Selecting a Control Strategy for Plug and Process Loads

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Technical Report
NREL/TP-5500-51708
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Executive Summary

Background

Plug and process loads (PPLs) are building electrical loads that are not related to lighting, heating, ventilation, cooling, and water heating, and typically do not provide comfort to the occupants. PPLs in commercial buildings account for almost 33% of U.S. commercial building electricity use (McKenney et al. 2010). At the building level, they account for approximately 25% of the total electrical load in a minimally code-compliant commercial building, and can exceed 50% in an ultra-high efficiency building (Lobato et al. 2011). Minimizing PPLs is a critical part of the design and operation of an energy-efficient building.

A complex array of technologies that meter and control PPLs has emerged in the marketplace. NREL has developed guidance for evaluating and selecting a range of technologies. Control strategies that match PPL energy use to user work schedules can save considerable energy in most commercial buildings. PPL control strategies are also effective in reducing peak demand.

Results

We evaluated PPLs and related control strategies to ensure that the RSF would meet its energy goals. These results were distilled into a flowchart so others could achieve similar savings based on our experiences (see Section 2.2.2). The flowchart asks a series of questions about a PPL's use and specifies a control strategy. It highlights situations where the PPL could be operated more efficiently, and points out key areas where manufacturers could make their equipment more energy efficient.

Uncontrolled workstations in an office building formed a baseline to highlight the savings potential—the importance of encouraging "good" behavior and turning off PPLs when they are not being used. Ideally, all PPL control strategies would counteract "bad users," but not all are "user proof." Educational programs that encourage "good" user behavior should be implemented along with these strategies wherever possible.

How To Use This Document To Choose a Cost-Effective Control Device

Figure ES–1 shows a step-by-step process for cost-effectively addressing and controlling PPLs.

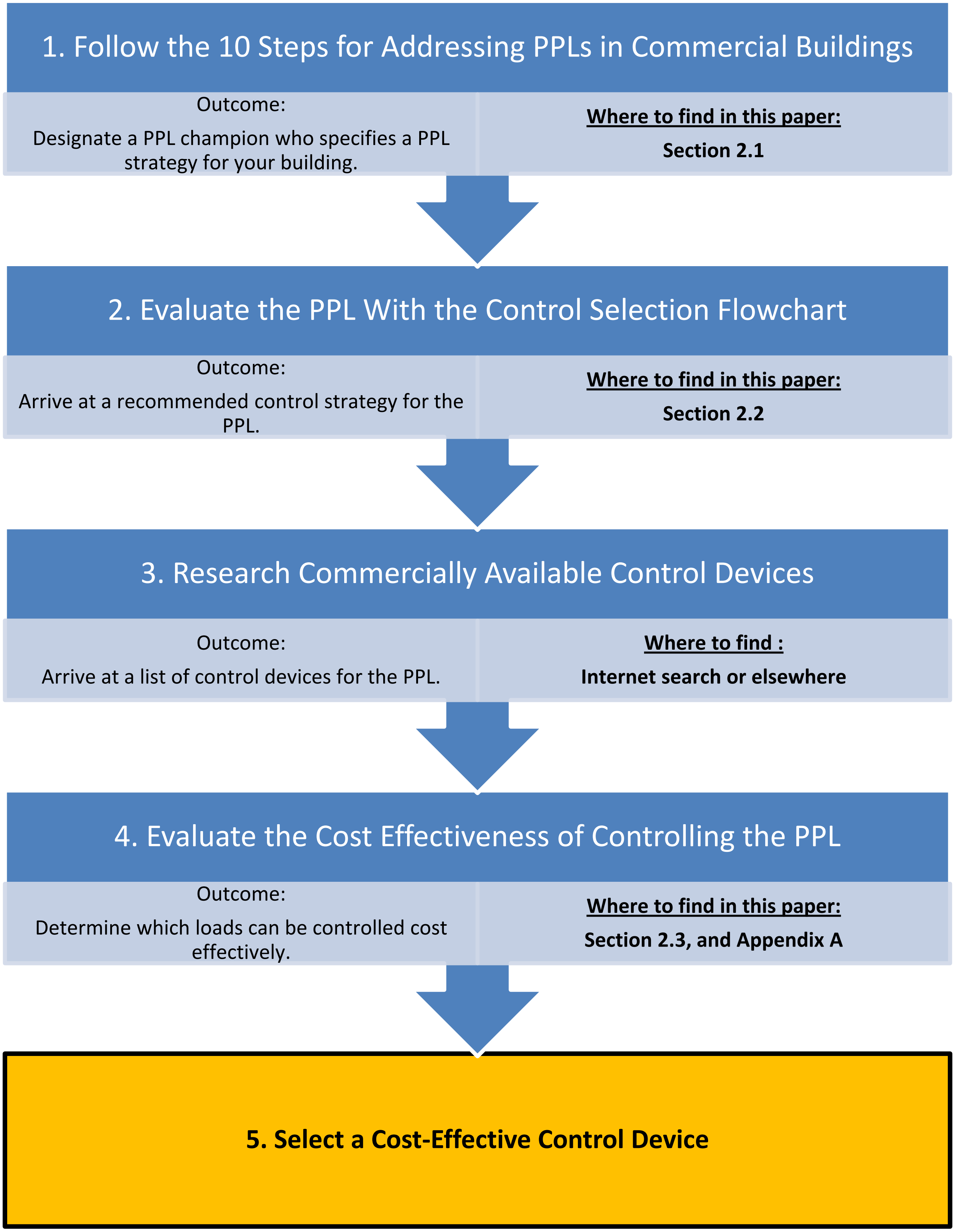

Figure ES–1 Steps to effectively control PPLs
(Credit: Michael Sheppy/NREL)

Nomenclature

BMS	building management system
CT	current transducer
DOE	U.S. Department of Energy
EUI	energy use intensity
ft^2	square feet
Hz	hertz
in	inch
IS	Information Services Office
kBtu	1000 British thermal units
kW	kilowatt
kWh	kilowatt-hours
LCD	liquid crystal display
LED	light emitting diode
NREL	National Renewable Energy Laboratory
PPL	plug and process load
PV	photovoltaics
RSF	Research Support Facility
UPS	uninterruptible power supply
USB	universal serial bus
V	Volt
W	Watt

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1.0 Introduction

Plug and process loads (PPLs) in commercial buildings account for almost 5% of U.S. primary energy consumption (McKenney et al. 2010). They account for 25%–30% of the total electrical load in a minimally code-compliant commercial building, and can exceed 50% in an ultra-high efficiency building such as the National Renewable Energy Laboratory's (NREL) new office building, the Research Support Facility (RSF) (Lobato et al. 2011).

Total building energy use from PPLs is increasing. By 2030, commercial building energy consumption is expected to increase by 36%; PPL energy consumption is anticipated to increase by 78% in the same time frame (DOE 2009). The disproportionate growth of PPL energy consumption compared to whole-building energy consumption is due to a combination of several trends:

- Lighting, mechanical systems, and other end uses are becoming more efficient.
- PPLs are becoming increasingly important for business activities.
- PPL installed equipment densities are increasing.
- PPL prices tend to decrease over time, which means they are available to more users (McKenney et al. 2010).

These trends illustrate the importance of PPL energy reduction to reduce whole-building energy consumption.

Traditionally, the design community has not viewed PPLs as an integral building system, but as a necessary evil. Designers have simply worked around the issue. Reducing and controlling these loads is a primary challenge in the design and operation of an energy-efficient building.

At the beginning of the RSF project, the goal was to use less than half the energy of a conventional office building. The owner and the design team required a 50% PPL reduction (Lobato et al. 2011). The NREL RSF energy targets are shown in Figure 1-1.

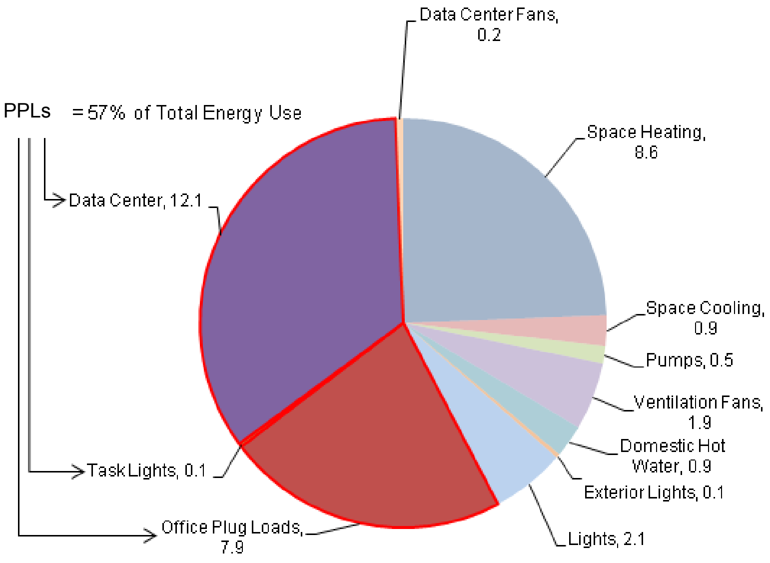


Figure 1-1 **RSF annual energy use breakdown targets (kBtu/ft^2)**
(Credit: Chad Lobato/NREL)

Many methods were available to reduce PPL energy use in the RSF:

- Reduce the number of PPLs.
- Specify energy-efficient PPLs.
- Turn off PPLs when not in use:
    - Through technology (e.g., PPL control power strips)
    - Through behavior changes (e.g., user engagement and involvement).

This report addresses all these methods so you can select cost-effective PPL control devices.

An array of technologies that meter and control PPLs has emerged in the marketplace. NREL has developed guidance for evaluating and selecting PPL control technologies, and is using this report to evaluate the range of technologies that turn off PPLs when not in use.

Many uncontrolled PPLs have significant parasitic loads, which are generally defined as power draw in an “off” state. We define a parasitic load more broadly as the power draw of a PPL, in any state, that is not performing useful work. All parasitic loads waste energy and should be transitioned to the lowest power state possible.

PPLs are driven primarily by user behavior. Occupants in office buildings are typically seated at their desks for less than one third of the average workday (U.S. General Services Administration 2006). And more than two thirds of the year consists of nonbusiness hours when users are not in the workplace, which means that some office PPLs are used only about 10% of the year. Control strategies that match PPL energy use to user work schedules will save considerable energy.

PPLs span a wide range of equipment types, provide multiple functions and services, and are variously operated. The same PPL type may have completely different use patterns in different locations, so control strategies must be individually tailored. Currently, no single commercially available control device can control all PPLs properly. Manufacturers market their control devices as the solution to PPL energy use, but do not specify where they apply. Building owners and occupants may believe these devices control all loads effectively, but they are uninformed about which strategy should be used for which PPL. Some PPLs can be effectively controlled with inexpensive scheduling devices such as electrical outlet timers; others require much more complicated solutions.

An in-depth analysis of the equipment and process is needed to arrive at the correct control strategy for a given PPL. The required PPLs can then be specified and the corresponding control strategy determined and implemented. This report discusses lessons learned and describes the process you should follow to achieve cost-effective PPL energy savings.

2.0 Guide To Addressing and Controlling Plug and Process Loads

The following subsections describe the complete process for achieving PPL energy savings. It can be applied to new construction, retrofits, and day-to-day operations.

2.1 Addressing Plug and Process Loads

To achieve the maximum PPL energy savings in your building, you must undertake an aggressive PPL benchmarking, specification, and procurement process. This will reveal your current PPLs and their uses, help you outfit your building with energy-efficient equipment, and ensure its efficient operation.

2.1.1 Establish a Plug and Process Load Champion

A PPL champion (or a team of champions) will initiate and help with these strategies. This person needs to understand basic energy efficiency opportunities and design strategies and be able to independently and objectively apply cost justifications. He or she must be willing and able to critically evaluate, address, and influence the building's operations, institutional policies, and procurement processes.

Often, PPLs are not viewed as an integral building system, but as a necessary evil. PPLs are often specified by many parties, so equipment and efficiency strategies are rarely handled by one decision maker. The champion will make sure that all decision makers are on the same page and that their decisions save energy and integrate well with other building systems.

2.1.2 Benchmark Current Equipment and Operations

A building walkthrough to identify and inventory PPLs will establish a baseline of current equipment and operations.

If your building is representative of multiple buildings in your portfolio, this process is required for only one building. You can then implement the applicable strategies portfolio wide.

2.1.2.1 Perform a Walkthrough

A walkthrough helps the champion understand the PPLs. He or she will assess all PPLs, noting the various types of equipment and the quantity of each type. The champion needs to identify PPLs that are common throughout the building, and those that are present in limited quantities. At this stage, the champion will also engage PPL users to learn how and why each device is used, and if the device is critical to health, safety, or business operations.

For a detailed example of how a PPL walkthrough is conducted, refer to Frank et al. (2010).

2.1.2.2 Develop a Metering Plan

The champion will then develop a metering plan. Common items require only a representative sample to be metered. For example, if every occupant uses the same type of computer monitor, only a small sample needs to be metered. The PPLs that are present in limited quantities, that have unknown use patterns, or that are otherwise unique should all be metered if possible. Commercially available PPL power meters can be used for this metering. Once the data from the walkthrough are collected and analyzed, they can be used to understand: when equipment is operated, highlight opportunities to turn off equipment, and replace energy wasting equipment with more efficient options.

2.1.2.3 Select a Power Meter

A meter that can measure and log electrical power (W) data at a sampling interval of 30 seconds or faster for a week or more is desirable. This should provide sufficient data to see a representative sample of a PPL's power draw in all power states. A meter that cannot log the measured data and that provides only instantaneous power measurements and total energy consumption will still offer valuable information, but the power draw profile will be limited to the number of measurements that are taken manually.

The meter should be designed for the type of circuit to be metered (typically 120 V, 15 amp, 60 Hz in the United States). Also, PPLs are numerous and varied, so the meter should be able to accurately meter loads of 0–1800 W (or greater for some larger PPLs). Other desirable features include an external display, an internal clock that time stamps each data point, an Underwriters Laboratories listing, and a way to transmit data to a local or remote repository. A more detailed meter specification list was developed by Frank et al. (2010).

2.1.2.4 Meter the Plug and Process Loads

The steps to execute the metering plan for a given PPL are:

1. Assure the users that the purpose of the metering effort is to gather data about the building's energy performance, and not to monitor their personal or business activities.
2. Determine whether the PPL can be de-energized to install the meter.
    a. Some PPLs cannot be de-energized because they:
        i. Pose health and safety concerns.
        ii. Interrupt business operations.
        iii. Reduce sales.
        iv. Affect shutdown procedures.
        v. Have complex reconfiguration requirements on startup.
    b. If the PPL cannot be de-energized, clamp-on meters can be used as long as each wire (phase) has already been safely isolated while in a de-energized state.
3. If a business function will be interrupted by installing the meter, consider waiting until nonbusiness hours to do so.
4. If applicable, install any necessary computer software so the meter can be configured and the measured data can later be downloaded and analyzed.
5. Set up the meter to measure electrical power at a sampling interval of 30 seconds.
6. Power down and unplug the device to be metered.
7. Plug the device into the meter. Plug the meter into an outlet.
8. If necessary, clear the memory on the meter and go through any other initial setup, such as setting the date and time.
9. Power on the device.

10. Meter the device all day, every day for at least one entire work week. Time and budget permitting, meter for longer periods to estimate annual energy use more accurately and to capture seasonal use patterns.
11. Download the metered data for analysis. Calculate at least the average load during business and nonbusiness hours.

2.1.2.5 Alternatives to Metering

If metering not possible, perhaps because metering is not an economical option, then Chapter 18 of the 2009 ASHRAE Fundamentals Handbook titled "Nonresidential Cooling and Heating Load Calculations" can be used to estimate some loads. The champion can also use the ENERGY STAR® database which provides estimates of annual energy use for common PPLs.

2.1.3 Develop a Business Case for Addressing Plug and Process Loads

To gain buy-in from all parties involved, the champion must develop a business case that justifies measures to reduce PPLs.

In most projects, the initial business case is based on energy cost savings. Energy savings alone may not be sufficient to justify the most efficient PPL reduction strategy, so nonenergy benefits should be highlighted. For example, it is often difficult to justify purchasing best-in-class laptop computers with energy cost savings alone. Laptops can be justified, however, because they enable work from home and travel mobility. If mobility is not necessary, mini-desktops are available that have the efficiency of laptops without their added costs and security concerns.

Another example is centralized multifunction devices, which can reduce maintenance costs and unique toner support over individual printers, copiers, and fax machines. Minimizing, centralizing, and standardizing document services greatly simplifies the implementation of robust standby power configurations and significantly lower service costs. Moreover, volatile organic compounds from the printer toners can be isolated to a few copy rooms with dedicated exhaust to improve indoor air quality. Depending on the building layout and function, as many as 300 printers can be replaced with as few as 20 widely distributed multifunction devices.

For projects such as the RSF with net-zero energy goals, one powerful strategy is the avoided cost of renewables metric. This equates the cost of PPL efficiency measures to avoided renewable costs. We used this metric to justify many demand-side efficiency measures, including PPL procurement and control decisions. The project's economics were such that the annual energy use of a continuous 1-W load required $33 worth of photovoltaics (PV) to meet the demand. The PV cost avoided by PPL reductions exceeded $4 million.

2.1.4 Identify Occupants' True Needs

Identify occupant and institutional true equipment needs—those that are required to achieve a given business function; perceived needs are often based on past experience without consideration for more efficient strategies.

To reduce PPLs, the champion must understand what the occupants produce as part of their jobs and what tools they require. He or she must be diplomatic enough to help them do their jobs energy efficiently without making them feel that the purposes of their jobs are being questioned. This can be challenging, because every occupant, including those working in sensitive operations (e.g., security, information technology, upper management), should be accounted for. Determining occupant needs will reveal any nonessential equipment. A business case should be made for its continued use; otherwise, it should be removed. Exceptions can be made, especially for equipment that preserves health and safety.

Certain PPLs may not be true needs, but are highly desirable. For these, the champion will need to work to meet the needs with a shared, centralized piece of equipment and reduce or eliminate personal devices. For example, a shared, centralized coffee maker can meet occupant demand and eliminate numerous personal coffee makers.

2.1.5 Meet Needs Efficiently

Once the champion determines the true needs, each must be met as efficiently as possible. Specifying ENERGY STAR® and EPEAT® equipment (or better) is a good start, but alone will not maximize cost-effective energy savings. The champion should review these databases thoroughly and specify the most efficient equipment. He or she should research nonrated equipment to find the most efficient model. The champion will need to work with equipment manufacturers and suppliers to determine the available options. Once a model is selected, it should be turned off when not in use, if possible.

2.1.6 Turn It All Off

Office buildings are unoccupied for 66%–75% of the hours in a year. A key step in any PPL reduction program is to reduce energy use during unoccupied hours, as this is generally wasted. Details are provided in Sections 2.2 and 2.3.

Table 2–1 Annual PPL EUIs in kBtu/ft^2·yr Based on Day and Night Power Densities

		Nighttime Power Density (W/ft^2)											
		0.10	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**	**1.10**	**1.20**
Daytime Power Density (W/ft^2)	**0.10**	3.0	5.2	7.4	9.7	11.9	14.1	16.3	18.6	20.8	23.0	25.2	27.4
	0.20	3.8	6.0	8.2	10.4	12.7	14.9	17.1	19.3	21.5	23.8	26.0	28.2
	0.30	4.5	6.8	9.0	11.2	13.4	15.6	17.9	20.1	22.3	24.5	26.8	29.0
	0.40	5.3	7.5	9.7	12.0	14.2	16.4	18.6	20.9	23.1	25.3	27.5	29.7
	0.50	6.1	8.3	10.5	12.7	15.0	17.2	19.4	21.6	23.8	26.1	28.3	30.5
	0.60	6.8	9.1	11.3	13.5	15.7	17.9	20.2	22.4	24.6	26.8	29.1	31.3
	0.70	7.6	9.8	12.0	14.3	16.5	18.7	20.9	23.2	25.4	27.6	29.8	32.1
	0.80	8.4	10.6	12.8	15.0	17.3	19.5	21.7	23.9	26.2	28.4	30.6	32.8
	0.90	9.1	11.4	13.6	15.8	18.0	20.3	22.5	24.7	26.9	29.1	31.4	33.6
	1.00	9.9	12.1	14.4	16.6	18.8	21.0	23.2	25.5	27.7	29.9	32.1	34.4
	1.10	10.7	12.9	15.1	17.3	19.6	21.8	24.0	26.2	28.5	30.7	32.9	35.1
	1.20	11.4	13.7	15.9	18.1	20.3	22.6	24.8	27.0	29.2	31.4	33.7	35.9

Table 2–1 shows the annual plug load energy use intensity (EUI) for a given average daytime and nighttime power density. (The table was developed assuming 9 occupied hours per work day and 250 work days per year.) Minimizing nighttime PPLs significantly reduces the annual

EUI. The area outlined in red shows the targeted PPLs densities and EUIs for the RSF, excluding the data center. Daytime PPLs were modeled to be about 0.50 W/ft^2; nighttime PPLs at about 0.19 W/ft^2.

2.1.7 Institutionalize Plug and Process Load Measures

The day-to-day energy efficiency of any building depends largely on the decisions of occupants, facility managers, and owners. You can therefore reduce PPL energy use significantly by institutionalizing PPL measures through procurement decisions and policy programs. The champion must identify decision makers who can institutionalize such programs.

2.1.8 Address Unique Plug and Process Loads

Outside contractors or vendors specify some equipment, but the building owner covers their energy costs. For such situations, you should contractually require or provide the most efficient equipment available.

Items such as energy-efficient gym equipment and automated teller machines may not be available and may be restricted from being turned off. The champion must address these individually with manufacturers to identify solutions.

2.1.9 Promote Occupant Awareness

A crucial step in PPL control is to promote occupant awareness of efficiency measures and best practices. Occupant awareness can come in such forms as:

- Training
- Informational letters
- Emails
- Signage
- Videos
- Periodic reminders or updates.

The occupants should be encouraged and allowed to “do good”; however, PPL control strategies should be designed to counteract “bad users” by turning off equipment that is not in use. Users should also be educated about the energy ramifications of leaving personal electronics running when they leave their workspaces.

2.1.10 Address Plug and Process Loads (Design Team)

New construction and retrofit projects present additional PPL reduction opportunities that the design team should address. The champion should work with the design team to question specifications, operations, and design standards that limit these opportunities. The design team plays a key role in reducing PPLs by maximizing space efficiency, which increases the number of occupants who use an area or a piece of equipment. This decreases areas of dense PPLs, such as break rooms, common print areas, and cafeterias, because the equipment in these areas is used more efficiently.

Early in the design phase, the design team can reduce energy use by integrating PPL control strategies into the electrical system to control the outlets at workstations and in common areas. This can be as simple as installing switches, vacancy sensors, or timed disconnects for outlets, or as sophisticated as controlling outlets through the building management system (BMS).

The design team is typically responsible for specifying equipment such as elevators and transformers. The team should first design the stairs to be inviting and convenient, then scrutinize elevators to find the most efficient model. Some important features are reduced speed, occupancy-controlled lighting and ventilation, and smart scheduling. Some projects may require the design team to specify appliances such as refrigerators, dishwashers, and drinking fountains. To achieve greater energy savings, the team must specify the most efficient models.

The design team is also responsible for process cooling systems in areas with concentrated PPLs (such as server rooms and information technology closets). These systems should use, where applicable, economizers, evaporative cooling, and waste heat recovery. In server rooms, energy use can be further reduced through hot and cold aisle containment. This allows cold air supply temperatures to be higher than usual and reduces the process cooling load.

2.2 Controlling Plug and Process Loads

2.2.1 Available Control Strategies for Plug and Process Loads

PPL control comes in two basic forms. The device is either transitioned to a low-power state, or it is de-energized to eliminate the power draw. Both can be executed either manually or automatically. *Low-power state* is between a de-energized state and a ready-to-use state. This includes standby, sleep, and hibernate modes, as well as any off state that has a parasitic power draw. *De-energize* is when electricity is not being provided to the device. This is analogous to physically unplugging a device's power cord from a standard electrical outlet.

All control strategies should provide manual override to accommodate atypical PPLs uses (e.g., using a PPL outside normal business hours). The design team must evaluate each control strategy relative to a PPL, examine its parasitic load versus the PPL's parasitic load, and determine its costs versus the energy cost savings.

The following sections discuss methods to achieve a low-power or de-energized state.

2.2.1.1 Built-in Automatic Low-Power State

The first, and in some cases, most effective, control method is a built-in automatic low-power state functionality such as standby or sleep. Some manufacturers include this functionality to reduce energy consumption of idle devices. Internal processes monitor idle time, and when the device has been in an idle state for a given period it will power down to a low-power state.

Built-in automatic low-power state functionality can be a cost-effective control strategy, because it is integral to the PPL and does not require additional control devices. It may, however, have several issues:

- Users can configure computers and other items and deactivate the automatic low-power state functionality.
- The power draw in a low-power state may be only slightly lower than in the ready-to-use state. In this case, the functionality is working as intended, but the power drop is less than desired or needed.
- A device may need to be activated or accessed remotely, which may not be possible in a low-power state.
- The time to transition from a low-power state to a ready-to-use state may be too long.

2.2.1.2 Scheduling Control Device

Certain PPLs have predictable load profiles. These devices are used during the same times each day or at regular intervals. A scheduling control device can effectively manage a predictable PPL. It applies user-programmed schedules to de-energize the PPL to match its use pattern and energize the PPL to account for the time it takes for it to become usable.

A scheduling control device can take multiple forms:

- Basic electrical outlet timers that control a single outlet, or power strips with integrated outlet timers to control multiple outlets, provide local scheduling control. Users program the schedules. Some PPLs have built-in auto-scheduling that can be used instead of an external scheduling control device. This functionality allows a device to transition from a low-power state to a ready-to-use state on a set schedule.
- Scheduling can be controlled with devices in a centralized location. These are typically wireless, plug-and-play devices that control one or more outlets and communicate with a centralized controller that energizes and de-energizes the outlets based on user-programmed schedules. One option for implementing centralized scheduling control is through the BMS, which could be programmed to implement schedules to energize and de-energize outlets. Depending on the building's electrical system and control level, schedules could be established for each outlet, or groups of outlets with similar use patterns could be grouped and controlled by a common schedule.

Scheduling devices are generally straightforward, consistent, and reliable. They target the energy that is wasted during nonbusiness hours, but do not necessarily provide the greatest energy savings. For instance, a PPL may not be needed during all business hours. All scheduling controls should allow for manual override for the times when energy is needed outside the preset schedules.

2.2.1.3 Load-Sensing Control Device

PPLs may have a primary-secondary relationship. A primary device, such as a computer, operates independently of other (secondary) devices. A secondary device, such as a monitor or other peripheral, depends on the operation of other (primary) devices. A load-sensing control device should be implemented for such a relationship. It automatically energizes and de-energizes secondary devices based on the power load of the primary device(s). The sensed (primary) load is typically an electrical outlet or an auxiliary port (e.g., universal serial bus [USB] in the case of a computer).

Load-sensing control may save more energy than scheduling control because it can reduce energy use during business and nonbusiness hours; however, it depends on "good" operation of the primary (sensed) device. "Good" operation is where users manually control the primary PPL by forcing a low-power state when the device is not in use (e.g. a user puts their laptop into standby when away from their desk). Alternatively, built-in automatic low-power state functionality in the primary device must be working effectively put devices into a low-power state. Otherwise, load-sensing control method does not save energy.

A load-sensing device can take several forms:

- Power strips that sense the load of a primary device and control several secondary devices locally.

- Central controls. These are typically wireless, plug-and-play devices that control a single or multiple outlets. They communicate with a centralized controller that energizes and de-energizes the outlets based on user-programmed load thresholds. Primary and secondary devices can be in different parts of a building. Also, the controller can be programmed such that when the primary device transitions between states, the secondary device(s) can be either energized or de-energized. Again, like the scheduling control, the central control can be provided by a dedicated PPL control system or integrated into the BMS.

2.2.1.4 Occupancy Control Device

In theory, occupancy control can save a great deal of energy. It energizes PPLs only when users are present and de-energizes them when the space is vacant. This approach pinpoints the main source of wasted energy during nonbusiness hours and reduces wasted energy during business hours.

Some of its drawbacks are:

- It may energize and de-energize outlets at inappropriate times.
- It must focus on the immediate zone surrounding the PPL to be controlled, but not extend into other areas. The PPL should be energized only when a user is nearby.
- Its significant parasitic load may reduce the net energy saved by de-energizing PPLs.

2.2.1.5 Manual On, Vacancy Off Control Device

A manual on, vacancy off control device (which is currently not available) is a slight modification of the occupancy control device. It energizes a PPL when it receives manual input from a user, and de-energizes the PPL automatically based on lack of occupancy. This control should be implemented for PPLs that are needed only when users are present.

This approach also has an even higher potential for energy savings than a typical occupancy control device. The PPL will stay in a de-energized state until a user manually energizes the device, thus eliminating the wasted energy associated with false positives. This strategy is commonly implemented in lighting controls because it effectively reduces wasted energy.

2.2.1.6 Manual Control

Most PPLs can be manually powered down with built-in power buttons, shutdown procedures, or a control device that energizes and de-energizes electrical outlets based only on manual input. Depending on the equipment, a built-in switch may provide a quick and easy manual method of powering the device down or up. Other devices may have a shutdown procedure that users must perform to shut down the device. For some devices, manual control is the best or only method.

The effectiveness of manual control depends entirely on user behavior, and should be implemented only if no other methods apply. PPLs could remain powered up at all times if users do not actively use manual control. When manual control is the only option, all users must be made aware that they are responsible for the operation and energy use of the equipment. They need to be educated about proper use and how their behavior can save or waste energy.

2.2.2 Selecting a Control Strategy for Plug and Process Loads

We developed a flowchart to guide building owners, occupants, operators, and designers through an effective control strategy for a given PPL and its operation. A poster version of the full chart is available for download at http://www.nrel.gov/buildings/pdfs/ppls_controls_flowchart.pdf.

To save the most energy possible, you should specify and procure every PPL according to the steps outlined in Section 2.1, then use the flowchart. See Figures **Figure A-1** through **Figure A-4** in Appendix A for a four page version of the flowchart.

The flowchart guides you through a series of questions that help you determine the functionality and use of a specific PPL. It provides guidance for an effective control strategy and insights into the weaknesses of the PPL if a control is not available. It indicates when the equipment or process should be changed in favor of a more efficient approach. If a control is not available, you can ask manufacturers to determine whether other equipment options better meet your needs, or if the products can be improved.

Once you determine the PPL, the chart recommends user education and awareness (see Section 2.1.9), which are key to PPL control. Users tend to leave equipment powered on for convenience. Educated users know how to balance convenience and energy savings.

In the flowchart, the first PPL feature that is examined is built-in, automatic low-power functionality. The path to a control strategy will depend on whether the PPL has a low-power state, such as standby, sleep, or hibernate. When a low-power state is available, the chart asks a series of questions to determine how the PPL is used. It determines whether the device is primary or secondary, whether it needs to be accessed remotely, and whether the startup or warm-up time from a low-power state is a concern. It then evaluates the effectiveness of the low-power state and whether options are available to improve it. After navigating through the low-power state branch, you will see one of three options:

- A control strategy is recommended.
- No control is available.
- The PPL can be changed and the evaluation restarts at the beginning with the new equipment.

When the PPL does not feature a low-power state, the flowchart questions whether it can be de-energized and reenergized without issue. Many PPLs, such as light bulbs, can be de-energized and reenergized, and still reach a ready-to-use state instantaneously or with a brief delay. Others require shutdown or startup procedures. Based on the answer, the chart asks questions to evaluate the PPL and to determine a control strategy. Then it shows one of three outcomes:

- A recommended control strategy
- No control available
- Change the equipment and start over.

In general, the chart is organized so each progression to the right moves the PPL toward an appropriate control strategy. When the questions move downward, the PPL is moving toward no control or a recommendation to replace. In the case of no control, you may want to ask the manufacturers to improve their products.

All PPLs must be well understood to be effectively controlled. Some do not have built-in control and can be managed by external control solutions. Still others may not be controllable because of their configurations, locations, and use patterns.

A PPL's use pattern also has to be known. Some have predictable and consistent use patterns; others do not. Some need to operate only while users are nearby; others may be operated while users are offsite. Some may be activated or accessed remotely; others only locally. There can be startup delays or configuration requirements if PPLs are controlled. PPLs vary greatly in their use patterns, so no single control strategy will effectively manage all devices. Each type of device requires a tailored control strategy to save the most energy.

2.2.2.1 Walkthrough of Control Strategy Flowchart for a Computer

This example illustrates the process to determine the recommended control strategy for a computer. Follow the steps outlined in Section 2.1 to determine that this computer will meet the user's needs. Then use the flowchart to determine a suitable control strategy. The first step is to educate the computer user about reducing energy use.

Figure 2-1 shows the first question and answer. In this example, the computer can transition to a standby state.

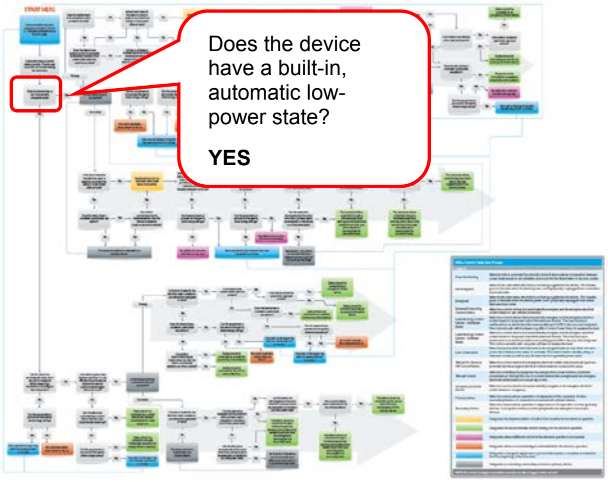


Figure 2-1 Flowchart control strategy for a computer example: question 1
(Credit: Joelynn Schroeder/NREL)

Figure 2-2 shows the second question and answer. The computer is a primary device because it operates independently of other equipment.

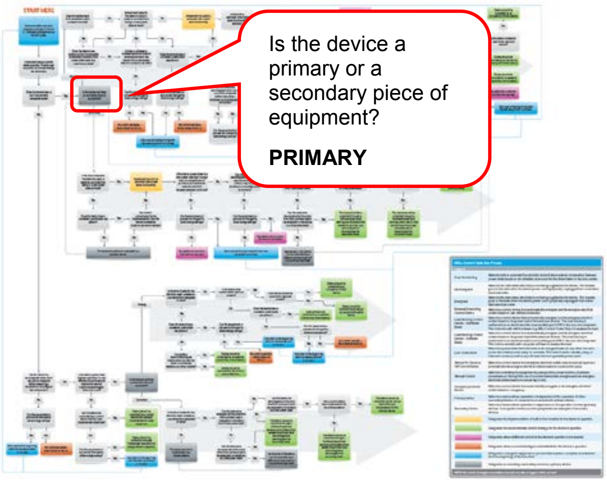


Figure 2-2 Flowchart control strategy for a computer example: question 2
(Credit: Joelynn Schroeder/NREL)

Figure 2-3 shows the third question and answer. This computer does not need to be accessed remotely, so the process continues toward a recommended control strategy.

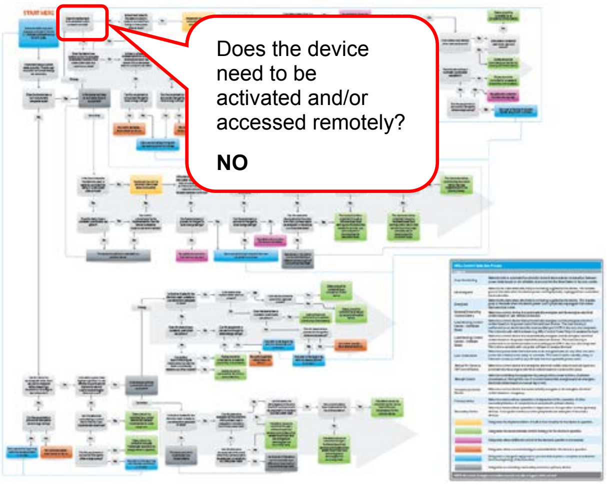


Figure 2-3 Flowchart control strategy for a computer example: question 3
(Credit: Joelynn Schroeder/NREL)

You must now determine whether the time it takes for the computer to come out of standby is an issue (see Figure 2-4). This computer transitions from standby to a ready-to-use state in very little time, so you can proceed.

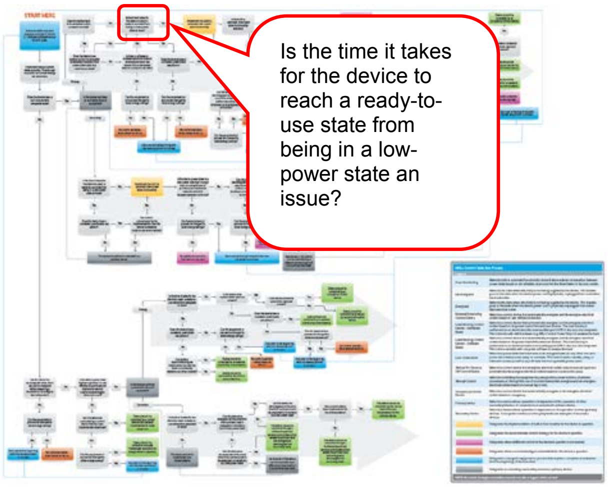


Figure 2-4 **Flowchart control strategy for a computer example: question 4**
(Credit: Joelynn Schroeder`/NREL)

The chart now recommends that the low-power state (standby in this case) be implemented as the first form of control (Figure 2-5).

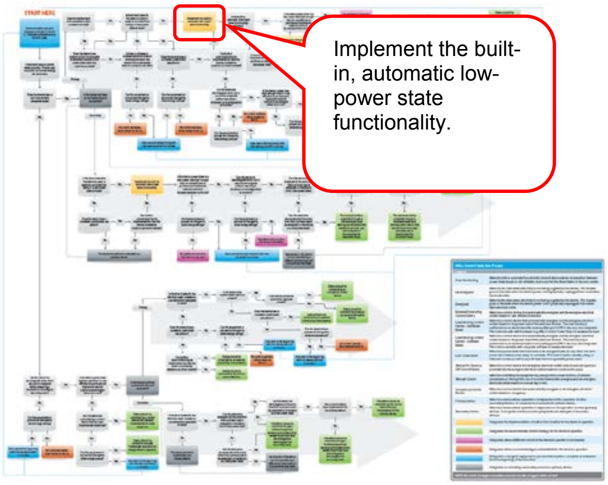


Figure 2-5 **Flowchart control strategy for a computer example: low-power state implemented**
(Credit: Joelynn Schroeder/NREL)

You must now analyze the effectiveness of the built-in standby function (see Figure 2-6). When the computer is in standby, is the power draw reduced significantly compared to its ready-to-use state? For this example, the computer goes into standby consistently and reliably; once in standby, its power use drops significantly.

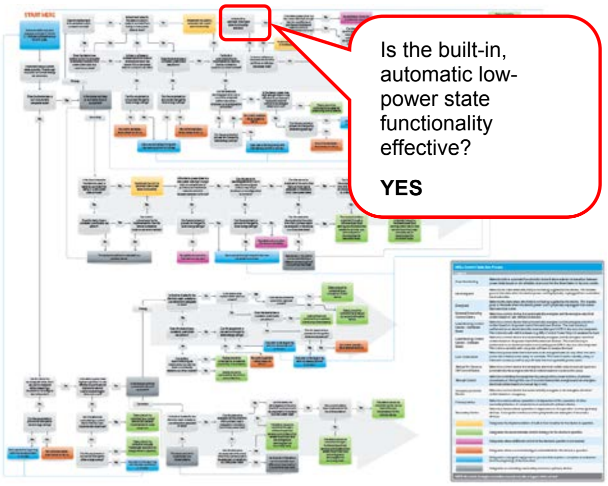


Figure 2-6 **Flowchart control strategy for a computer example: question 5**
(Credit: Joelynn Schroeder/NREL)

You must perform additional analysis at this point (Figure 2-7). The computer's parasitic load is greater than that associated with an external control strategy, and the building's energy goals and economics are such that further controlling the computer is cost effective. (See Section 2.3 to determine whether a PPL can be controlled cost effectively.)

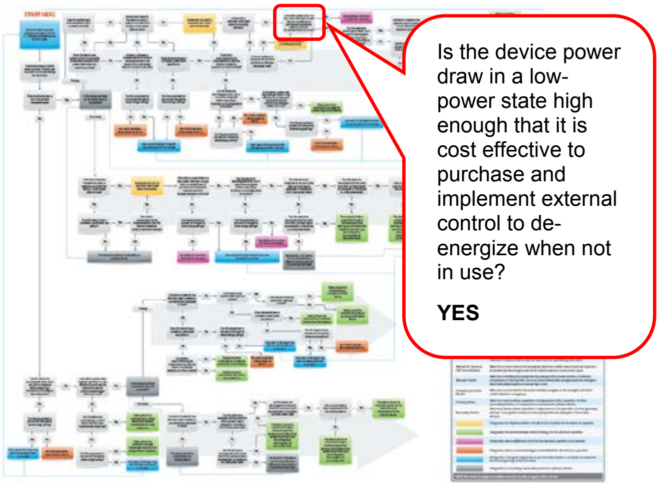


Figure 2-7 **Flowchart control strategy for a computer example: question 6**
(Credit: Joelynn Schroeder/NREL)

To further reduce the computer's energy use, you must determine whether it can be de-energized and reenergized without being reconfigured (Figure 2-8). This computer cannot be de-energized.

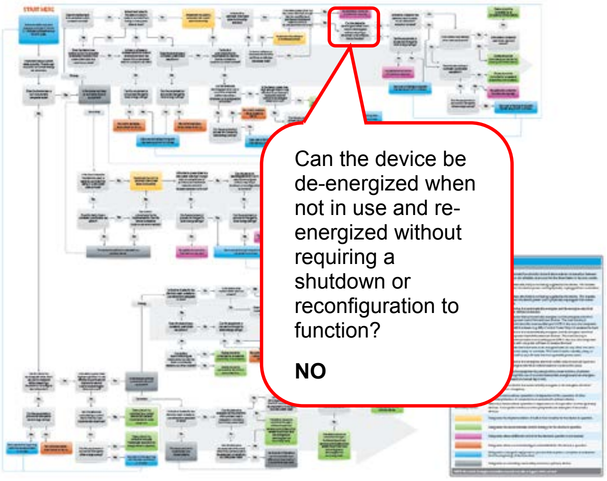


Figure 2-8 Flowchart control strategy for a computer example: question 7
(Credit: Joelynn Schroeder/NREL)

Figure 2-9 Shows that the computer is energy efficient and must be used to meet the user's needs. It cannot be changed out.

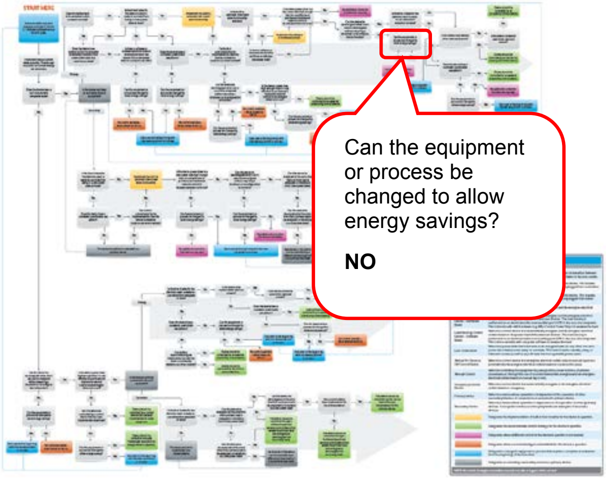


Figure 2-9 Flowchart control strategy for a computer example: question 8
(Credit: Joelynn Schroeder/NREL)

A recommended control strategy is shown in Figure 2-10. No additional control is required. The flowchart recommends that the computer be controlled by its built-in low-power state and manual shutdown procedures.

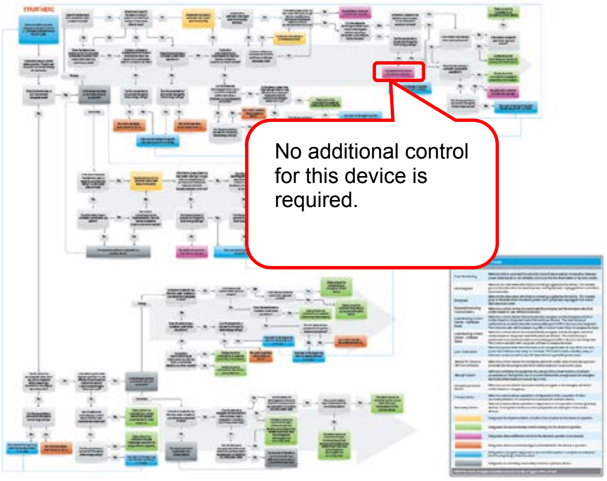


Figure 2-10 Flowchart control strategy for a computer example: recommended control
(Credit: Joelynn Schroeder/NREL)

2.2.2.2 Walkthrough of Control Strategy Flowchart for an Ice Machine

This example illustrates the process to determine the recommended control strategy for an ice machine. Follow the steps outlined in Section 2.1 to determine that an ice machine will meet the user's needs. Then use the flowchart to determine a suitable control strategy. The first step is to educate the ice machine user about how to reduce its energy use.

Figure 2-11 shows that the ice machine cannot transition to a standby state.

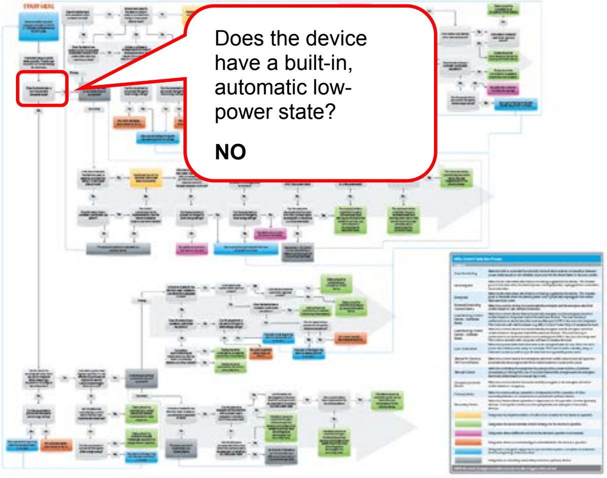


Figure 2-11 Flowchart control strategy for an ice machine example: question 1
(Credit: Joelynn Schroeder/NREL)

Figure 2-12 shows that the ice machine can be de-energized without being reconfigured.

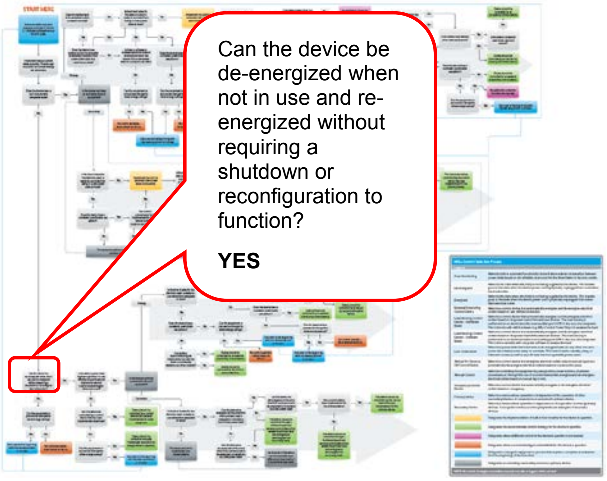


Figure 2-12 **Flowchart control strategy for an ice machine example: question 2**
(Credit: Joelynn Schroeder/NREL)

The next question is whether the ice machine's power draw is high enough that external control is cost effective (see Figure 2-13). The ice machine has a significant load when it is operating, whether or not it is needed, so the process continues to move to the right on the flowchart. (See Section 2.3 to determine whether a PPL can be controlled cost effectively.)

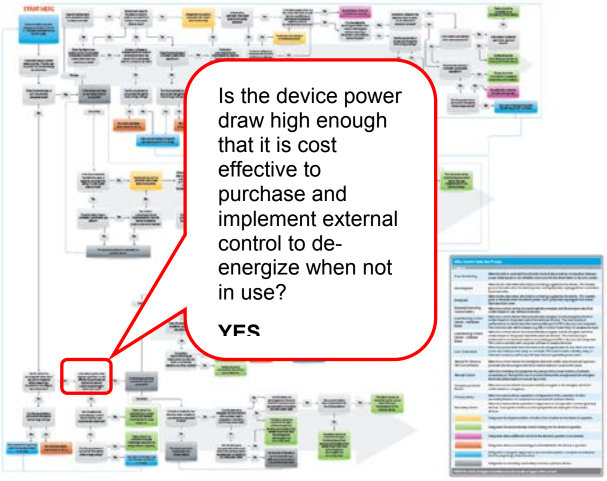


Figure 2-13 **Flowchart control strategy for an ice machine example: question 3**
(Credit: Joelynn Schroeder/NREL)

Figure 2-14 shows that the ice machine is a primary device because it operates independently of other devices, so you can proceed.

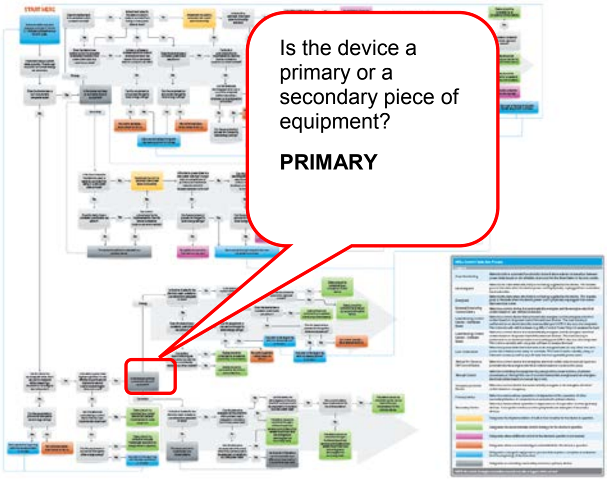


Figure 2-14 Flowchart control strategy for an ice machine example: question 4
(Credit: Joelynn Schroeder/NREL)

Figure 2-15 shows that the ice machine requires a significant amount of time to produce ice after being de-energized and reenergized, so you can proceed down on the chart.

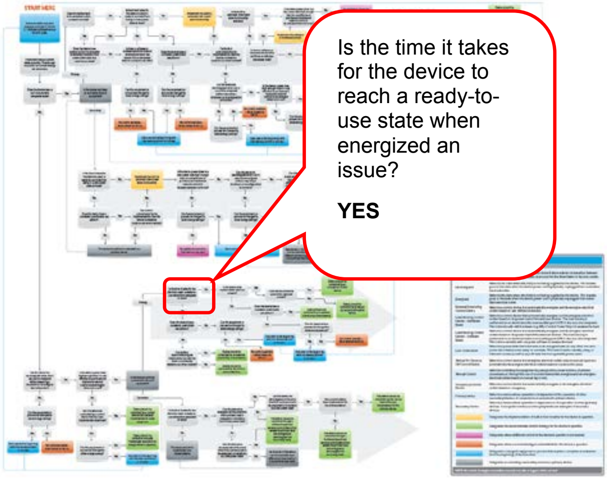


Figure 2-15 Flowchart control strategy for an ice machine example: question 5
(Credit: Joelynn Schroeder/NREL)

Figure 2-16 shows that the ice machine has a predictable use pattern, as it needs to provide ice from 7:00 a.m. to 5:00 p.m. You can proceed.

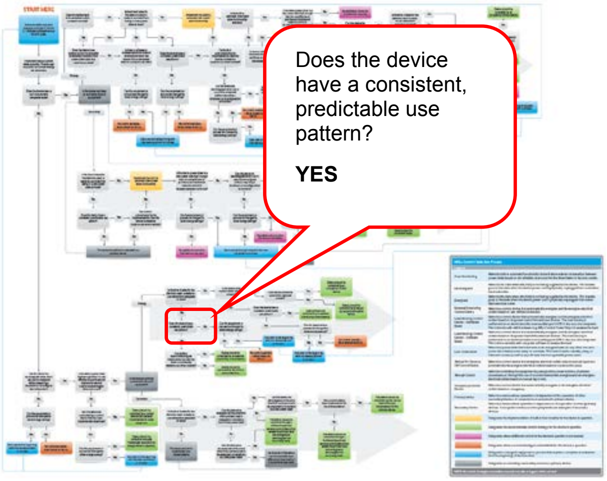


Figure 2-16 **Flowchart control strategy for an ice machine example: question 6**
(Credit: Joelynn Schroeder/NREL)

Figure 2-17 shows that the ice machine does not have auto-scheduling, so it should be controlled by an electrical outlet timer.

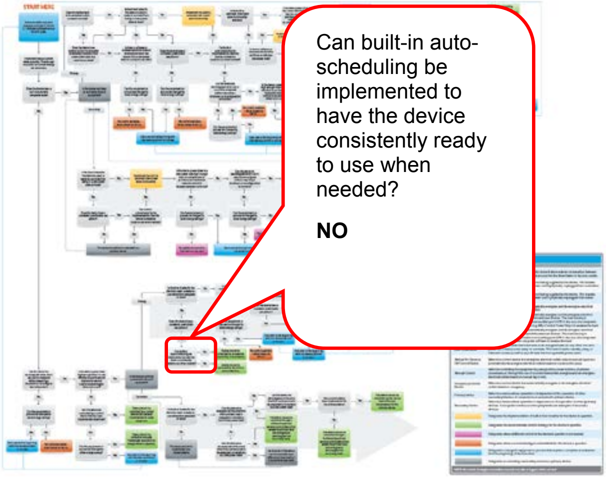
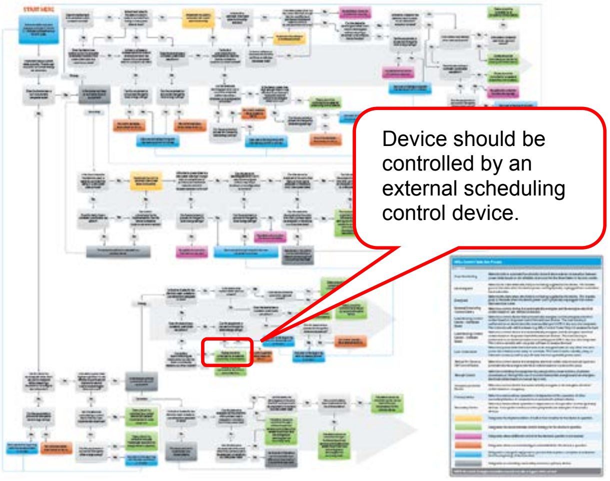


Figure 2-17 **Flowchart control strategy for an ice machine example: question 7**
(Credit: Joelynn Schroeder/NREL)

Figure 2-18 shows that an electrical outlet timer should be used to energize the ice machine a few hours before it is needed (7:00 a.m.) so sufficient ice is ready. The electrical outlet timer should de-energize the ice machine at 5:00 p.m. each day to mitigate wasted energy.



Device should be controlled by an external scheduling control device.

Figure 2-18 Flowchart control strategy for an ice machine example: recommended control
(Credit: Joelynn Schroeder/NREL)

2.2.3 Controlling Typical Plug and Process Loads

NREL researchers have performed extensive PPL research through work on the RSF project and on Commercial Building Partnership projects. Table 2–2 shows the recommend control strategies for PPLs that are typically found in commercial buildings. The devices listed have been processed by the flowchart shown in Section 2.2.2 to arrive at the recommended strategies.

Table 2–2 Recommended Controls for Typical PPLs

Device	Built-In Automatic Low-Power State	Scheduling	Load Sensing	Occupancy	Manual On, Vacancy Off	Manual Control	No Control
Audio equipment		X	X	X	X		
Battery chargers		X					
Cash registers		X		X	X		
Computer monitors	X		X				
Credit card machines	X		X				
Decorative lighting			X		X		
Desktop computers	X						
Digital photo frames			X		X		
Dishwashers		X					
Drinking fountains		X		X	X		
Electric hole punchers		X	X		X		
Electric information displays	X	X		X	X		
Electric pencil sharpeners		X	X		X		
Electric staplers		X	X		X		
Fans		X		X	X		
Floor cleaners		X			X	X	
Floor polishers		X			X	X	
Freezers							X
Gym equipment		X			X		
Heaters		X			X		
Label makers/printers		X	X		X		
Laptop computers	X		X				
Ovens/stoves/ranges		X					
Paper shredders		X	X		X		
Peripherals			X				
Personal print/copy equipment			X				
Phones	X						X
Projectors	X	X	X		X		
Refrigerators							X
Shared print/copy equipment	X	X					
Small kitchen appliances		X			X		
Smart boards		X			X		
Task lighting			X		X		
Televisions	X	X		X	X		
UPS units		X	X				
Vacuums					X	X	
Vending machine – nonrefrigerated		X		X			
Vending machine – refrigerated (parishable items)		X		X			X
Vending machine – refrigerated (non-parishble items)		X		X			
Water coolers		X		X	X		
Water filters		X		X	X		
Water heaters		X		X	X		

Several PPLs have multiple recommended strategies, because PPLs and buildings are variously operated. You should use the flowchart to analyze devices that are not listed or that are listed with multiple recommendations to find the best control strategy for your project and PPL.

2.3 Selecting a Cost-Effective Control Device

You need to evaluate the parasitic load of each potential control device. It would ideally have zero parasitic load; in any case, the load must be low enough that it does not negatively offset the energy saved by controlling the PPL. For example, a control device with a load of 3 W may, depending on its cost, the cost of electricity, and the payback, be acceptable for a PPL that has a parasitic load of 20 W. If the PPL has a parasitic load of 2 W, however, the control device will use more energy than it saves, so you should find one with a lower parasitic load.

PPL control devices have an associated cost for features over a standard power strip. Once you determine a control strategy, you need to evaluate the devices that feature that control to determine whether they function as intended and that the additional cost is justified.

PPL control device prices can vary greatly. At the time this report was written, simple scheduling devices could be purchased for less than $20; strategies tied to the BMS may be $1000 or more per point. The business case that was developed in Section 2.1.3 can be used to determine whether the applicable control device costs can be justified and if the project payback requirements are met.

Figure 2-19 shows the minimum average power draw for a PPL that can be cost-effectively controlled by a control device. The graph was developed assuming 9 hours of operation per workday and 250 workdays per year. It is also based on a 2-year payback period and for simplicity does not account for demand charges. (See Appendix B for other payback periods.) For a given utility rate, all PPLs with an average power above the line should be controlled. If a PPL's power is below the line, controlling it is not cost effective. For example, if the utility rate is $0.06/kWh, and a control device is available for $30 per device, it is cost effective to control all PPLs with an average power of 38 W or more.

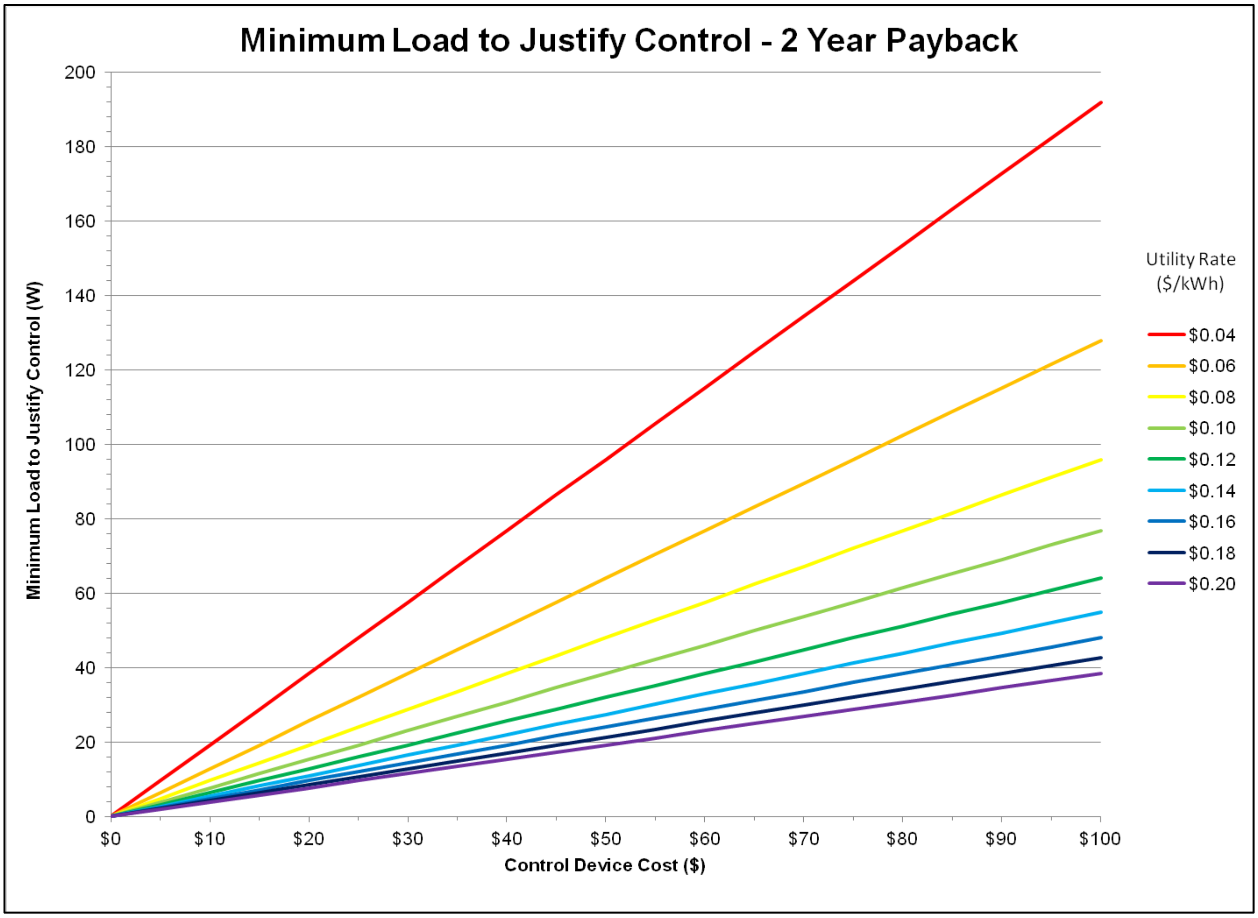


Figure 2-19 Minimum load that can be cost-effectively controlled by a control device
(Credit: Chad Lobato/NREL)

2.3.1 Other Evaluation Criteria for Control Devices

You should also evaluate control devices for usability, form factor, aesthetics, and user friendliness, because users will bypass complicated control devices. A de-energized PPL will sometimes be needed during atypical times, so the control devices should also incorporate a manual override to energize the PPL.

The devices should integrate well with the PPLs they are to control and with the building space. Plug-in, external control devices should be sized to fit into the spaces between the PPL and the electrical outlet. If the device is intended to be visible, its design should, if possible, integrate well with the building decor and furniture.

Energy metering can add value to control devices because it provides feedback. When metered data are paired with user education, users can alter their behavior to reduce energy use. The metering can indicate when energy is being wasted. It will highlight times when energy was used unexpectedly so the situation can be investigated. To take full advantage of metering, the measured data for all PPLs should be available to all occupants so they can compare their energy use to that of their peers. They may even want to have a friendly competition to reduce energy use. Desirable features of a control device with metering are provided in Section 2.1.2.1.

Table 2–3 illustrates the evaluation criteria used to select a control device.

Table 2–3 PPLs Control Evaluation Criteria

Parasitic Load Mitigation	Power Management	Usability, Form Factor, and Aesthetics	Metering Capability	Price
• Minimal parasitic load for the control device • Minimize or eliminate the parasitic load of the PPLs	• Consistent and reliable operation of the controlled PPL • Number of controlled outlets on the control device meets occupants needs • Compatible with the BMS	• User friendly • Incorporated manual override • Physical dimensions do not cause space issues • Integrates well with the workstation • Integrates well with building decor and furniture • Ability for the electrical outlets to be oriented to accommodate different sized plugs	• High level of accuracy with the ability to be recalibrated • Local display to provide user feedback • Ability to record and store electrical load time series data • Ability to remote access and control • Wireless communication	• Energy savings from the control device justifies higher cost and the payback requirements are met

3.0 Potential Equipment Improvements

The flowchart presented in Section 2.2.2 sometimes recommends that the PPL be changed or that there is no control. In such cases, the champion (or equipment procurement staff) should ask PPL equipment manufacturers to reduce the energy use of their products.

3.1 Built-in Low-Power Functionality

One of the first checks in the flowchart is whether the equipment has built-in low-power functionality. If it does not, it moves one step closer to a no control or replacement recommendation, which indicates that the champion needs to ask the manufacturers to include low-power states in their equipment designs.

Ideally, all PPLs would have built-in low-power functionality, because accurately matching an external control strategy to a PPL can be difficult. Integrated control features could reduce costs (to users) because there would be no need to purchase additional devices and the control would likely be more consistent and reliable. The PPL manufacturers are more qualified to tailor the control to the PPL than would a third-party, who would almost certainly have a less effective product that is designed to be universally applicable.

3.1.1 Remote Access

Some PPLs receive a “no control” recommendation (see even though they have built-in low-power functionality, because they cannot be brought out of a low-power state remotely. In this case, you should ask the manufacturers to incorporate remote “wake up” functionality. For example, most computers have low-power functionality, but they may be left in idle, uncontrolled states because they need to be accessed remotely. This may waste significant energy.

3.1.2 Warm-up Time

Some PPLs can go uncontrolled because it takes too much time for them be ready to use from a low-power state. Users will disable built-in low-power functionality in this case.

3.1.2.1 Auto-Scheduling

If a PPL has a low-power state and a predictable use pattern, but a significant warm-up time, it would benefit from built-in auto-scheduling. This functionality would begin the warm-up process in advance so it is ready to be used when it is needed. Otherwise the PPL would be uncontrolled and waste energy.

3.1.3 Effective Low-Power Functionality

A PPL may receive a “no control” recommendation because its low-power functionality is not effective. The champion should request product improvements in this case. An effective low-power state functions reliably and consistently. The device transitions to a low-power state whenever it sits idle for a specified time. Once in a low-power state, the power draw should be drastically reduced from the idle or in-use power state. Our research has shown that many PPLs have inconsistent low-power functionality. Various processes keep the PPLs from transitioning to their low-power states. In some cases, the power draw does not decrease enough to be save significant energy.

3.2 De-Energize and Reenergize Functionality

Most control devices reduce PPL energy consumption by de-energizing the outlet that provides energy to the equipment. Energy is restored when the PPL needs to be used again. To take advantage of these control devices, PPLs must be able to be de-energized and reenergized and be ready to use. Many PPLs cannot be controlled because they cannot be de-energized and reenergized. These PPLs sometimes require a specific shutdown procedure and may become damaged if they are de-energized before completing the shutdown. Or, they may require a lengthy reconfiguration process once reenergized. Other devices cannot be de-energized and reenergized because of convenience or safety concerns. They simply take too long to warm up when energy is restored. When the flowchart recommends no control because a PPL cannot be de-energized, the device should be improved.

4.0 Research Support Facility Results: Plug and Process Load Controls Evaluation

The RSF has almost 1000 workstations; thus, we procured energy-efficient equipment whenever possible and strove to find the best control strategies. Previous NREL workstations had standard multiplug power strips with surge protection and manual on/off power switching. They did not feature automated power control, and did not have measureable parasitic loads.

The following sections highlight the process and results of our evaluations of various PPL controls in the RSF.

4.1 Evaluating the Effectiveness of Various Plug and Process Loads Control Strategies in the Research Support Facility

We evaluated commercially available PPL control devices for their energy saving effectiveness, generally at workstations with common equipment. Each user at each workstation has a unique use pattern, which is a function of work schedule, time spent at the workstation, and time spent using the computer. Therefore, results are presented on a user-by-user basis instead of as an average. In the following sections, “good” user behavior is when users power down their workstations each day. Ideally, “good” users would also put their computers into standby and turn off their task lights each time they are away from their workstations.

We tested a few control devices in other areas of the building. The results are presented in the following sections.

4.1.1 Baseline Measurements: No Control

We monitored a set of workstations with uncontrolled plug loads to establish a baseline of energy use profiles. A typical RSF workstation has two light-emitting diode (LED) backlit liquid crystal diode (LCD) monitors (consuming approximately 15 W each), a laptop (consuming approximately 30 W), a laptop docking station, and a 6-W LED task light. Some users had additional equipment based on their job responsibilities. The computer power management settings cut signal to the monitors after 5 minutes of idle time; metering indicated that this setting worked automatically and consistently.

The NREL Information Services Office (IS) managed the campus information technologies. IS implemented additional power management settings on all computers that were supposed to force standby after 15 minutes of idle time; however, our baseline measurements showed that these settings did not work. None of the laptops we metered went into standby automatically. Solutions are presented in later sections.

Figure 4-1 represents the “no control” workstation that was used as a basis for comparison when evaluating PPL control devices. All the equipment (the laptop, docking station, two LED backlit LCD monitors, and an LED task light) was left powered 24/7. All the computer power management settings were disabled so the computer would not go into standby mode or screensaver mode, or cut signal to the monitors. The average load was 62 W.

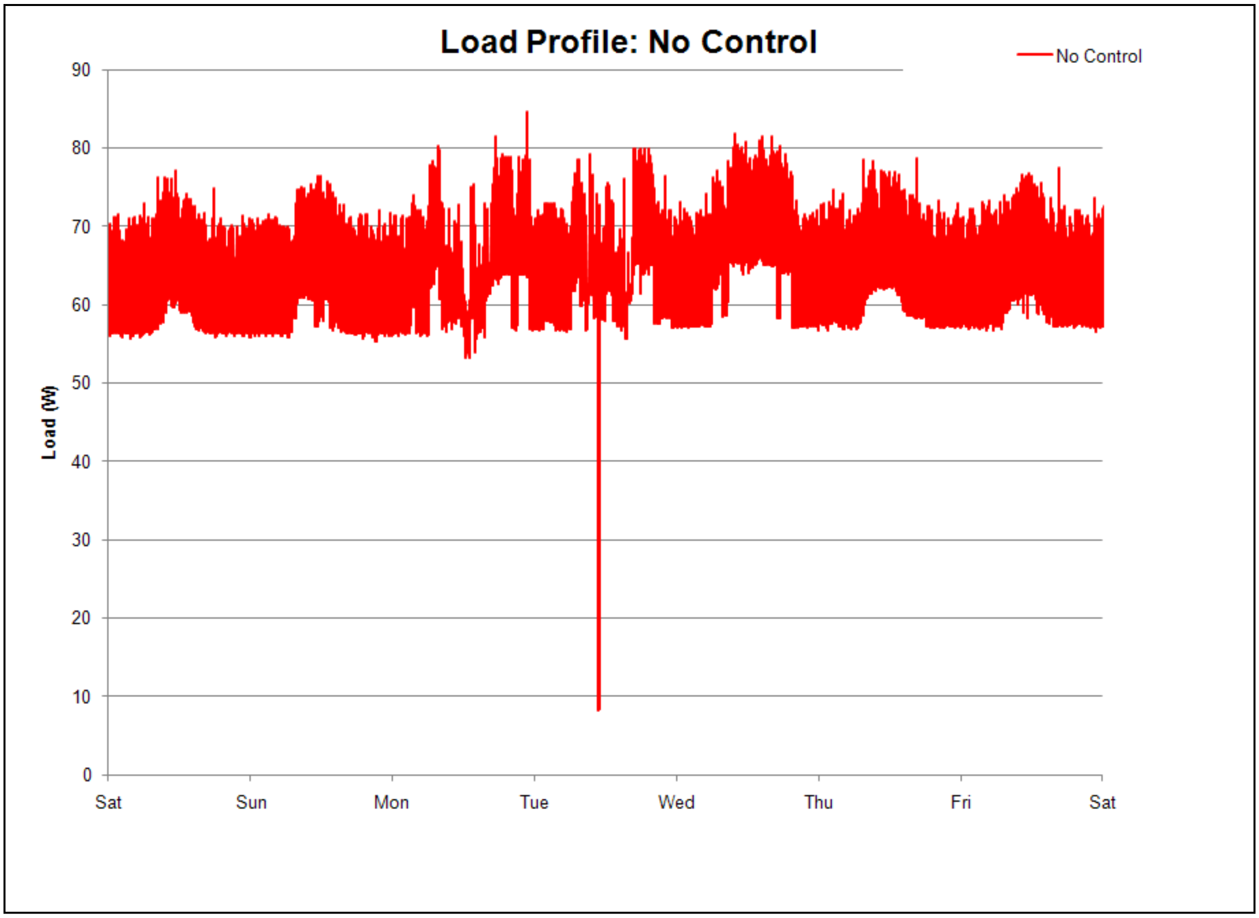


Figure 4-1 **Load profile of the "no control" workstation; all equipment powered up 24/7**
(Credit: Michael Sheppy/NREL)

4.1.1.1 Energy Impact of User Behavior: The Importance of User Education

Results from the baseline measurements of uncontrolled workstations revealed the importance of encouraging "good" user behavior. Ideally, all PPLs control strategies would counteract "bad users," but not all strategies are "user proof." Controlling every PPL is not always feasible, because of budget constraints or because implementing and managing a given strategy are too time consuming. Encouraging "good" user behavior can be an effective and inexpensive control strategy.

Figure 4-2 and Figure 4-3 show the workstation load profiles for a user with good behavior and a typical user, respectively. Both workstations had the following controls implemented:

- No signal to monitors after 5 minutes of idle time
- Monitors with built-in automatic low-power state
- Manual power management control.

Figure 4-2 shows a peak demand that was 8 times higher than that shown in Figure 4-3 (915 W compared to 120 W); this was due to extra equipment, including a large printer and several other miscellaneous electrical items. Despite the high peak demand, this workstation used about half the energy (weekly average load 3.4 kWh compared to 6.2 kWh) because everything was turned off at night. The user depicted in Figure 4-3 was not educated about effective power management and simply locked the computer when away from the workstation. This wasted energy. Figure 4-3 illustrates the need for user education and the consistent use of standby functionality.

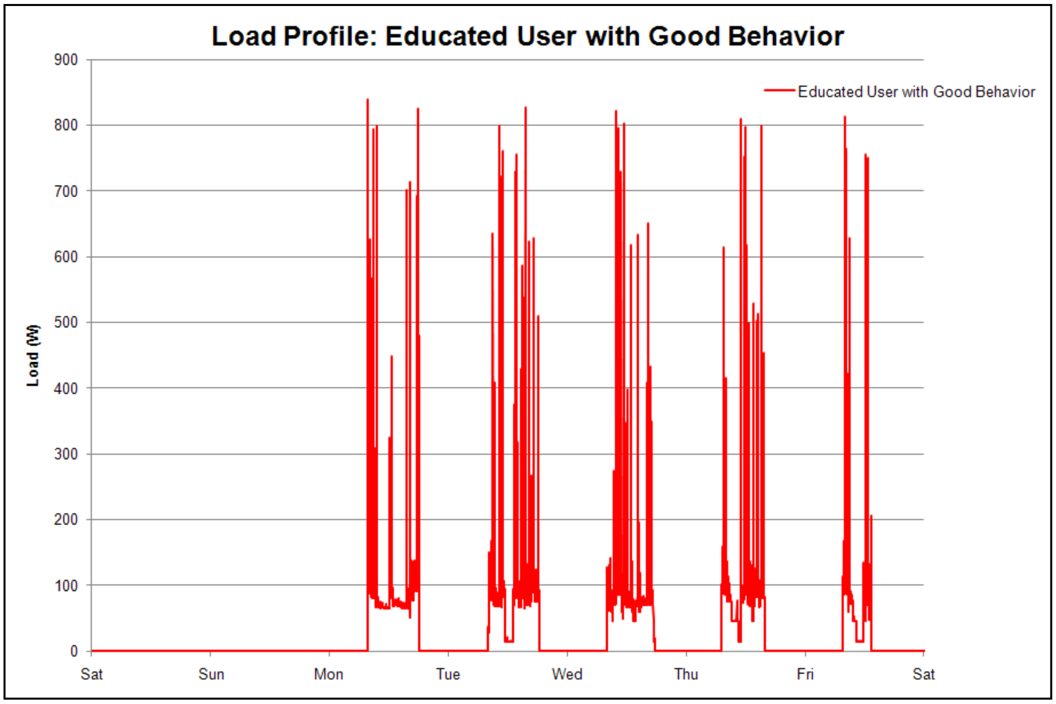


Figure 4-2 Measured load profile of a workstation with good occupant behavior
(Credit: Chad Lobato/NREL)

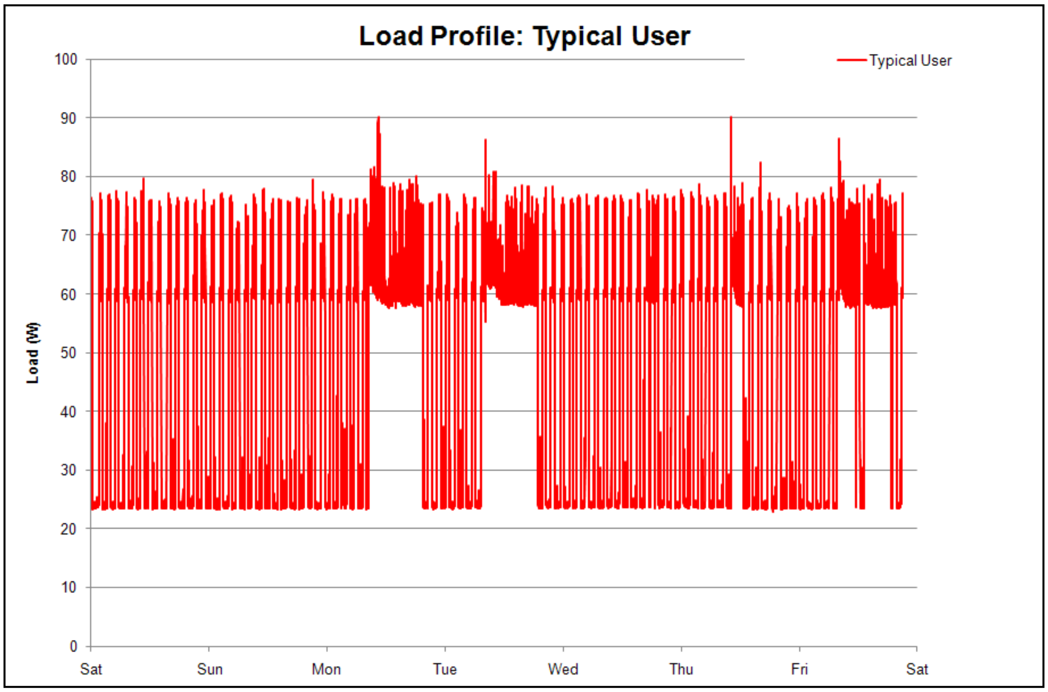


Figure 4-3 Measured load profile of a workstation without good occupant behavior

(Credit: Chad Lobato/NREL)

4.1.2 Built-In Automatic Low-Power State Control

As mentioned in Section 4.1.1, NREL's IS implemented computer power management settings that force standby after 15 minutes of idle time. These efforts were ineffective because our network activity kept the computers from going into standby. We evaluated several third-party programs (Invent 2011; Slawdog 2003) to counteract the network activity and to consistently and automatically force standby.

Figure 4-4 shows the load profile of a workstation that used an effective third-party power management program. This program was set to force standby after 6 minutes of idle time and after 5:00 p.m. each day. This workstation had the following additional controls implemented: no signal to monitors after 5 minutes of idle time; monitors with built-in automatic low-power state; and manual power management control.

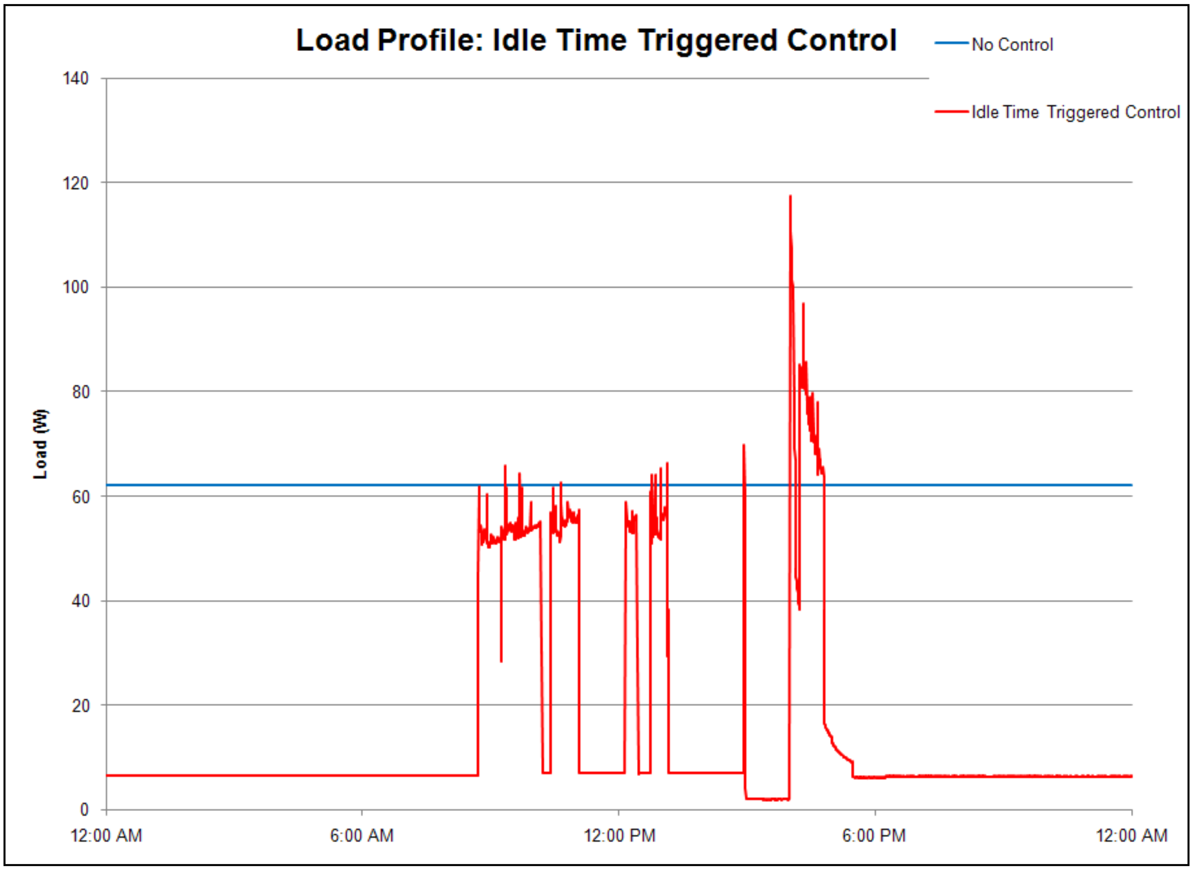


Figure 4-4 Load profile of a workstation with idle time triggered control only and good occupant behavior
(Credit: Michael Sheppy/NREL)

Compared to the "no control" workstation, the third-party software reduced the average power of the workstation by 47.5 W (14.5 W compared to 62 W). The remaining load (when the computer was in standby) was from the docking station and laptop charging.

4.1.2.1 Usability Issues

In our study, several users disabled the third-party power management program. Some regularly ran computer simulations that required their computers to run for long periods without user input. The program forced their computers into standby before their simulations were complete, because it was based on user inputs only and not on computer processing. Ideally, the power management program would also account for computer processing to determine whether the computer is idle. Other users disabled the power management program because their computers took too long to emerge from standby state. On the other hand, the power management program caused almost no issues with users who had typical computing needs (creating and editing documents and spreadsheets, reading and sending emails, using the Internet). With more than a 75% reduction in the average workstation load by using standby, we strongly recommend that built-in automatic low-power state control be implemented on as many workstations as possible. If there are issues similar to the network activity experienced at NREL, we recommend user education to promote manual implementation of standby and investigating third-party programs to force low-power states.

4.1.3 Scheduling Control Device

Figure 4-5 shows the load profile of a workstation that used a power strip with digital timer control. The power strip was configured to energize the workstation only between 5:30 a.m. and 7:00 p.m. on weekdays. This workstation had the following additional controls implemented: no signal to monitors after 5 minutes of idle time; monitors with built-in automatic low-power state; and manual power management control. The workstation was configured so all equipment (e.g., laptop, docking station, monitors, and task light) was powered by control outlets.

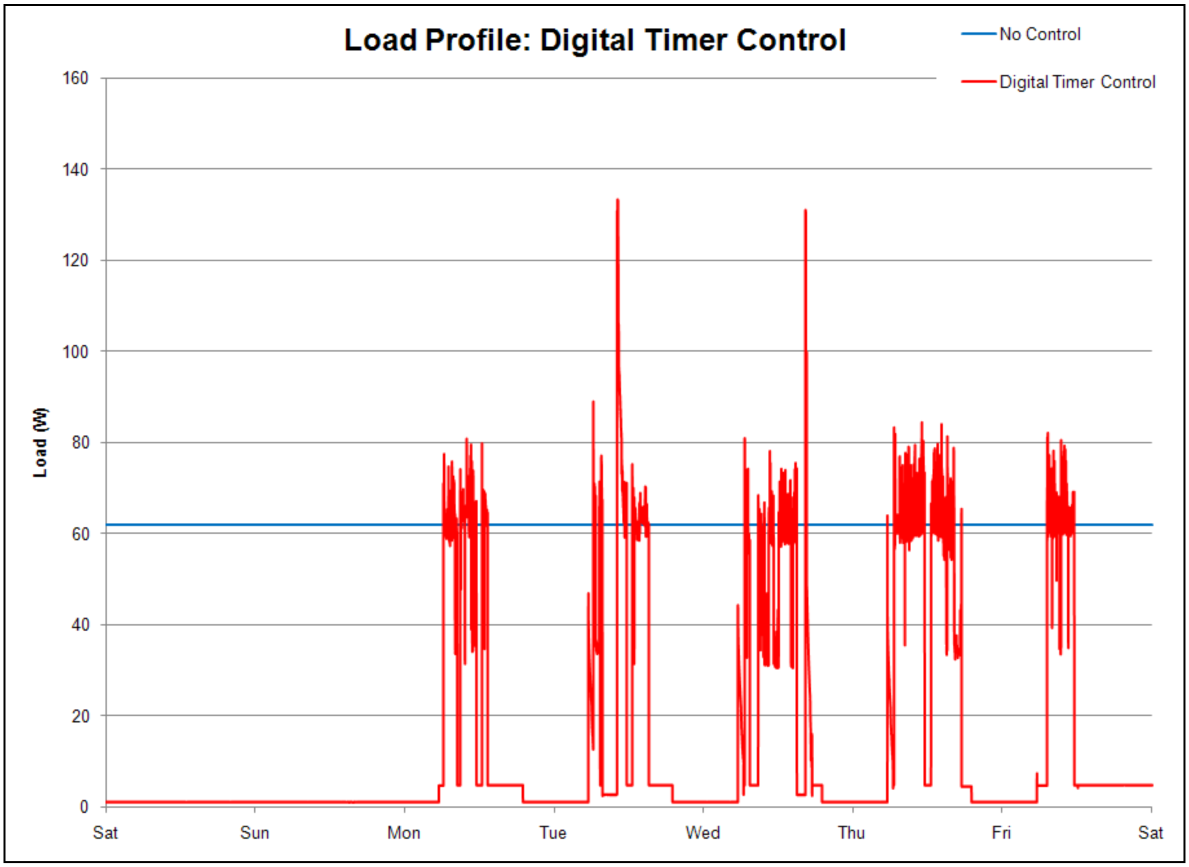


Figure 4-5 **Load profile of a workstation with digital timer control only and good user behavior**
(Credit: Michael Sheppy/NREL)

The digital timer power strip reduced the average power of this workstation by 48.5 W over the "no control" workstation (13.5 W compared to 62 W). It could be reduced further if the digital timer were configured to match the user's work schedule instead of a general 5:30 a.m. to 7:00 p.m., Monday through Friday schedule. Implementing either a consistent built-in automatic low-power state or third-party low-power state control (see Section 4.1.2) would yield maximum savings for the digital timer power strip control strategy.

Scheduling control is best suited to PPLs that have a consistent, predictable use pattern. The ice machine in the RSF's coffee kiosk is one example. A power strip with digital timer control was configured to energize its outlets between 5:15 a.m. and 3:00 p.m. weekdays. This gave the ice machine enough time to make ice in the morning before the coffee kiosk opened (7:00 a.m.). The machine was de-energized at the same time that the coffee kiosk closed every day (3:00 p.m.). Figure 4-6 is the measured daily load profile of the ice machine with and without scheduling control.

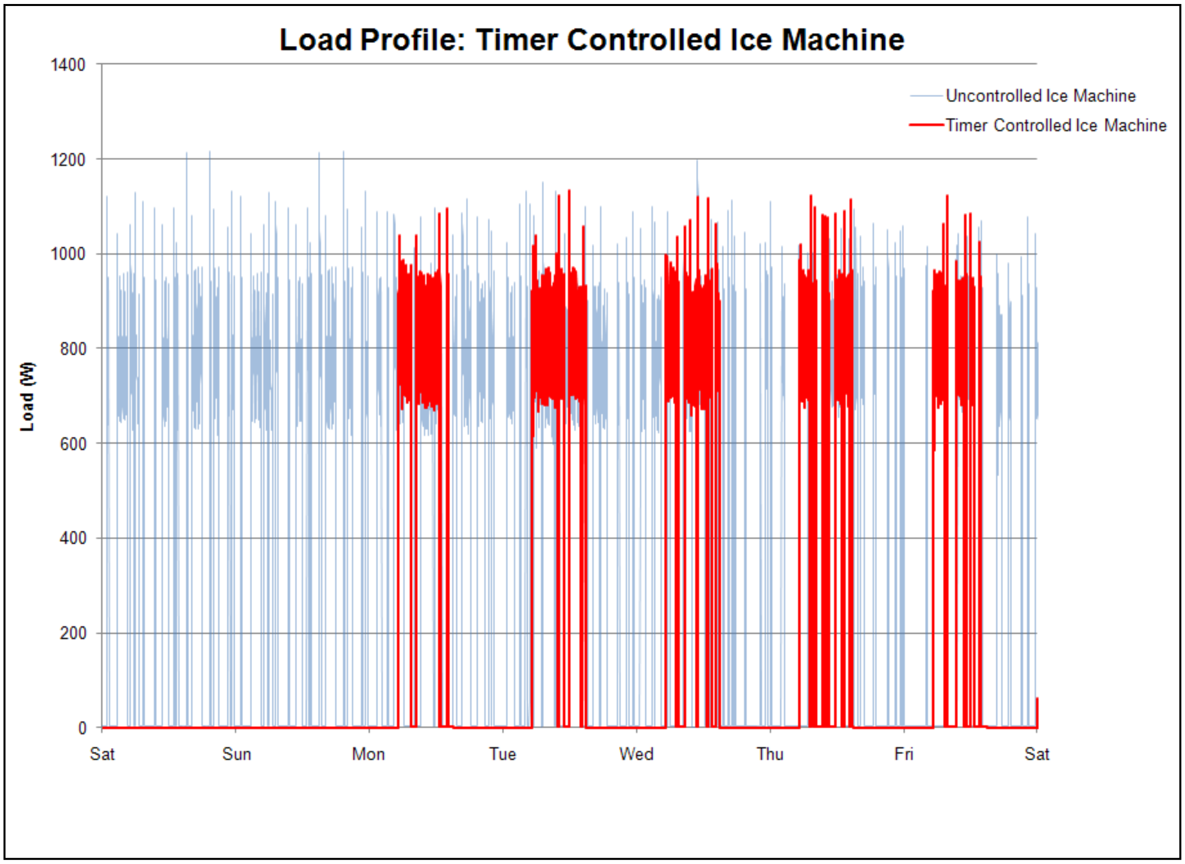


Figure 4-6 Load profile of the ice machine in the RSF's coffee kiosk
(Credit: Chad Lobato/NREL)

The digital timer-controlled power strip reduced the average power of the ice machine from 327 W to 157 W, a 52% saving, without impacting the quality of ice production during business hours.

4.1.3.1 Usability Issues

The default configuration was to have all the workstation outlets controlled by the digital timer. Very few users had problems. Users who needed to run computer simulations on their laptops overnight found in the morning that the battery had fully discharged. This was corrected by plugging the laptop into an "always on" outlet and leaving the other workstation equipment to be controlled by the digital timer.

Some digital timer power strips have an override function that bypasses the digital timer control; however, unless the user turns off the override function, the auto-scheduling control will not be implemented.

4.1.4 Load-Sensing Control Device

4.1.4.1 Universal Serial Bus Load-Sensing Control Device

A USB load-sensing power strip senses when a computer's USB port is de-energized when the computer transitions to a standby or off state, and cuts all power to workstation outlets. In our study, the power strip was configured to monitor one of the USB ports on a laptop. Figure 4-7 is the measured daily load profile of a workstation that used a USB load-sensing power strip. This workstation had the following additional controls implemented: no signal to monitors after 5 minutes of idle time; monitors with built-in automatic low-power state; and manual power management control. The workstation was configured so that all equipment (e.g., laptop, docking station, monitors, and task light) was powered by control outlets.

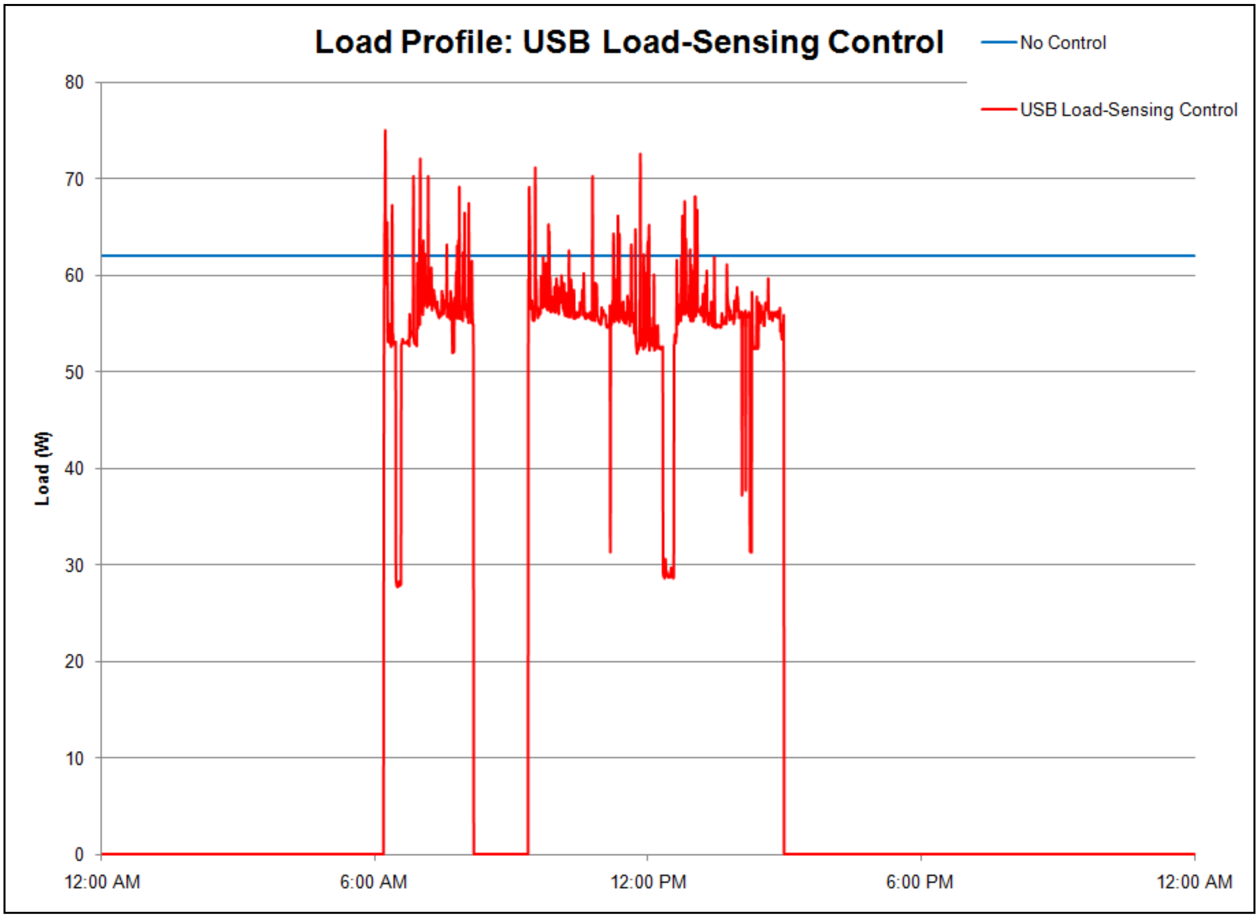


Figure 4-7 Load profile of a workstation with USB load-sensing control only and good user behavior
(Credit: Michael Sheppy/NREL)

The user of this workstation put his laptop into standby only once per day. The average load was 17 W (a 45-W saving over the "no control" workstation).

4.1.4.1.1 Usability Issues

No issues were reported for this control device.

4.1.4.2 Plug Load-Sensing Control Device

A plug load-sensing power strip senses a change in the power draw on an outlet, because the plugged-in PPL is transitioning from an in-use state to a low-power state, and cuts all power to workstation outlets. In our study, the power strip was configured to monitor the plug that powers the laptop docking station. Figure 4-8 shows the measured daily load profile of a workstation that used a plug load-sensing power strip. This workstation had the following additional controls implemented: no signal to monitors after 5 minutes of idle time; monitors with built-in automatic low-power state; and manual power management control. The workstation was configured so that the computer and docking station was powered by the sensing outlet and the rest of the equipment (e.g., monitors and task light) was powered by control outlets.

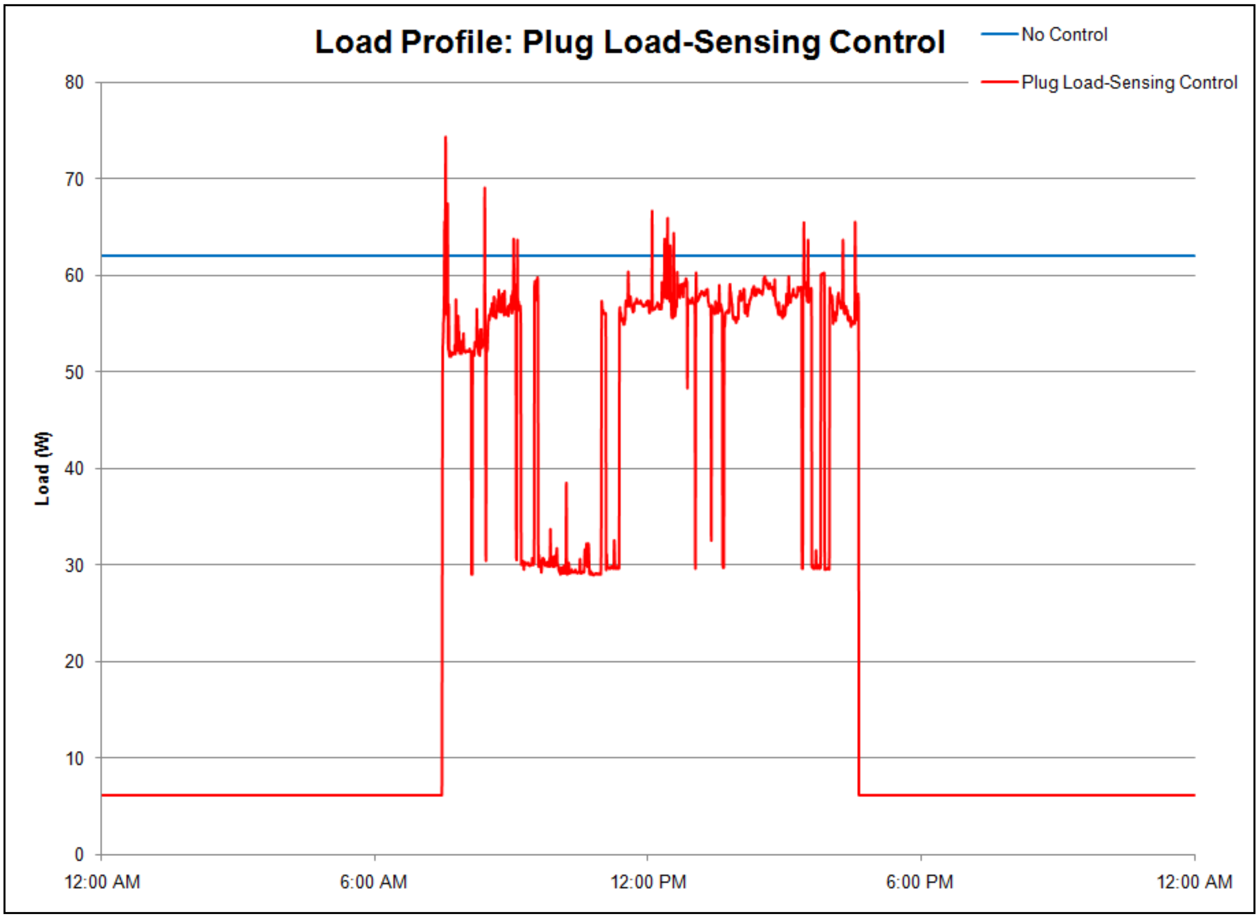


Figure 4-8 Load profile of a workstation with plug load-sensing control only and good user behavior

(Credit: Michael Sheppy/NREL)

The user of this workstation put his laptop into standby only once per day. The average load was 22 W (a 40-W saving over the "no control" workstation).

4.1.4.2.1 Usability Issues

No issues were reported for this control device.

4.1.5 Occupancy Control Device

Occupancy control is not the most suitable for controlling computer power because power is interrupted periodically, independent of the state of a computer. An occupancy control power strip was used to control only the workstation task light because of the power interruption issue. Figure 4-9 shows the measured daily load profile of a task light that used an occupancy control power strip.

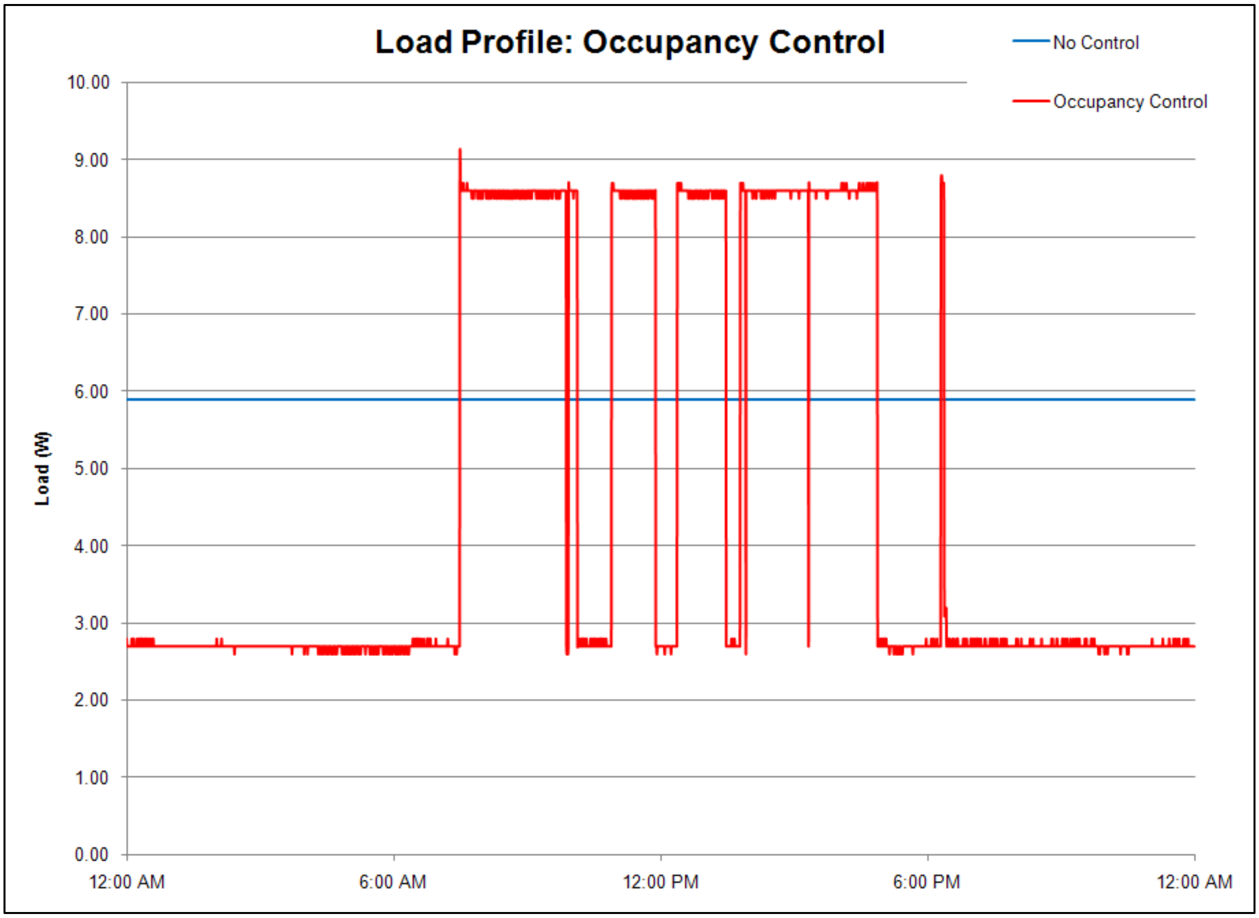


Figure 4-9 **Load profile of a task light with occupancy control only**
(Credit: Michael Sheppy/NREL)

This task light had an average load of 4.6 W (a 1.2-W saving over the "no control" task light) because of the occupancy control power strip's parasitic load (2.7 W).

4.1.5.1 Usability Issues

The main complaint about the tested occupancy control power strip was that it did not always detect movements. Most users turned the no-motion-power-off delay on their power strips to 15 minutes. Repositioning the occupancy sensor also helped improve movement detection.

4.1.6 Manual On, Vacancy Off Control Device

Manual on, vacancy off control devices were not studied because they are not currently available.

4.1.7 Manual Control

Manual control of PPLs can take many forms, including mechanical switches tied to wall outlets, remote controls, and built-in power switches. It can be used to power down a device or just put it into a low-power state. However, its effectiveness depends on "good" user behavior. Three power strips with remote switches were studied. Two used a wireless remote placed on the desktop to allow manual control of the power strip outlets; one used a wired remote. All offered a remote that gave users a conveniently located manual switch to de-energize the outlets. The primary difference between these power strips and a conventional one is that the manual switch is located on the desktop rather than under the desk, on the floor, behind a cabinet, or at another less convenient location. Figure 4-10 is the measured daily load profile of a workstation that used a remotely controlled power strip. This workstation had the following additional controls implemented: no signal to monitors after 5 minutes of idle time; monitors with built-in automatic low-power state; and manual power management control. The workstation was configured so that all equipment (e.g., laptop, docking station, monitors, and task light) was powered by control outlets.

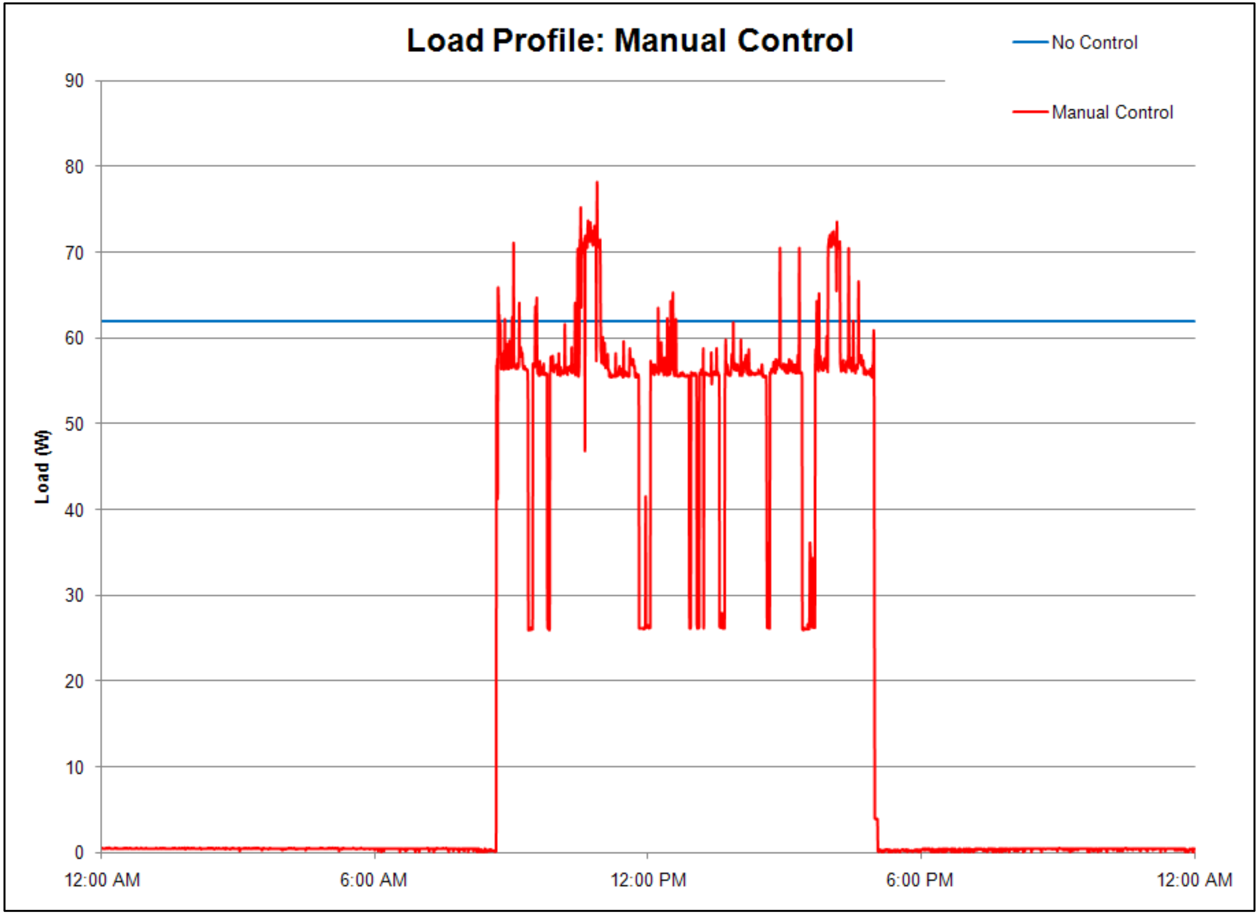


Figure 4-10 Load profile of a workstation with manual control only "good" behavior
(Credit: Michael Sheppy/NREL)

The user of this workstation used the remote control power switch only once per day. His average load was 19 W (a 43-W saving over the "no control" workstation).

5.0 Equipment and Strategies Implemented in the Research Support Facility

The following energy-efficient equipment and strategies were implemented in the RSF to meet occupant needs and reduce PPLs. Control solutions implemented in the RSF are highlighted.

5.1.1 Server Room

5.1.1.1 Research Support Facility Server Room Equipment and Controls

NREL's previous data center used a number of servers that typically had a utilization of less than 5%. When the total data center power draw was divided among all users, the continuous power consumption rate per person was 119 W (Sheppy et al. 2011). The uninterruptible power supply (UPS) and room power distribution units were 80% efficient.

The RSF data center uses blade servers running virtualized servers. When the total data center power draw is divided among all users at NREL, the continuous power consumption rate per person is 45 W (Sheppy et al. 2011). The current UPS and room power distribution are 97% efficient.

The RSF data center's lighting is controlled by manual on, vacancy off light switches. The blade servers have variable-speed fans that can ramp up or down to meet cooling needs.

5.1.1.2 Equipment and Operation Guidelines for Server Rooms

UPSs serve two main functions in server rooms: (1) they condition line power; and (2) they maintain power delivery during power outages until the backup generator kicks on. Typical legacy UPS efficiency is around 80%; these devices produce extra heat that requires additional cooling. When procuring a new UPS, the following features are critical:

- 95% + energy efficiency
- Scalable design
- Built-in redundancy
- End user serviceable
- Sufficient uptime
- Compliant with the efficiency guidelines of the Server System Infrastructure initiative, which set open industry specifications for server power supplies and electronic bays.

The UPS should be loaded so it operates at peak efficiency. The manufacturer's documentation provides information about the relationship between loading and efficiency.

Energy-efficient power distribution units should be used. To further reduce the power footprint, blade servers should be procured that use variable-speed fans and energy-efficient power supplies, and run virtualization software (to decrease the required number of physical servers).

Hot aisle containment dramatically reduces cooling loads by preventing supply and return air from short circuiting (mixing with each other). This strategy also provides the opportunity for waste heat recovery; however, it is an involved change to the server room that is best suited for new construction and retrofit projects that can afford the downtime to arrange the cabinets.

5.1.2 Workstations

5.1.2.1 Research Support Facility Workstation Equipment and Controls

The PPL audit of previously occupied NREL office space revealed numerous opportunities to reduce PPLs from workstation equipment. Approximately 90% of employees used desktop computers. When idle, these computers went into a screensaver mode or displayed an idle desktop screen. Monitors were typically either fluorescent backlit LCD displays or cathode ray tube displays. To reduce computer energy consumption, 90% of the RSF occupants use laptop computers with LED backlit LCD monitors. Figure 5-1 shows the measured load profile of a laptop computer and two, 22-in. LED backlit LCD monitors.

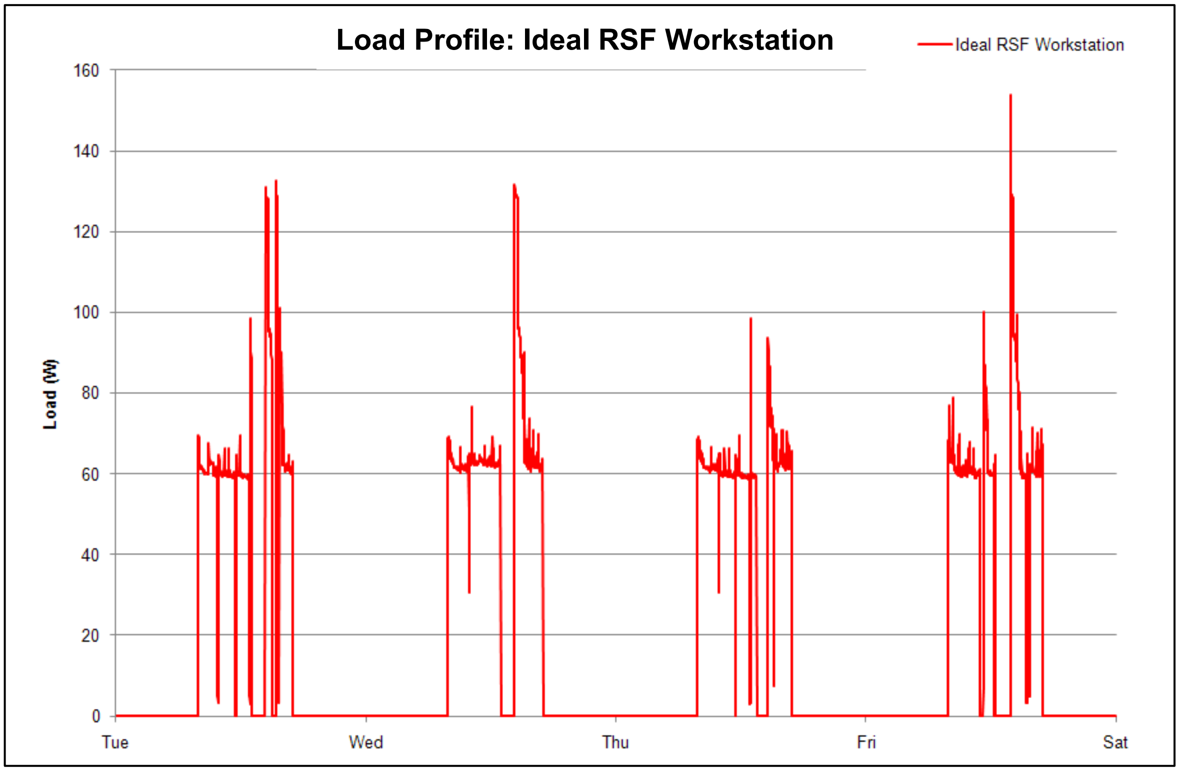


Figure 5-1 Load profile of a laptop computer and two monitors with ideal control and user behavior
(Credit: Chad Lobato/NREL)

The average power draw for this laptop and display combination was 54 W during occupied hours and 5 W during unoccupied hours. Further savings during unoccupied hours are achieved with a load-sensing controlled outlet on a power management surge protector to eliminate the parasitic load of the docking station (see Figure 5-1).

The previous strategy for dealing with idle computers was to lock them out after 15 minutes and display a security screensaver. The screensaver increased average power by 5 W compared to an idle state (30–35 W for a laptop locked out in the security screensaver versus 25–30 W for a laptop in use). Setting the monitor into a standby state while the computer runs the screensaver reduces power draw, but is not an optimal solution. Setting both the computer and monitor into standby saves the most energy, reducing power from 25–30 W to 5 W. To further reduce computer energy use, the computers used in the RSF have been set to put the monitor into standby after 5 minutes of idle time, and then the computer into standby after 15 minutes of idle time. As previously stated, the built-in standby functionality has not performed as intended. The users have been instructed to manually force standby to reduce energy use.

Additional equipment in the previously occupied workspaces included a task light, a phone, and miscellaneous items such as cell phone chargers, lights (decorative or functional, or both), mini-refrigerators, coffee pots, electric teapots, fans, personal heaters, label makers, and radios. The task lighting used traditional linear fluorescent lamps and fixtures and the phones were standard models. These items received power from standard six-plug surge protectors.

The RSF workstations feature efficient 6-W LED task lighting and voice-over Internet protocol phones that consume a constant 2 W. NREL IS power settings turn off the LCD screens on these phones after 1 minute of idle time. All other items have been discouraged or allowed only as approved. Some users initially wished to bring the additional equipment from the previous office space. NREL provided employees with educational documentation that discussed the building's specifics and goals and emphasized the impact the building occupants have on overall energy use. The effort increased buy-in by helping employees understand why the equipment was being limited.

We intended that power at the workstation be controlled by a load-sensing power strip that has a 1.5-W parasitic load. It has two pairs of controlled outlets and four always-powered outlets. It is designed so that when power draw on one of the paired sensor outlets drops, power is cut to the sensor outlet and paired controlled outlet. It is desktop mounted so the main power button is easily accessible. We evaluated and compared this to other available devices and determined it was a suitable option; however, the evaluation process discussed in this report was not yet developed. In practice, the installed control devices have not performed as expected. Their load sensing is inconsistent, causing equipment to be de-energized at inappropriate times or not at all. This has caused some usability issues, so occupants are bypassing the control outlets and using only the always-powered outlets. Also, its parasitic load is higher than that of the equipment it controls.

5.1.2.2 Equipment and Operation Guidelines for Workstations

Workstations represent a significant fraction of office building PPLs and overall building energy use. Moorefield et al. (2008) found that computers and monitors account for the largest share of PPLs energy use in office spaces. Computers are usually their biggest energy users. An in-use standard desktop computer will consume 100 W on average (Lobato et al. 2011). Replacing desktop computers with laptop computers, which have an average power draw of 30 W while in use, saves considerable energy. The champion needs to work with information technology representatives to implement computer power options that save energy. Computers that sit idle or that run screensavers waste considerable energy (see Figure 5-2 below).

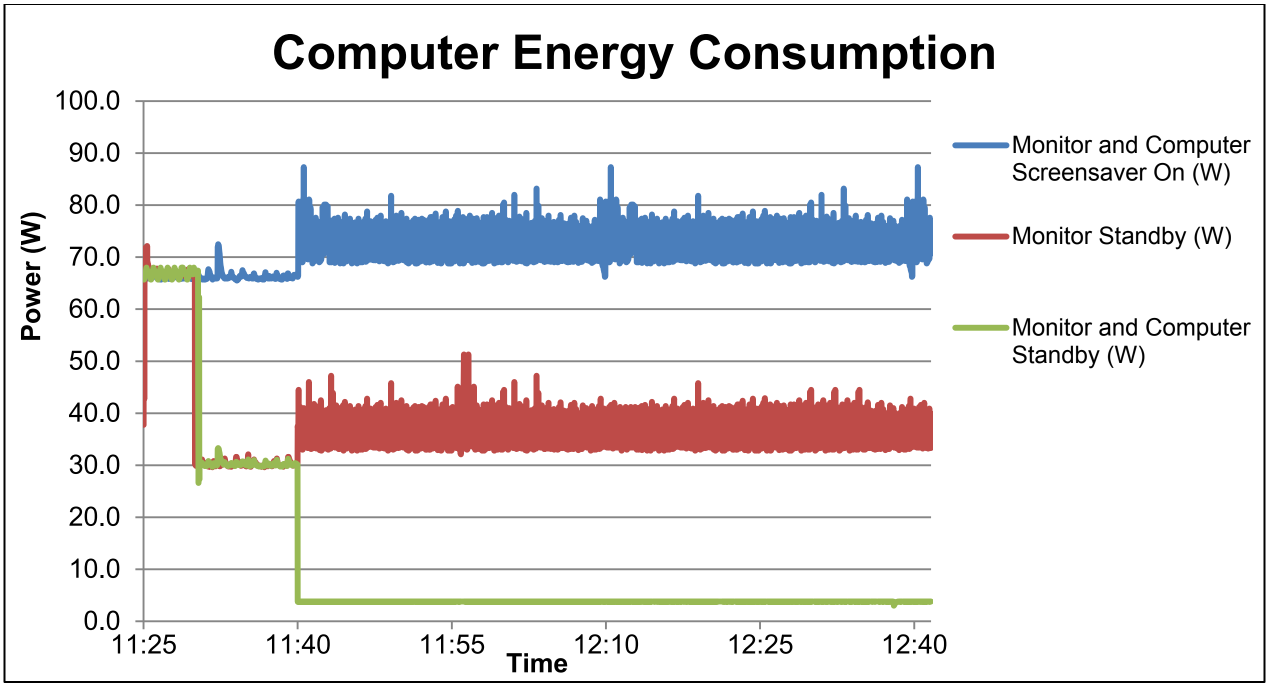


Figure 5-2 **Load profile of a computer and two monitors with various screensaver and power management settings. (Credit: Chad Lobato/ NREL)**

Figure 5-2 shows that the screensaver causes computers to consume on average 5 W more than an idle computer. Instead of a screensaver, if the monitors are set to go into standby after five minutes of inactivity, there would be a savings of 36 W. Additional savings can be had if the computer is set to go into standby after 15 minutes of inactivity (a total of 68 W compared to the base case). Power management options should be set such that computers and monitors go into standby or sleep mode after 15 and 5 minutes of idle time, respectively. If built-in power management functionality is ineffective, third-party software solutions should be implemented to achieve reliable standby operation.

Monitors are the next-largest energy consumer at workstations. A powered-up cathode ray tube monitor can draw as much as 70 W. Replacing old monitors with energy-efficient LCD monitors saves energy. To achieve the greatest savings, LED backlit LCD monitors should be used. A powered-up 19-in. fluorescent backlit LCD monitor uses approximately 30 W; a powered-up 19-in. LED LCD monitor uses 10 W.

Depending on the number of workstations, replacing computers and monitors can be a very costly measure. If capital is not available, you can replace equipment in stages as the project budget allows, or when older pieces fail. For the NREL RSF project, the normal turn-over rate on computers is 3 years and with a procurement strategy, nearly all equipment has now been replaced with energy efficient equipment.

Incandescent or fluorescent tube task lighting should be replaced by efficient compact fluorescent lamps or LED task lighting. Replacing standard phones with low-power voice-over Internet protocol phones provides additional workstation savings.

Office workstations are often equipped with personal single-function devices such as printers, scanners, and fax machines. Consolidating these items into shared multifunction devices reduces

PPLs and saves energy. Further savings can be realized by enabling the power option settings on the multifunction devices to go into standby after 15 minutes of idle time.

5.1.3 Break Rooms and Kitchens

5.1.3.1 Research Support Facility Break Room and Kitchen Equipment and Controls

A key design team contribution to reducing PPLs included maximizing space efficiency in shared areas. The previously occupied NREL office buildings had break rooms with refrigerators, microwaves, coffee pots, drinking fountains, and vending machines. Each served approximately 40 occupants. The RSF features the same amenities, but each break room serves approximately 60 occupants, which reduced the number of energy-consuming appliances. Further savings are achieved with efficient refrigerators (48 W average load) and by eliminating mechanically cooled drinking fountains. The kitchens have ample refrigerator space, dishwashers, coffee makers, and microwaves to eliminate the need for personal equipment. Where available, all equipment is best-in-class Energy Star specified equipment. Management and safety policies disallow the use of personal equipment at individual workstations. Special cases are considered for business or other justified reasons.

The nonrefrigerated kitchen appliances are controlled by digital timer-controlled power strips.

5.1.3.2 Equipment and Operation Guidelines for Break Rooms and Kitchens

Old refrigerators can waste energy. Aging, inefficient refrigerators should be replaced with the most efficient full-size ENERGY STAR refrigerators. All personal mini-refrigerators and underused full-size refrigerators should be removed. The PPL audit performed on the NREL coffee kiosk revealed that mini-refrigerators can use the same energy as full-size refrigerators.

Items such as coffee pots, toasters, and microwaves should be upgraded with units that have limited parasitic loads from status LED lights or displays. In many cases, the lights and displays are not needed and waste energy. These items should be powered by electrical outlet timers so they are powered down during unoccupied hours.

Vending machines can consume a large amount of energy. Underused machines should be removed and aging, inefficient machines replaced with the most efficient ENERGY STAR equipment. Removing the display lighting yields additional energy savings. Deru et al. (2003) found that combining a load-managing device with delamping could reduce energy consumption in vending machines by 45%–55%. Many such devices are commercially available; the simplest is an electrical outlet timer.

The drinking fountain coolers should be removed or disconnected. Bottled water coolers should also be removed. Filtered water at each sink replaced bottled water dispensers which not only use energy as a PPL, but also require trucking water to the site.

5.1.4 Elevators

5.1.4.1 Research Support Facility Elevators and Controls

The RSF employs energy-efficient regenerative traction elevators rather than the standard hydraulic elevators that typically operate in low-rise office buildings. Each has a potential annual saving of 7000 kWh (KONE 2006), depending on use, compared to standard hydraulic elevators. Each is equipped with energy-efficient fluorescent lighting and fans, which are turned off when the car is unoccupied. The stairwell design is inviting (to encourage their use), with wide steps and windows for daylighting and mountain views.

Occupancy-controlled lighting and ventilation are installed in RSF elevators. This helps to reduce loads when the cars are unoccupied.

5.1.4.2 Equipment and Operation Guidelines for Elevators

Elevator car lighting and ventilation are typically powered whether or not the car is occupied. Adding occupancy sensors to control lighting and ventilation saves energy.

5.1.5 Telecommunications Room Equipment

5.1.5.1 Research Support Facility Telecommunications Room Equipment and Controls

Standard equipment is used and no control strategies are implemented in the RSF.

5.1.5.2 Equipment and Operation Guidelines for Telecommunications Rooms

Typical telecommunications rooms provide continuous power to all Ethernet switches and ports. To reduce PPLs, these switches and ports should be intelligently powered and enabled based on occupant needs.

5.1.6 Conference Room Equipment

5.1.6.1 Research Support Facility Conference Room Equipment and Controls

Conference rooms use video projectors, high-definition multimedia interface switchers and extenders, Blu-ray and DVD players, wireless microphone systems, integrated controllers, speaker systems, audio amplifiers, and electric projector screens as standard equipment. PPL controls were not implemented for the RSF conference rooms.

5.1.6.2 Equipment and Operation Guidelines for Conference Rooms

Conference rooms are subject to varying use schedules. A key to reducing PPL energy use is to 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. Beyond load control, the space should be outfitted with energy-efficient equipment. LED backlit LCD televisions and energy-efficient audiovisual equipment should be used. Policies should be implemented to address equipment that is supplied by individual users and that is only temporarily powered. The policies would require use of efficient equipment that is powered only when needed.

5.1.7 Small-Scale Food Service Areas

5.1.7.1 Research Support Facility Equipment and Controls

A coffee kiosk provided a variety of hot and cold beverages and food to occupants in three of NREL's previous office buildings. The espresso machine and water heater were powered up all day and all night. The espresso machine had a continuous average load of 455 W. Multiple glass-front mini-refrigerators were used to store food and cold drinks. Overall, it had an average continuous load of nearly 1400 W.

The RSF coffee kiosks are significantly more energy efficient. The espresso machines go into standby mode when they are not in use during occupied hours, and are turned off during unoccupied hours. The manufacturer claims a 30% in-use energy saving (General Espresso Equipment Corporation 2009). They have an estimated continuous average load of 150 W each. Food and cold drinks are stored in full-size refrigerators with nontransparent doors. All mini-refrigerators have been eliminated. Four coffee brewers automatically reduce the water temperature in their boilers when idle. Mechanical switches cut power to all items except the refrigerators, freezers, and cash registers during unoccupied hours. Overall, the coffee kiosks have an estimated average continuous load of nearly 700 W each. The ice machines are controlled by electrical outlet timers to turn off during unoccupied hours, which reduces continuous power draw from 327 W to 110 W each. The RSF has two ENERGY STAR soda vending machines and one snack vending machine that feature efficient LED display lighting, which is controlled by occupancy sensors.

5.1.7.2 Equipment and Operation Guidelines for Small-Scale Food Service Areas

As with the break rooms and kitchens, replacing aging, inefficient equipment with the most efficient ENERGY STAR rated equipment saves energy. Food service areas present unique challenges because they are often outfitted and operated by outside vendors. It is important to set contractual requirements and to work with vendors to ensure energy-efficient PPLs and operations in these areas. For example, refrigerators should be required to have solid front doors rather than glass doors. A glass door refrigerator can use twice the energy of a similarly sized solid front refrigerator. Multiple mini-refrigerators should be consolidated into fewer full-size refrigerators to save energy.

Food service equipment can have large parasitic loads when the space is unoccupied. Electrical switches, or a similar method, should be provided to easily disconnect power to all nonessential equipment during nonbusiness hours. Cutting the loads during nonbusiness hours drastically reduces annual energy use. Contractual requirements should be set to ensure outside vendor equipment is disconnected and powered down during nonbusiness hours.

For equipment that is not rated by ENERGY STAR, those responsible for specification and procurement should work directly with manufacturers to determine the most efficient option. Many manufacturers offer low-energy options.

5.1.8 Miscellaneous

5.1.8.1 Equipment and Operation Guidelines for Miscellaneous Areas

For office buildings that have large file storage needs, motorized compact shelving units should be replaced with manual hand crank compact shelving units to save energy. Compact shelving manufacturers offer manual models that provide adequate gearing in the hand crank to limit the effort needed to move the shelving.

Management policies should be implemented to address PPLs. They should minimize or eliminate personal electronic equipment (coffee makers, fans, heaters, mini-refrigerators, decorative lighting, etc.) at the workstations. The policies should establish a standardized list of the energy-efficient equipment to be used in the building, and provide a process for addressing atypical circumstances and granting exceptions.

Items such as lobby displays, ice machines, and exercise equipment can be effectively controlled by outlet timers, which should be configured so the equipment is powered up only during business hours.

For new construction and extensive retrofits, it is good practice to aggregate plug loads onto dedicated electrical panels. With dedicated plug load panels, the circuits can be integrated with the building control system to turn off all plug loads during unoccupied times. These panels also allow for easy submetering.

Plug loads often depend heavily on occupant behavior and equipment operation. To maximize savings, office building owners need to educate employees about the energy impacts of their behaviors.

6.0 Conclusion

PPLs are found in every building type. In a minimally code-compliant building, they may account for up to 25% of the total building energy use, but as buildings become more efficient, that number can increase to as high as 50%. Occupants in office buildings are typically seated at their desks for 10% of the year. Using a control strategy to match plug load use to occupancy is a huge untapped potential for energy savings.

The importance of controlling PPLs was low in the past, as the energy use has historically been small relative to other building energy end uses. Also, the loads vary drastically, which complicates the control. As the other building systems become more efficient, the energy performance of buildings is driven more by occupant behavior and the resulting PPL energy use. PPLs are unique loads that provide multiple functions and services, and are variously operated. Building design teams are rarely held accountable for PPLs because they are owner specified and are highly occupant dependent. At the same time, building owners and occupants do not always know what is required to specify, procure, and operate PPLs energy efficiently.

To complicate matters, manufacturers are starting to bring products to market to reduce PPL energy use. Each claims savings, but few provide the detailed information needed to make an educated decision about the best control strategy for a given PPL.

The same PPL type may have completely different use patterns from one location to another. Control schemes must therefore be individually tailored. Presently, no single device can control all PPLs properly. This, paired with the ever-growing market for control devices with limited product information, drives the need for the guidance provided by the flowchart discussed in this paper. The flowchart removes some of the confusion associated with PPL controls and provides a roadmap for you to select an appropriate control. You can then evaluate a condensed list of available devices that offer the appropriate control to determine which best meets your needs. In existing buildings, equipment needs to be inventoried and benchmarked (see Section 2.1). This process will help you understand what is needed to meet the occupants' business needs. Then these needs should be met as efficiently as possible. Only then can the control provide the highest energy savings.

Computers are unique and challenging PPLs; they are also among the most common PPLs in commercial buildings and therefore require specific attention. In office buildings, computers quickly become major energy consumers because they are typically provided for all building occupants. Reducing their energy consumption when not in use may save significant energy.

Computers are generally set up at workstations that feature multiple secondary devices. When energy-efficient equipment such as LED backlit computer monitors and LED task lights replace equipment with dated technology, the parasitic load is reduced to the point that controlling the computer becomes the main concern.

A desktop computer should not be de-energized without going through a proper shutdown procedure. A laptop computer can be de-energized because of the built-in battery backup, but if it is left in an idle state the battery can fully discharge before a proper shutdown procedure is performed. Thus, computers should not be controlled by scheduling or occupancy-based control devices. They also should not be set up as secondary devices that are controlled by load sensing on a primary device.

Computers are primary devices that must rely on manual control, built-in low-power states, or third-party hardware and software solutions that perform the needed tasks to transition them from a ready-to-use state to a low-power state. Manual control can be effective, but it is not consistent and can vary depending on the users. Additional control should be implemented to account for this inconsistency. This is where the built-in low-power state should provide the main control. Unfortunately, this control can become as inconsistent as manual control. Once computers are configured to meet the user needs, installed programs could maintain processes that do not allow the computer to transition to the low-power state.

Ideally, the built-in functionality would operate consistently and provide the control needed to decrease energy consumption in computers. This, however, is not the case. Third-party programs can be used to improve the built-in functionality. Hardware and software options are available that force a transition to a low-power state based on user input. Other software options use computer idle time and scheduling to force the transition without relying on user input. These solutions are temporary fixes until the built-in functionality can be improved to work consistently in all installations. Computer manufacturers need to focus on this to enable the greatest PPL energy savings. Once computers can reliably and consistently go into low-power states, they can be used reliably as the sensed (primary) device in a load-sensing control scheme to control secondary devices.

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Appendix A Flowchart for Selecting a Control Strategy for Plug and Process Loads

A.1 Flowchart Sheet A

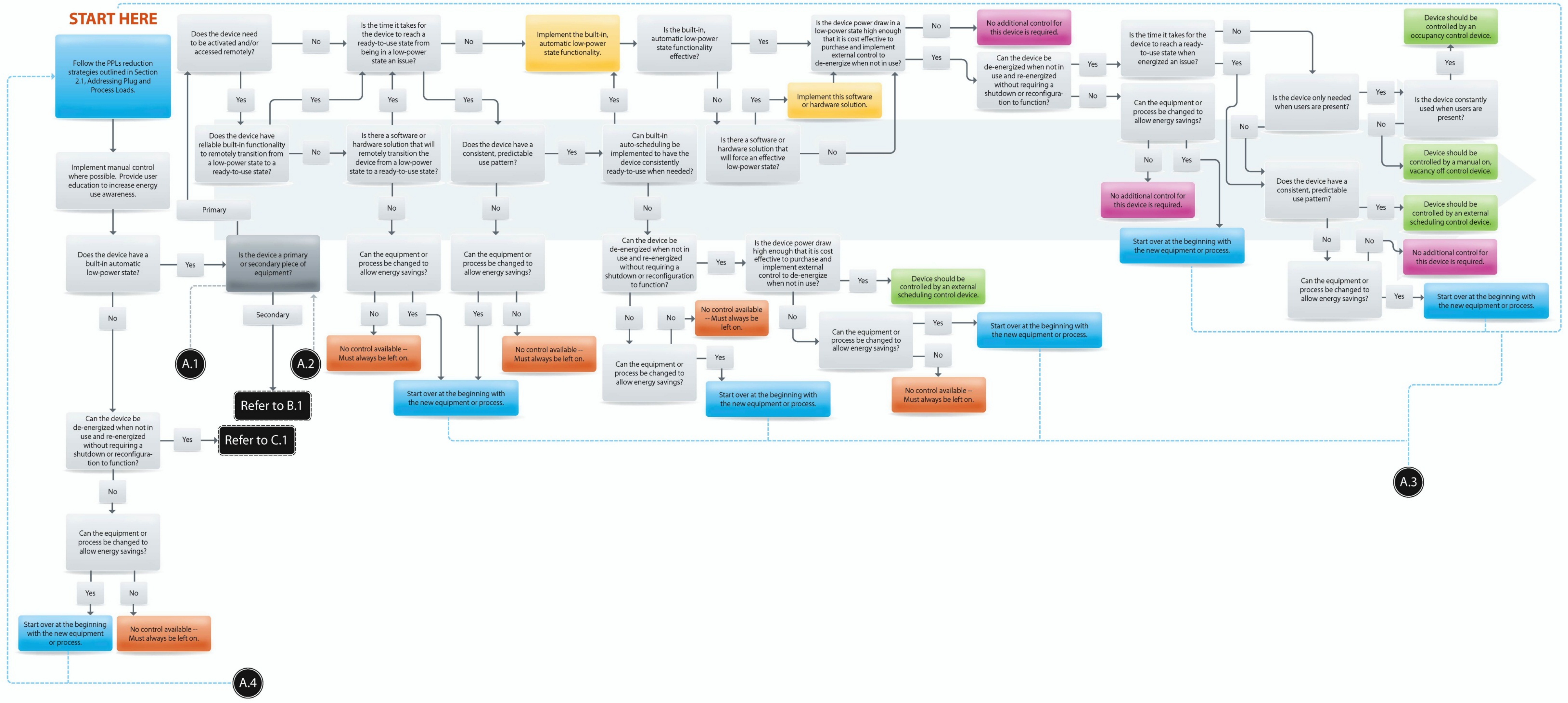


Figure A-1 PPL control selection process flowchart: Sheet A

(Credit: Joelynn Schroeder/NREL)

A.2 Flowchart Sheet B

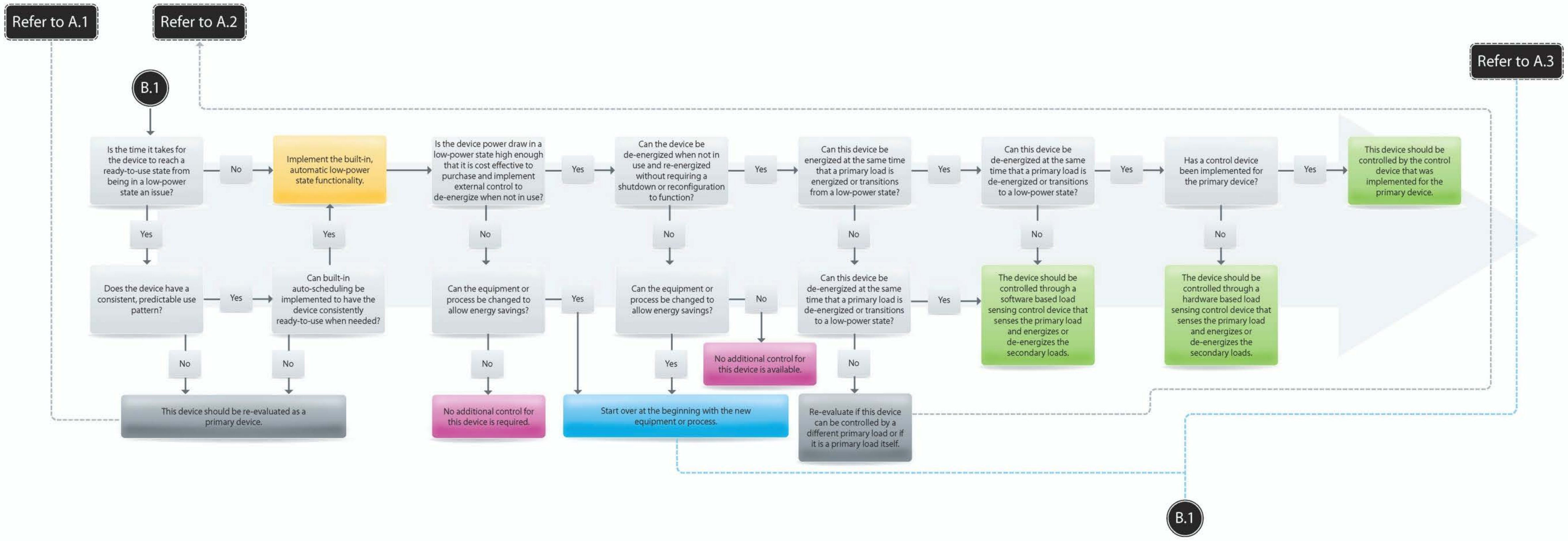


Figure A-2 PPL control selection process flowchart: Sheet B

(Credit: Joelynn Schroeder/NREL)

A.3 Flowchart Sheet C

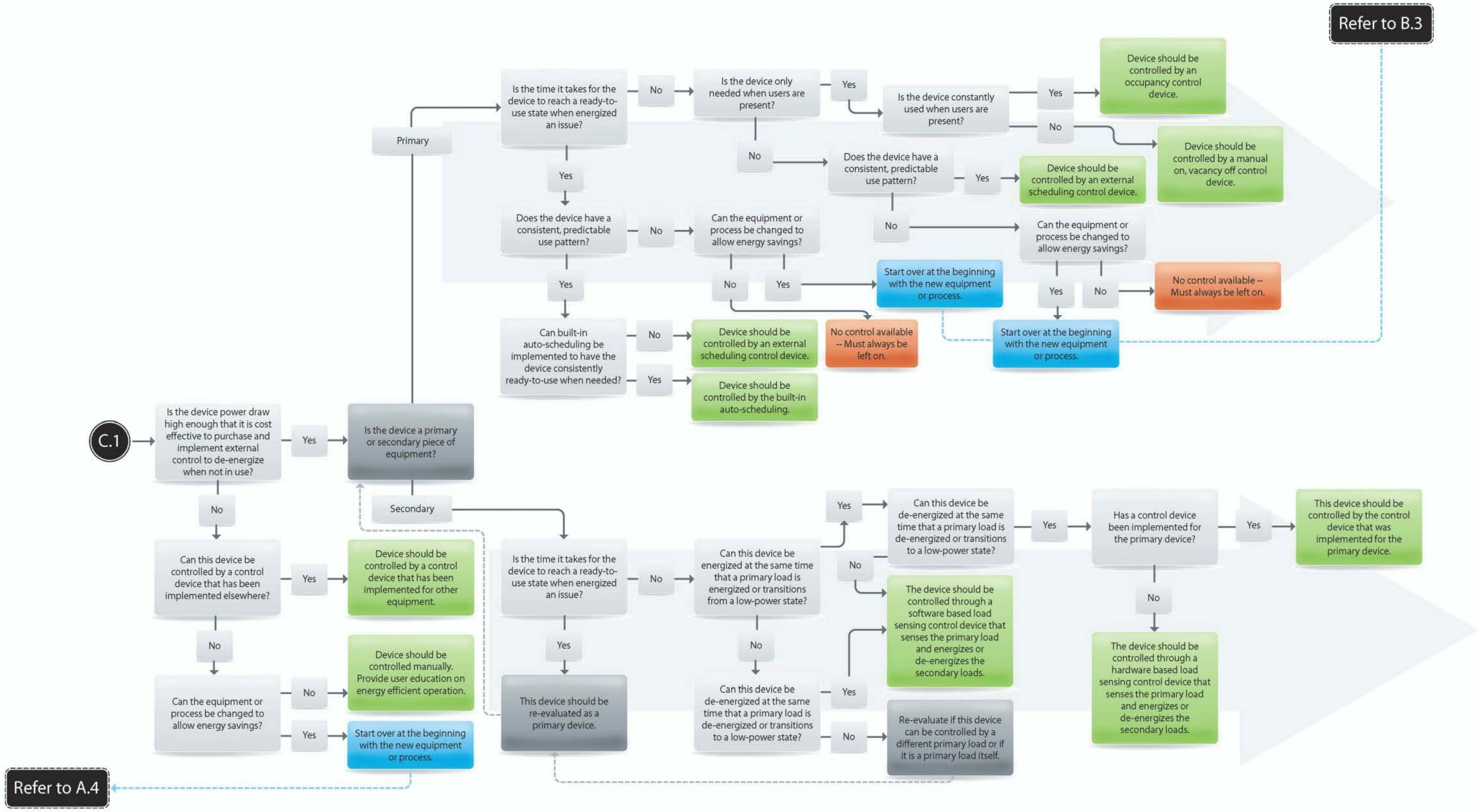
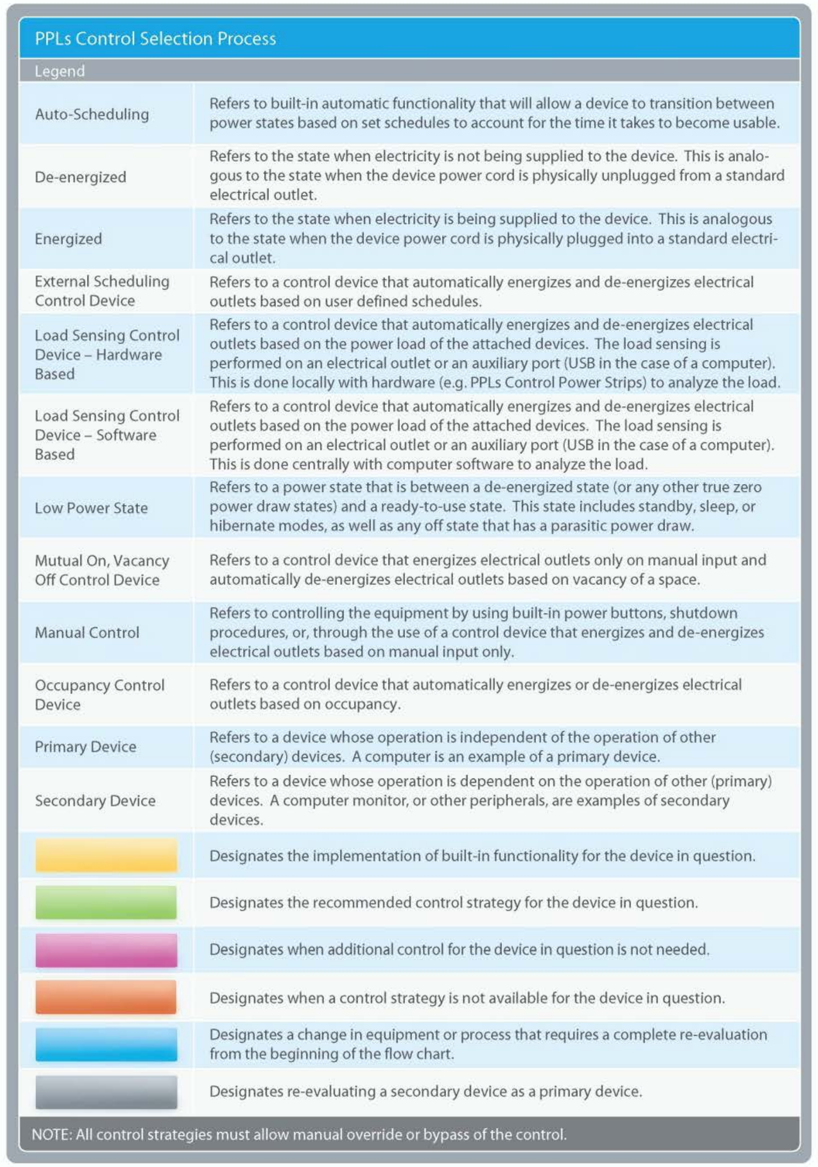


Figure A-3 PPL control selection process flowchart: Sheet C

(Credit: Joelynn Schroeder/NREL)

A.4 Flowchart Legend



PPLs Control Selection Process

Legend	
Auto-Scheduling	Refers to built-in automatic functionality that will allow a device to transition between power states based on set schedules to account for the time it takes to become usable.
De-energized	Refers to the state when electricity is not being supplied to the device. This is analogous to the state when the device power cord is physically unplugged from a standard electrical outlet.
Energized	Refers to the state when electricity is being supplied to the device. This is analogous to the state when the device power cord is physically plugged into a standard electrical outlet.
External Scheduling Control Device	Refers to a control device that automatically energizes and de-energizes electrical outlets based on user defined schedules.
Load Sensing Control Device – Hardware Based	Refers to a control device that automatically energizes and de-energizes electrical outlets based on the power load of the attached devices. The load sensing is performed on an electrical outlet or an auxiliary port (USB in the case of a computer). This is done locally with hardware (e.g. PPLs Control Power Strips) to analyze the load.
Load Sensing Control Device – Software Based	Refers to a control device that automatically energizes and de-energizes electrical outlets based on the power load of the attached devices. The load sensing is performed on an electrical outlet or an auxiliary port (USB in the case of a computer). This is done centrally with computer software to analyze the load.
Low Power State	Refers to a power state that is between a de-energized state (or any other true zero power draw states) and a ready-to-use state. This state includes standby, sleep, or hibernate modes, as well as any off state that has a parasitic power draw.
Mutual On, Vacancy Off Control Device	Refers to a control device that energizes electrical outlets only on manual input and automatically de-energizes electrical outlets based on vacancy of a space.
Manual Control	Refers to controlling the equipment by using built-in power buttons, shutdown procedures, or, through the use of a control device that energizes and de-energizes electrical outlets based on manual input only.
Occupancy Control Device	Refers to a control device that automatically energizes or de-energizes electrical outlets based on occupancy.
Primary Device	Refers to a device whose operation is independent of the operation of other (secondary) devices. A computer is an example of a primary device.
Secondary Device	Refers to a device whose operation is dependent on the operation of other (primary) devices. A computer monitor, or other peripherals, are examples of secondary devices.
🟨	Designates the implementation of built-in functionality for the device in question.
🟩	Designates the recommended control strategy for the device in question.
🟪	Designates when additional control for the device in question is not needed.
🟧	Designates when a control strategy is not available for the device in question.
🟦	Designates a change in equipment or process that requires a complete re-evaluation from the beginning of the flow chart.
⬜	Designates re-evaluating a secondary device as a primary device.

NOTE: All control strategies must allow manual override or bypass of the control.

Figure A-4 Flowchart Legend

(Credit: Joelynn Schroeder/NREL)

Appendix B Minimum Power Draw to Justify Control

Sections B.1 through B.5 show the minimum average power draw for a PPL that is not in use that can be cost effectively controlled by a control device. The graphs were developed assuming 9 hours of operation per work day and 250 work days per year. They vary by the assumed payback period. For a given utility rate, all PPLs with an average power while not in use above the line should be controlled. If a PPL's power is below the line, controlling it is not cost effective. Figure B–1 through Figure B–5 show 1-, 3-, 4-, 5-, and 10-year paybacks.

B.1 One-Year Payback Period

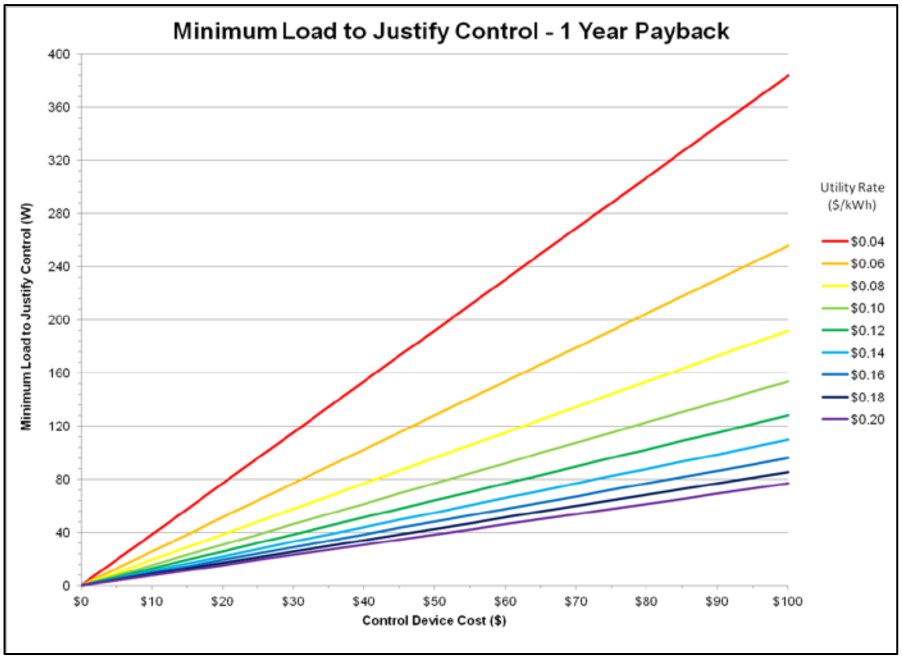


Figure B–1 Minimum load that can be cost-effectively controlled by a control device – 1-year payback

(Credit: Chad Lobato/NREL)

B.2 Three-Year Payback Period

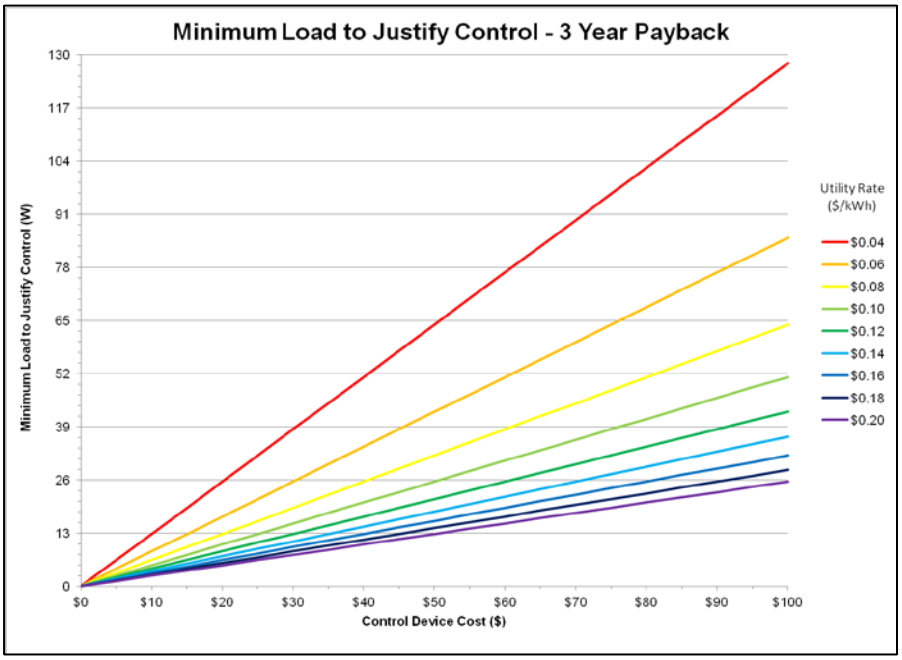


Figure B–2 Minimum load that can be cost-effectively controlled by a control device – 3-year payback

(Credit: Chad Lobato/NREL)

B.3 Four-Year Payback Period

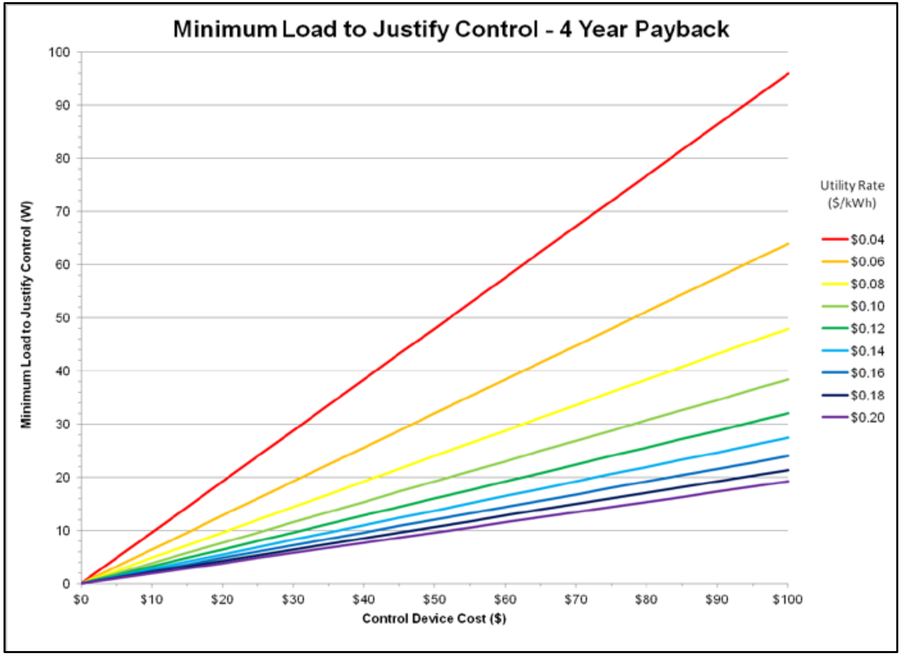


Figure B–3 Minimum load that can be cost-effectively controlled by a control device – 4-year payback

(Credit: Chad Lobato/NREL)

B.4 Five-Year Payback Period

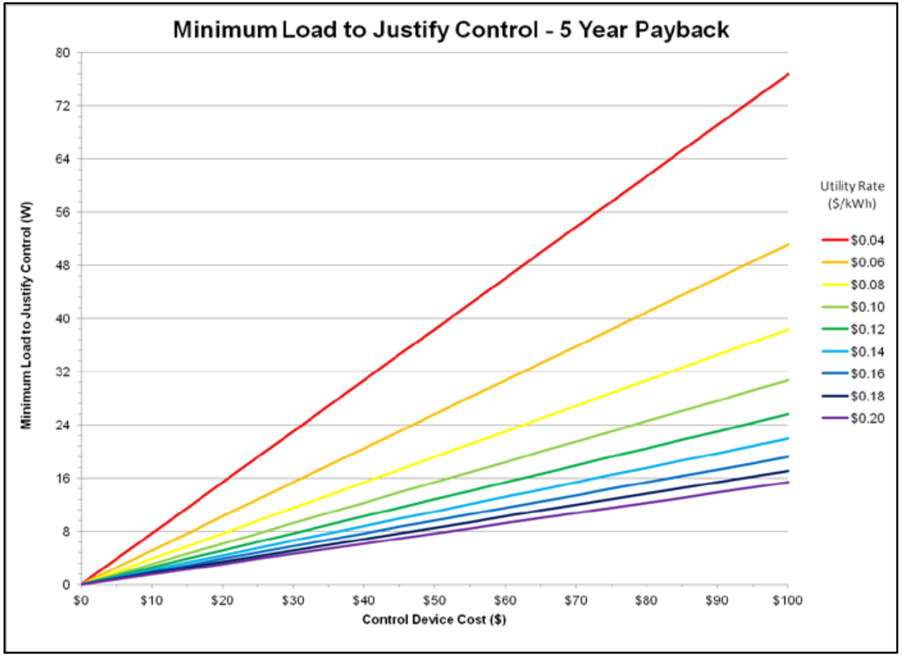


Figure B–4 Minimum load that can be cost-effectively controlled by a control device – 5-year payback

(Credit: Chad Lobato/NREL)

B.5 Ten-Year Payback Period

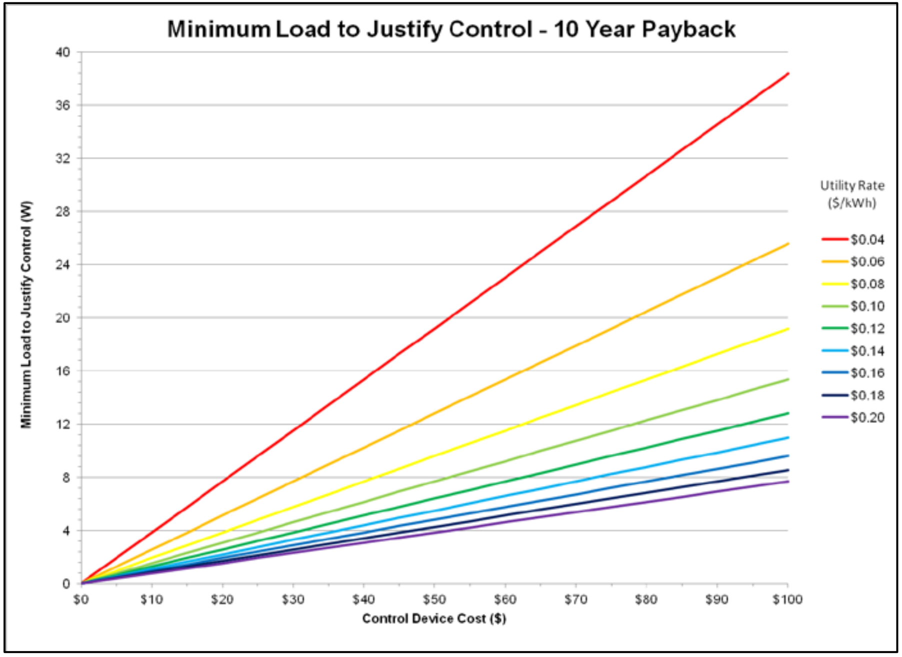


Figure B–5 Minimum load that can be cost-effectively controlled by a control device – 10-year payback

(Credit: Chad Lobato/NREL)

Appendix C Control Devices

The parasitic load of each control device was measured with a Watts Up? Pro ES meter. This meter has known inaccuracies, which are discussed by Frank et al. (Frank 2010). The table below represents a sample of testing that NREL conducted on select control devices. This table is not a comprehensive list of equipment available and represents a sample of control devices on the market at the date that NREL did the testing. It should be used as a template for others to study.

Table A - 1 List of Tested Control Devices

Device Name	Control Type	Metering Capable?	Parasitic Load (W)		Number of Outlets
			Energized	De-energized	
ThinkEco Modlet	Schedule – Wireless	Yes	0.3	0.3	2
Jetlun Appliance Module and Gateway	Schedule – Wireless	Yes	1.1	1.1	1
Belkin Conserve Switch	Switch – Wireless	No	0.9	0.1	8
Belkin Conserve Surge with Timer	Schedule – Built-In Timer; Switch – Wired	No	0.1	0.0	8
Isole IDP-3050 Power Strip with Personal Sensor	Occupancy	No	2.6	2.6	8
Lightning Switch Continental Transmitter and Plug-In Receiver	Switch – Wireless	No	0.1	0.6	1
GE Digital Strip Timer (GE06694)	Schedule – Built-In Timer	No	0.9	0.9	8
EcoStrip USB 2.0	Power Level Sensed – USB	No	0.0	0.0	6
iGo Power Smart Tower	Power Level Sensed – Plug	No	1.5	0.1	8
Belkin Conserve Smart AV	Power Level Sensed – Plug	No	0.0	0.0	8