 3. Sticker used at NREL to promote awareness.
Illustration by Marjorie Schott, NREL

Control Strategies

Wireless Meter and Control Systems

Figure 4. Plug-in smart outlet. *Photo from WattIQ*

Wireless meter and control systems involve a system of smart outlets that are plugged into existing outlets and measure energy usage. They wirelessly transmit data and can be controlled to turn power on or off. This strategy is effective for automatically controlling devices based on the device schedule and understanding full building and device specific energy usage and behavior.

Advanced Power Strips

Advanced power strips (APS) are separate power strips that can be controlled manually or with sensors to shut off power to specific appliances. There are many APS providers and varieties that come with different capabilities to meet different needs. For example, depending on the APS purchased, there may be wireless transmission and energy monitoring capability (Earle and Sparn 2012). This strategy is most effective for controlling specific devices, rather than the whole building, and allows the linking of multiple appliances under the same control. To determine what control (schedule, load-based, occupancy) is most relevant for each device, see Table 2-2 in Lobato et al. (2012).

Automatic Receptacle Controls

Figure 5. Automatic controlled receptacle. *Photo from Legrand*

Automatic receptacle controls are outlets installed in the building that can be controlled to shut off power to appliances based on schedule or occupancy. This may be done wirelessly, using sensors, or using buttons on the device. This strategy is effective for automatically controlling devices and for meeting the most recent ASHRAE standards (ASHRAE 2019) on PPL controls. To determine what method of control (schedule, occupancy) is most relevant for each device, see Table 2-2 in Lobato et al. (2012).

Integrated Controls

Integrated controls are an emerging area that offers potential for connecting lighting, HVAC, and PPL systems to monitor and control them together. They are not widely available yet but will soon be relevant in the market. This strategy is effective for automatically controlling devices and understanding full-building and device-specific energy usage and behavior. Using various sensors (such as occupancy and photosensors), they can connect multiple systems for centralized control and monitoring and further interoperability. The sensor data is logged and can be analyzed to better understand energy savings and the building operation.

Figure 6. Advanced power strip and its installation. *Photos by Werner Slocum, NREL 46058, 46055*

Control Strategies	*Wireless Meter and Control Systems*	*Advanced Power Strips*	*Automatic Receptacle Controls*	*Integrated Controls*
Description	System of smart outlets that measure energy usage and turn devices on/off	Power strips that can be controlled to shut off power to specific appliances	Outlets that are installed in the building and can be controlled to turn devices on/off	Connects lighting, HVAC, and PPL systems to monitor and control them together
PPL Reduction Goal	Control PPLs using a device schedule and understand the PPL energy usage of the entire building	Control the energy usage of specific devices	Control PPLs using a device schedule or occupancy sensors and meet code requirements	Control PPLs alongside lighting controls and understand the PPL energy usage of the entire building.
Characteristics	• Wireless control • Automated system • Full picture of energy use • Device health monitoring	• Shared control of multiple devices • Focus on specific devices	• Wireless control • Automated system • Required for ASHRAE standard 90.1-2019 (ASHRAE 2019) compliance	• Wireless control • Automated system • Full picture of energy use • Device health monitoring • Connecting multiple systems • Interoperability
Metering	Use smart outlets	Use separate plug-in metering devices	Use separate plug-in metering devices	Use building management system
Load Analysis to Determine Device Attributes	*Determine loads that:* • Are high energy, especially in low-power modes (e.g., audio-visual systems) • Can be turned off or set to low power modes • Are used according to a building/device schedule	*Determine:* • Devices that could be connected • What controls (schedule, load-based, occupancy) are relevant	*Determine loads that:* • Are high energy, especially in low-power modes (e.g., audio-visual systems) • Can be turned off or set to low power modes • Are used according to a building/device schedule or according to occupancy	*Determine loads that:* • Are high energy, especially in low-power modes (e.g., audio-visual systems) • Can be turned off or set to low power modes • Can be connected to lighting/HVAC controls and sensors
Applying Controls	Program the smart outlets according to schedule	See NREL Guidance: How to Use Advanced Power Strips (NREL n.d.-c)	Program the controlled receptacles to be schedule-based or occupancy-based	PPLs are controlled by the building management system and lighting controls
Strategy Maintenance	• Reprogram plug-load management system to accommodate changes • Education and training • Check up on the plug load management dashboard /energy usage and provide feedback	• Check up on APS usage by occupants • Education and training	• Reprogram controlled receptacles system to accommodate changes • Education and training	• Education and training • Check up on the building management system dashboard/ energy usage and provide feedback

New Construction and Major Retrofits

New construction and retrofit projects bring additional PPL reduction opportunities that the design team should address. The champion should work with the design team to question standard specifications, operations, and design standards that limit energy savings opportunities. One major design change is to incorporate PPL controls and monitoring into the building infrastructure. The most recent ASHRAE codes (ASHRAE 2019) require that a percentage of outlets be controlled by automatic control devices. Automatic receptacle controls fulfill this requirement and are most easily incorporated in the design and construction phase when outlets are being installed. Installing separate submeters for PPLs is also beneficial to understand energy usage and realize many of the nonenergy benefits. It is also important to accurately assess required PPL capacity (W/ft^2). Overestimating the PPL capacity, which is frequently done, results in over-sizing electrical infrastructure that increases capital costs and energy usage. In addition, the design team should consider process loads, such as elevators, computing facilities, and cooking facilities, to ensure that they are designed for maximum efficiency. This could involve finding the most energy-efficient models or incorporating waste heat recovery. With the increasing percentage of PPL energy use, these are crucial considerations during design and construction.

Appliance Specific Strategies

Break Rooms and Kitchens

Refrigerators

For refrigerators in break rooms and kitchens, implement the following:

- ☐ Remove underused refrigerators to save $40–$80/year/refrigerator.
- ☐ Replace aging, inefficient refrigerators with the most efficient refrigerators to save $40/year/refrigerator.
- ☐ Consolidate multiple mini-refrigerators into a full-size refrigerator to save $35/year/mini-refrigerator.
- ☐ Replace glass-door refrigerators with similarly sized solid-door refrigerators to save $60/year/glass-door refrigerator.

Small Kitchen Appliances

- ☐ Upgrade items such as coffee pots, toasters, and microwaves with units that have limited parasitic loads from light-emitting diode (LED) lights or displays to save $1/year/item.
- ☐ Control these items with electrical outlet timers so they are powered down during nonbusiness hours to save $3/year/item.

Vending Machines

Vending machines have an approximate energy cost of $350/year/refrigerated machine. Implement the following strategies to reduce vending machine energy consumption:

- ☐ Remove underused machines to save $350/year/machine.
- ☐ Replace aging, inefficient vending machines with the most efficient equipment to save $150/year/machine.
- ☐ Remove the display lighting to save $65/year/machine
- ☐ Implement a load-managing device (Deru et al. 2003) to save $95/year/machine.
- ☐ Set contractual requirements for vendors to use only delamped, energy-efficient vending machines that have a load-managing device preinstalled.

Drinking Fountains

- ☐ Disconnect or remove drinking fountain coolers and bottled water coolers.
- ☐ Replace aging drinking fountains and bottled water coolers with noncooled drinking fountains to save $55/year/cooler.

Workstations

Workstations represent a significant fraction of office building PPLs and overall building energy use. Figure 4 is an example of a low-energy workstation.

Figure 7. Diagram of an example low-energy workstation.
Illustration by Matthew Luckwitz, NREL

Computers

- ☐ Replace standard desktop computers with miniature desktop, laptop, or thin client computers to save as much as $60/year/computer.
- ☐ Disable screensavers and enable computer power management settings to save as much as $50/year/computer with use of the computer management features (ENERGY STAR n.d).

- ☐ Configure computers so users can manually trigger standby or sleep mode via:
  - ☐ The computer power button
  - ☐ The laptop docking station power button
  - ☐ Designated keyboard buttons
  - ☐ A standby icon on the computer desktop
  - ☐ Other external standby triggering devices.

Monitors

- ☐ Replace aging monitors with LED backlit liquid crystal display (LCD) monitors to save as much as $13/year/monitor (Lobato et al. 2011).

Task Lights

- ☐ Replace incandescent or fluorescent-tube task lighting with efficient compact fluorescent lamps (CFLs) or LED task lighting to save $15/year/task light.

Phone

- ☐ Replace standard phones with low-power (2 W maximum) voice over internet protocol phones to save $10/year/phone.

Printers, Copiers, Scanners, and Fax Machines

- ☐ Consolidate multiple personal devices into a single multifunction device to save $8/year/personal device.
- ☐ Enable the power option settings on the multifunction devices to go into standby after 15 minutes of idle time

Vertical Transport

Elevators

Elevator car lighting and ventilation are typically powered whether the car is occupied or not:

- ☐ Control elevator lighting and ventilation with occupancy sensors to save as much as $100/year/elevator.

Stairs

- ☐ Building occupants should be encouraged to use stairs to reduce energy use and improve health.

Escalators

- ☐ Escalators generally operate continuously during business hours, and, in some cases, continuously during nonbusiness hours.
- ☐ Control escalators so that they operate only during business hours or when needed to save as much as $900/year/escalator.

Small-Scale Food Service Areas

As with the break rooms and kitchens, replacing aging, inefficient equipment with the most efficient ENERGY STAR (n.d.) equipment will save energy. Food service areas present unique challenges because they are often outfitted and operated by outside vendors. It is important to work with the vendor to supply energy-efficient PPLs that meet their needs.

Refrigerators

- ☐ Remove underused refrigerators to save $40–$80/year/refrigerator.
- ☐ Replace aging, inefficient refrigerators with the most efficient refrigerators to save $40/year/refrigerator.
- ☐ Consolidate multiple mini-refrigerators into a full-size refrigerator for a savings of $35/year/mini-refrigerator.
- ☐ Replace glass-door refrigerators with similarly sized solid-door refrigerators to save $60/year/glass-door refrigerator.
- ☐ Set contractual requirements for vendors to use only the most energy-efficient commercial refrigerators.

Small Kitchen Appliances

- ☐ Upgrade items such as coffee pots, toasters, and microwaves with units that have limited parasitic loads from status LED lights or displays to save $1/year/item.
- ☐ Control these items with electrical outlet timers so they are powered down during nonbusiness hours to save $3/year/item.
- ☐ Set contractual requirements for vendors to use only the most energy-efficient appliances.

Conference Room Equipment

Conference rooms are subject to varying use schedules. Implement controls that disconnect or turn off equipment when the space is unoccupied. Electrical outlet timers can be used to power down equipment during nonbusiness hours. Occupancy sensors can be used to disconnect power when the rooms are unoccupied during business hours. Outfit the space with energy-efficient equipment. LED backlit LCD televisions and energy-efficient projectors should be used for display purposes.

Server Room Equipment

- ☐ Implement an uninterruptible power supply that has the following features:
  - ☐ At least 95% energy efficiency
  - ☐ Scalable design
  - ☐ Built-in redundancy

- ☐ End-user serviceable
- ☐ Sufficient uptime until the backup generator starts
- ☐ Compliance with the efficiency guidelines of the Server System Infrastructure initiative, which sets open industry specifications for server power supplies and electronic bays.

☐ Load the uninterruptible power supply so it operates at peak efficiency.

☐ Use energy-efficient power distribution units.

☐ Use blade servers with variable-speed fans and energy-efficient power supplies.

☐ Implement virtualization software.

☐ Implement a hot aisle/cold aisle configuration.

☐ Implement hot aisle containment.

☐ Depending on climate zone, implement economizers and evaporative cooling.

☐ Capture waste heat from the servers for use in other areas of the building.

☐ Sheppy et al. (2011) provide more details about energy reduction strategies in server rooms and data centers.

Using the Workbook

Shown below is a sample of the workbook available for download in full as an Excel file. It will help you identify potential energy savings by reducing plug loads.

For each strategy listed, answer the question "Is your building doing this?" If your response is "No" for any strategy, fill out the adjacent cells to the right to determine the total approximate savings that the given strategy could yield in your building. Strategies that are listed without savings numbers are highly variable depending on the office building being assessed.

	Is your building doing this?			If you answered "NO," enter the quantity for each piece of equipment below to determine the approximate savings in your building.		
Strategies	**YES**	**NO**	**N/A**	**Potential Energy Savings per Piece of Equipment**	**Quantity in Your Building**	**Potential Annual Savings for Your Building (kWh)**
▶ **Break Rooms and Kitchens**						
Remove underused refrigerators	☐	☐	☐	**400 kWh/year** for every underused refrigerator that is removed	x ___ =	
Replace aging, inefficient refrigerators with one of the most efficient, full-size ENERGY STAR® refrigerators for every 60 people	☐	☐	☐	**400 kWh/year** for every inefficient refrigerator that is replaced	x ___ =	
Consolidate personal mini-refrigerators into a full-size shared refrigerator	☐	☐	☐	**350 kWh/year** for every mini-refrigerator that is removed	x ___ =	
Replace glass-door refrigerators with similarly sized solid-door refrigerators	☐	☐	☐	**600 kWh/year** for every glass-door refrigerator that is replaced	x ___ =	

NOTE: Potential energy savings are based on an assumption of 10 hours of operation per work day

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