Automatic Receptacle Controls: How Understanding User Behavior Can Drive Adoption at Scale

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ABSTRACT

Most building system energy use is expected to decline in the future. However, plug and process are loads are expected to grow in the future. Plug loads (devices that are not hard-wired and are plugged into the wall) are expected to grow despite energy codes requiring automatic off functionality in some spaces. Automatic receptacle control (ARC) is an energy code requirement for plug load controls in certain spaces in a commercial building, the receptacle (also known as an outlet) turned off when the space has been unoccupied for more than 20 minutes.

Plug and process loads are highly dependent on the behavior of building occupants, and methods of taming these loads are necessary to achieve the Biden Administration's goals to achieve carbon pollution-free electricity by 2035.

For ARCs to function and save energy, diverse users must be able to easily differentiate ARCs from other receptacle types (e.g., USB, GFCI, isolated ground, or general receptacles). Once a user correctly identifies the ARC, the user must then determine which electric devices to plug into the ARC because not all devices are suitable for ARC operation. The power draw, start-up time, integral energy saving modes, and other features may affect a user's decision to plug a device into a controlled receptacle.

This paper presents data from multiple studies on user behavior related to ARCs, including results of a 2023 and 2024 surveys of user preferences, choice of devices, and recommendations for policymakers.

The results will support DOE research investments and help inform efficiency programs of the potential of these emerging technologies, and how they may fit within the clean energy future.

Introduction

This paper summarizes three surveys related to the behavior of those who might interact with automatic receptacle controls (ARCs). ARCs are plug load (devices that plug into the wall and are not hard wired) controls that automatically turn off electrical devices (e.g., table lamp, space heaters, monitors, etc.) connected to them when a space is unoccupied. The surveys were developed in response to observations of user confusion related to ARCs.

This paper will provide a review of energy saving studies related to ARCs (or similar devices), energy code requirements of ARCs, electric code requirements related to ARCs, and the survey design. Each of the three survey categories focused on different aspects of user behavior. Survey 1 focused on the best markings for users for identifying the controlled receptacle. Survey 2 (A and B) focused on if users could identify ARCs amongst other receptacle types. Survey 3 focused on which devices users would select to plug into the ARCs.

A limitation of this research is that it was conducted via survey and not via field research. Field research could have either observed what was actually plugged into ARCs or presented participants with multiple receptacles in the space and asked them to identify the ARCs.

Background

Per the Energy Information Agency (EIA) of the U.S. Department of Energy, plug and process loads account for 47% of the commercial building energy consumption (EIA 2020). Plug loads are not disaggregated in this value, but a lower portion than process loads.

Although energy codes specify overall allowed power in a building as one method to curb lighting energy usage, plug load capacity is not limited in buildings. Building designers can specify as many receptacles as desired and allowed per the overall circuit design. Therefore, to curb plug load energy usage, two main strategies are sought: 1) install more efficient equipment, and 2) reduce operating hours of the technology. Building designers have limited knowledge of the equipment intended for use in the building and therefore more efficient equipment is less a focus of building designers and more a focus of building operators. Strategies that can reduce operation can be included in building energy codes and time of construction. Reducing operating hours of the equipment while it is operating would negate the use of the technology. Therefore, plug load energy reduction strategies focus on reducing power while the equipment is either left on and not-in-use (e.g., television on lobby wall operating overnight) or when idle (not in direct use). Power reduction when the device is idle occurs in two forms: internal to the device where it goes into a low-power (sleep) state (e.g., printer) or de-energizing (e.g., turning off) the receptacle powering the device while it is idle. If a device draws power while idle, de-energizing saves energy. Product designers and energy efficiency programs (e.g., ENERGY STAR) have focused on low-power operations. This analysis focuses on strategies related to de-energizing the power to the devices.

The General Services Administration (GSA) published a review of different plug load research strategies (Institute for the Built Environment 2013). The main methods are as follows:

- ARC (automatic receptacle control): hard-wired receptacle in wall that turns off when space is not occupied.
- Advanced power strip (APS): also known as a plug strip or as a surge protector because these devices also include surge protection. These contain a strip of plugs that may contain all or some of different options listed below, and the overall device is plugged into the standard always-on receptacle.
  - Load sensing – plugs in APS that monitor power, and when load is low and constant, these plugs turn off.
  - Controlled plugs – similar to ARC, these are plugs in the APS that turn off when no occupancy is detected.
  - Timer – plugs in the APS that turn off based on a determined time schedule.
- Behavior: methods of encouraging operational changes to turn off equipment either left on or sitting idle.

As briefly described in the next section, the energy savings from these approaches vary greatly.

Energy Savings and Behavior

Plug load energy savings can be achieved by turning off receptacles using timers and occupancy sensing devices. Mercier & Moorefield (2011) found that plug load energy can be reduced by 40% in an office using power management, advanced plug strips[1] and timers, and occupant behavior measures. Another study reported a total average of 27% energy savings attributed to the use of occupancy sensor plug strips, and 28% energy savings due to the use of load sensing plug strips (Acker et al. 2012).

Metzger, Alicen, and VanGeet (2011) studied plug load and behavior by comparing three energy saving methods: 1. An automatic/technology-driven approach that turned off plug loads 15 minutes after no occupancy; 2. Behavioral change via letters educating occupants; and 3. A competition among office workers in an open plan office. The study found 21% energy savings via the automatic approach, no energy savings via the letter approach, and 6% energy savings via the competition. This suggests that automatic approaches are necessary, but also demonstrates the role occupant behavior plays in saving plug load energy.

Metzger, Cutler, and Sheppy (2012) compared a time-based control method that turned on/off the plug loads at specific unoccupied times to a load-sensing device that de-energized the plug when the load was determined to be in a low-power state and a combination of both methods at eight GSA buildings. Table 1 demonstrates the range of savings and summary of savings per method.

Table 1. Summary of Savings by Device and Control Methods from Metzger, Cutler, and Sheppy (2012)

Control	Bldg	Printer	Laptop	Monitor	Cabinet Light	Misc. Equip.	Kitchen Equip.	Total
Timer	Court 1	68%	13%	14%	14%	25%	13%	43%
Timer	Green	31%	54%	27%	34%	67%	79%	52%
Load-Sensing	Court 2	69%	-4%	-6%	N/A	51%	N/A	23%
Load-Sensing	VA	-5%	16%	11%	0%	54%	N/A	10%
Both	Court 3	18%	35%	-2%	22%	40%	N/A	23%
Both	Cohen	27%	14%	-1%	-1%	68%	N/A	12%
Avg – Timer		50%	34%	21%	48%	46%	46%	48%
Avg – Load-Sensing		32%	6%	3%	N/A	53%	N/A	17%
Avg – Both		23%	25%	-2%	11%	54%	N/A	18%

Source: Metzger, Cutler, and Sheppy, 2012.

In Metzger et. al. (2012), occupant feedback indicated a lack of education in some instances. Thorough education programs were recommended for any future installations. As the authors explained, schedule timer controls are simple and easy to understand for users, which led to larger energy savings in this study. Load-sensing controls are more complicated and difficult to understand leading to complaints and disabling in some instances, which resulted in limited energy savings.

[1] Note plug strips (also known as power strips) are not the focus of this study, but these studies demonstrate the savings potential from similar technologies that turn on/off based on occupancy.

Metzger et. al. (2012) revealed a number of best practices for future implementation of advanced power strips (APSs)[2] in GSA office spaces. At a very high level, simple devices with simple controls are desirable. There should be thorough training for all the occupants and facility site managers. Occupants should have the ability to customize their own controls to better understand and obtain ownership of the APS.

Code Requirements

ARCs were introduced into energy codes in ASHRAE/IES Standard 90.1-2010 (ASHRAE/IES 2010). Since 2010, ARCs were added to California Title 24 as well as the International Energy Conservation Code (IECC). The language across the energy codes is similar but may vary slightly. The ARC requirements specified in ASHRAE/IES Standard 90.1-2022 are presented in the box below (ASHRAE/IES 2022).

8.4.2 Automatic Receptacle Control.
The following shall be automatically controlled:

a. At least 50% of all 125 V, 15 and 20 amp receptacles in all private offices, conference rooms, rooms used primarily for printing and/or copying functions, break rooms, classrooms, and individual workstations.
b. At least 25% of branch circuit feeders installed for modular furniture not shown on the construction documents.

This control shall function on

a. a scheduled basis using a time-of-day operated control device that turns receptacles off at specific programmed times—an independent program schedule shall be provided for controlled areas of no more than 5000 ft^2 and not more than one floor (the occupant shall be able to manually override the control device for up to two hours);
b. an occupancy sensor that shall turn receptacles off within 20 minutes of all occupants leaving a space; or
c. an automated signal from another control or alarm system that shall turn receptacles off within 20 minutes after determining that the area is unoccupied.

All controlled receptacles shall be permanently marked to visually differentiate them from uncontrolled receptacles and are to be uniformly distributed throughout the space. Plug-in devices shall not be used to comply with Section 8.4.2.

Exceptions to 8.4.2: Receptacles for the following shall not require an automatic control device:

1. Receptacles specifically designated for equipment requiring continuous operation (24/day, 365 days/year).
2. Spaces where an automatic control would endanger the safety or security of the room or building occupants

[2] For research studies, APS can be quick and easily to use because they just plug in to the wall. ARCs require receptacle replacement and a communication signal which involves more work. Although APS and ARCs are different, both can turn off plug load devices either via a signal or timer. APS were included because the off mechanism is similar and occupant behavior is similar for both technologies.

Energy codes state that the receptacle shall be permanently marked to visually differentiate it from uncontrolled receptacles, but do not specify marking requirements. However, the National Fire Protection Association (NFPA) National Electric Code (NEC), NFPA 70, does specify the visual design of these markings.

Figure 1 provides a timeline of NEC changes related to ARCs. The bottom row of Figure 1 shows a standard always-on receptacle (typical ones found in homes, offices, schools, retail, etc.) and two versions of ARC.

<table>
<tr>
<td colspan="2">NEC Timeline
• 2014: NEC requires that for ARC that that the outlet should be marked with the “power” symbol (right). NEC stated that this not required for receptacles controlled by a wall switch.
• 2017: NEC requires the term “controlled” to appear on the receptacle as well; stipulates that both the power symbol and term had to be permanent and thus on the outlet and not the plate cover; and “In both cases where a multiple receptacle device is used, the required marking of the word ‘controlled’ and the symbol shall denote which contact device(s) are controlled.” (bottom right)
• 2020 and 2023: Revisions were clerical and editorial that did not relate to markings.</td>
<td></td>
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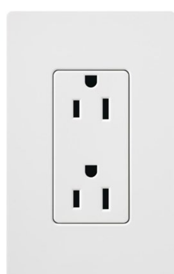
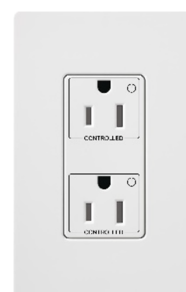
<tr>
<td>
Standard always-on receptacle</td>
<td>
Single-controlled ARC (top is controlled)</td>
<td>

Double-controlled ARC (both top and bottom)</td>
</tr>
</table>

Figure 1. Single-controlled receptacles presented to survey respondents. *Source*: Myer and Abboushi 2023.

As demonstrated in the background section of this paper, research indicates that automatic features (e.g., time-based or load-sensing features) save more energy than encouraging behavior change. However, once an ARC is installed, there are still multiple behavior interactions with the automatic device. First, can users correctly identify the controlled receptacle? This question is addressed in survey 1, which evaluated the clarity of different markings, as well as in surveys 2a and 2b, which evaluated whether users can identify the ARC among other common receptacles. Second, what devices will users opt to plug into the ARCs? This question is investigated in survey 3.

Process

Amazon Mechanical Turk (MTurk) was used to recruit survey respondents, who completed visual-based surveys hosted by SurveyMonkey. MTurk identified potential survey respondents from their large survey pool, sometimes referred to as “crowdworkers”. Because receptacles are ubiquitous and common to all buildings, no restrictions nor additional qualifications were placed on the MTurkers – anyone over 18 could participate. MTurk has been used for other visual-based and non-visual based surveys in the past. An advantage of MTurk relates to both speed and recruitment. Recruiting occurred via MTurk, and once the survey was live digitally on the platform, all 250 surveys were completed in less than 10 hours. All surveys were completed on March 1, 2023. More work and time were required with U.S. national laboratory contracting, Institutional Review Board (IRB), and Amazon’s billing practices than the survey gathering time. Per our IRB, MTurkers were incentivized around $1.70 per survey, and Amazon applies a small fee per survey. The total cost of the survey was <$600 for 250 respondents and recruiting.

In each of the surveys, multiple checks were included in the questions to verify the survey respondents were paying attention. For example:

“What is your favorite color? Read all of the items, but select none of the above regardless of your selection.”

a. Blue
b. Green
c. Red
d. None of the above

Survey 1 – Best Markings to Identify ARCs

Anecdotal evidence indicates that building occupants may be confused by ARC markings. NEC only requires that ARCs be marked with the term “controlled” and the power symbol. The limited requirements of markings by NEC allow potential confusion, especially with single-controlled ARCs. In a single-controlled ARC, one of the receptacles is controlled and the other receptacle is a standard always-on receptacle in a duplex receptacle.

Researchers reviewed the different markings of currently available products on the market (Myer and Abboushi 2023). In survey 1 (*n*=210), respondents selected which receptacle (in a side-by-side comparison) was more obvious as the ARC. Survey 1 showed single-controlled ARCs, double-controlled ARCs, as well as both high and low contrast versions of the receptacles.

Single-Controlled Receptacles

Prior to the start of the visual-based MTurk survey, the team compiled a visual inventory of market-available ARCs. This was used to develop the generic images to present to survey respondents. Some of the receptacles contained borders, some had the word “controlled” in different orientations, and the contrast ranged. For this paper, only the results from single-controlled receptacles are presented as shown in Figure 2.

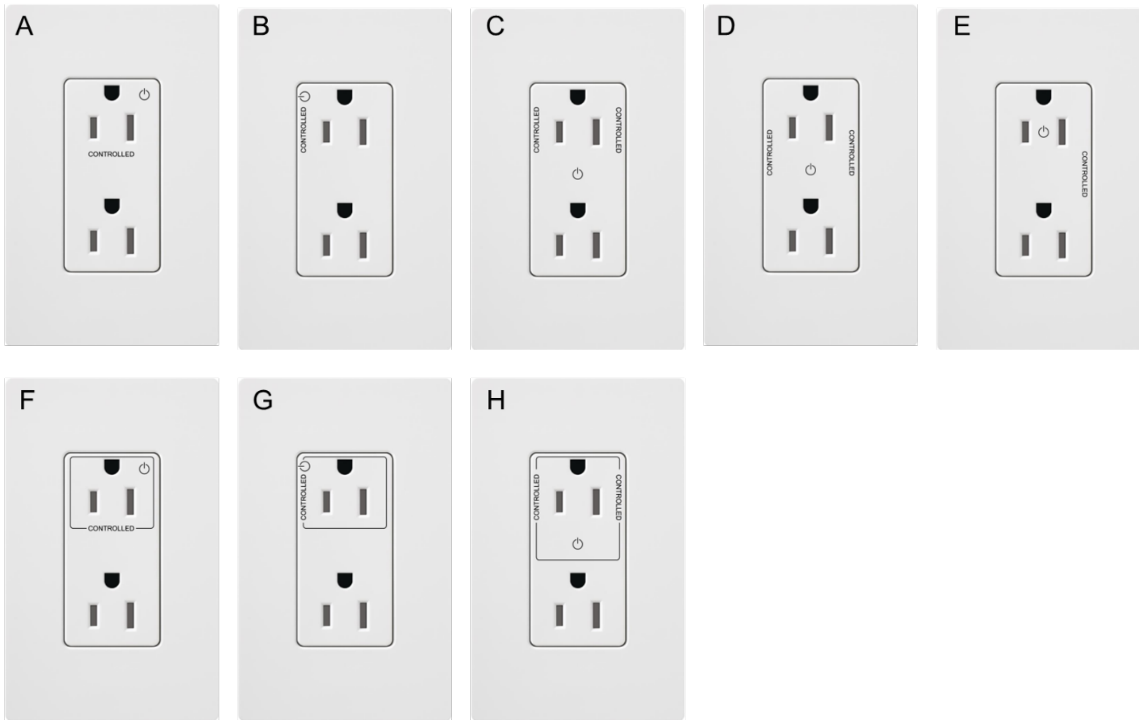


Figure 2. Single-controlled receptacles presented to survey respondents. *Source*: Myer and Abboushi 2023.

Figure 2 shows the results from Survey 1 for single-controlled receptacles. The results for double-controlled were similar. Receptacles with a border around the controlled receptacle had the highest number of times selected (styles F, G, and H) compared to the receptacles without the borders (styles A, B, C, D, and E). As shown in Figure 3, the use of the border plays a significant role in identification. Styles F/A, G/B, and H/C as shown in Figure 2 all have the “controlled” term and power symbols in the same locations, yet F, G, and H all scored higher. The only difference is that F, G, and H include the borders.

Beyond the use of the border, the orientation of the term “controlled” also played a role in identification. As shown in Figure 2, styles F and G are virtually the same, except the position and orientation of the word “controlled” and the power symbol. When the word is presented horizontally in a standard reading format, F scores higher than G. This relationship is evident in comparing A and B as well. Beyond the direct comparisons of similar styles whenever the word is presented horizontally, that style always scored higher than the other options (i.e., comparing F to G and H; and comparing A to B–E).

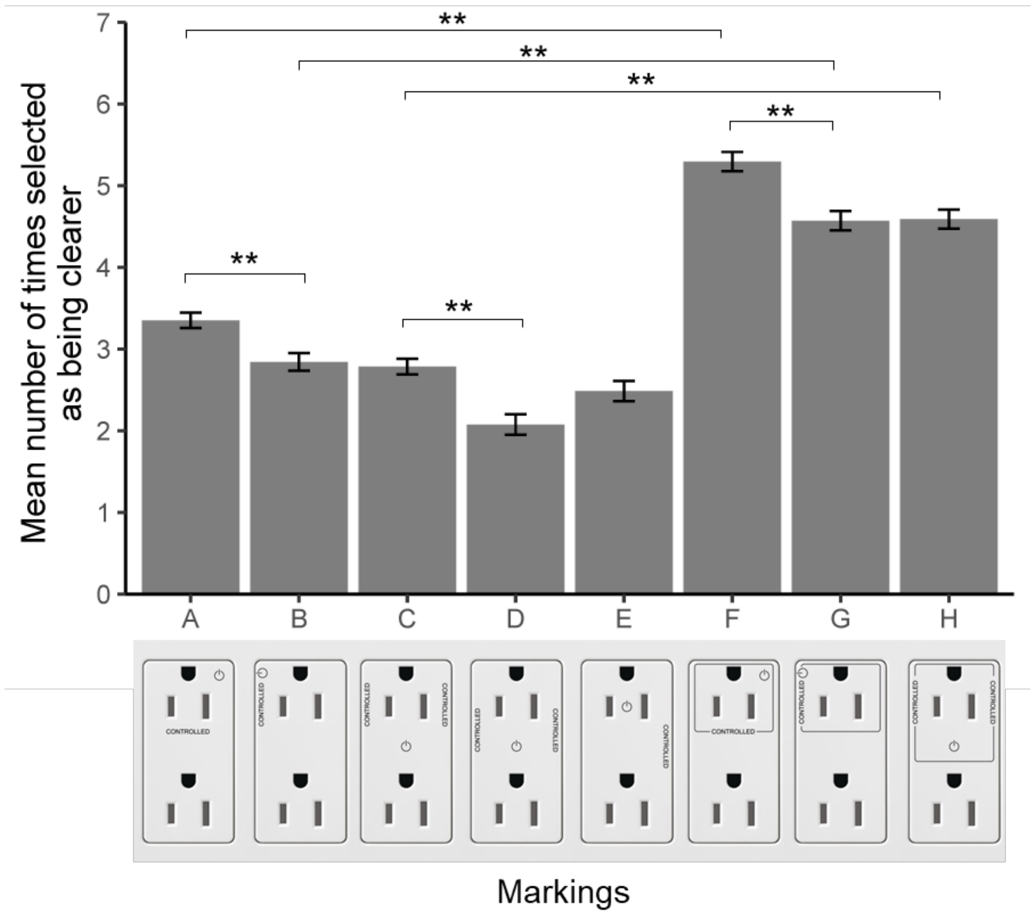
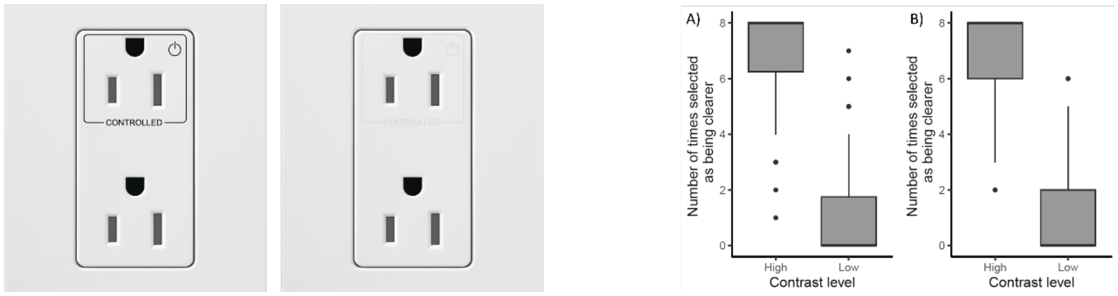


Figure 3. Results of survey 1, indicating preferred Styles F, and G and H. *Source*: Myer and Abboushi 2023. ** indicates a significant difference at the 1% level. The horizontal line shows the receptacles directly compared.

ARC Marking Contrast and Border

NEC does not have any requirements related to the contrast level of the markings. Many of the manufacturers engrave the plastic with the term “controlled” and power symbol. Engraved markings result in low contrast between the face of the receptacle and the text/symbol. Part of Survey 1, respondents were also shown samples with low and high contrast.

Figure 4(a) demonstrates the two styles of contrast presented to the survey respondents. The left image is high contrast, and the right image is low contrast (30%). The low contrast version is consistent with other products on the market. Figure 4(b) shows the results of comparing the contrast versions of receptacles. High contrast receptacles scored much higher than low contrast receptacles as shown in the Figure 4(b) by high-contrast images scoring high (gray box) and few respondents selecting the low contrast receptacles.



(a). Contrast Comparison (b). Contrast Results

Figure 4. Results of contrast questions. In panel B, boxplots show the number of times high-contrast markings were selected as being more distinct compared to low-contrast markings. Panel b/ left shows results for single-controlled receptacles and panel b/ right shows results for double-controlled receptacles. The whiskers extend to smallest and largest values, at most 1.5 × interquartile range. Values beyond the whiskers have been plotted individually (outlying points). *Source*: Myer and Abboushi 2023.

Findings from Survey 1

Contrast is a necessary requirement for reading and visual detection by the eye. Therefore, although it may seem obvious that the high contrast receptacles would yield higher response rates, the research clearly indicates it as well. Although contrast needs are well-known in vision science, the NEC does not stipulate contrast requirements. As a result, multiple products on the market use makings with a low contrast. Low contrast markings are harder for people to see, especially when viewed under a desk with reduced light levels or in other places in a building.

NEC requires the word "controlled" to be included in the receptacle. NEC does not stipulate the orientation of the word. Figure 2 demonstrates that respondents preferred horizontal orientation. However, receptacles can be oriented with the long axis in a vertical orientation. Within the vertical orientation, the receptacles could be ground pin up or down. Figures 1 and 2 show the receptacle ground pin up. If installed ground pin down, the receptacles would be 180° from those shown in Figure 1 and 2. If style F was ground pin down, although the word is written horizontally, it would be upside down for the reader. ARCs should have the term "controlled" oriented parallel to the long axis of the receptacle (i.e., styles B–E, G, H). Orienting parallel to the long axis allows for any installation orientation (e.g., vertical ground pin up, vertical ground pin down, horizontal, etc.) Preference of style H is similar to F and preference of style C is similar to A. Even with the term "controlled" along the long axis, orientation can be affected because the word could be upside down. Results of style G and H are similar. This indicates placing "controlled" twice along the long axis (style H) may best reduce any orientation issues related to reading "controlled".

In addition to contrast and the orientation of the term "controlled," borders are another key element of identification of the controlled receptacle. Style F–H (all borders) significantly outscored style A–E (none with borders). Although Figure 1 only shows the single-controlled receptacles, Myer and Abboushi 2023 also presented double-controlled receptacles. Borders were included in the double-controlled receptacle options. Similar to the results in Figure 1, the double-controlled receptacles with borders scored higher than the double-controlled receptacles without borders. Therefore, ARCs should include borders to clearly indicate the controlled receptacle.

Survey 2 – Can Users Identify ARCs

In survey 1, respondents were asked to indicate which ARC marking more clearly indicted the controlled receptacle across a variety of option but were only presented with ARCs. Survey 2, which has two components, seeks to determine how well respondents can identify ARCs when presented with other common types of receptacles. Both versions of Survey 2 asked respondents to assume that they worked in an office a set number of hours per week. Survey 2 explained that one of the two receptacles presented may turn off to save energy for devices drawing power during non-working hours (i.e., controlled receptacle). Respondents were asked to identify the controlled receptacle.

The research team reviewed the variety of receptacle types that building occupants may encounter. Ten different receptacle types including ARCs were found. To manage the overall survey size, only 5 non-ARCs were selected to be presented: 1. Standard always-on receptacle, 2. Tamper resistant receptacle marked with a “TR” on the receptacle; 3. Isolated ground receptacle marked by an orange triangle; 4. Hospital grade receptacle marked by a green circle; and 5. ground-fault circuit interrupter (GFCI) receptacle that has both a test and reset button on the receptacle. The receptacles were selected for two reasons: 1. Commonality/likelihood of experiencing that receptacle and 2. Receptacle had a marking(s) and those markings could be confused with an ARC. Table 2 shows the options presented in the survey.

Receptacle examples from Survey 1 were included in Survey 2A and B. The ARC styles with highest markings from Survey 1 as well as ARC styles with the lowest rankings were included in Survey 2A and B. Survey 2A and 2B occurred at the same time, and respondents were directed on one or the other survey. No respondents completed both versions.

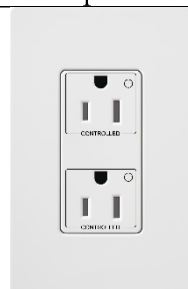
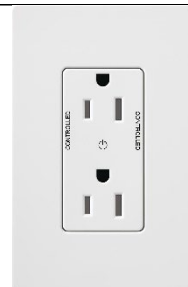
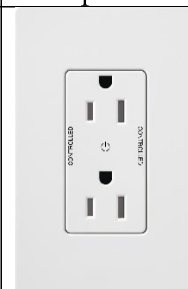
No Information Provided - Survey (2A)

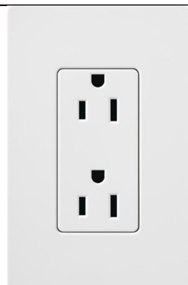
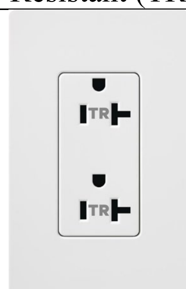
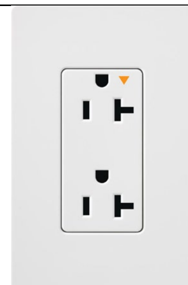
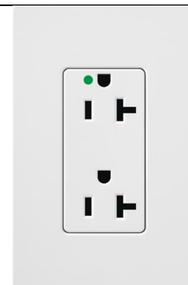
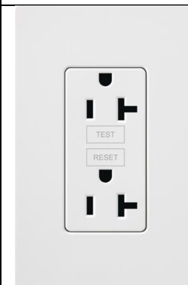
In many current installations, no information about ARCs is provided to the occupants (e.g., posted on the wall or in accessible literature). In Survey 2A, ARCs are only vaguely explained to the survey responders (i.e., turn off after hours) to avoid bias towards receptacles containing the “controlled” marking with no other specific information about the receptacles provided. Per energy codes, ARCs can be turned off via three different options. The survey standardized a time-based approach to avoid bias about ARCs.

Information Provided - Survey (2B)

In survey 2B, survey respondents were provided background information about how ARCs work and explicitly informed that that ARCs would include a marking of “controlled” on the receptacle. Providing this information allowed the surveyors to assess if the percentage of ARCs being identified increases after an explicit information is provided and if that needs to be a standard element for effective use of ARCs.

Table 2. Survey 2 receptacle options, first row are examples of ARCs from Survey 1 and second row are possible other receptacles that may be encountered in a building.

#	1	2	3	4
Description	Most clear Single ARC	Most clear Duplex ARC	Least clear Single ARC	Least clear Duplex ARC
Survey 1 ARCs				

#	5	6	7	8	9
Description	Standard	Tamper Resistant (TR)	Isolated Ground	Hospital Grade	GFCI
Potential other interior space receptacles					

Selecting the appropriate Style applies many attributes automatically.

Findings from Survey 2

Respondents were presented with two receptacles from Table 2 (#1 – 9) side by side. Respondents were asked which receptacle(s) were controlled (top left, bottom left, top right, bottom right, or none of the four receptacles). Four analyses compared:

1. Highest ranked single-ARC from Survey 1 (#1) to non-ARCs (#6 – 9);
2. Lowest ranked single-ARC from Survey 1 (#3) to non-ARCs (#6 – 9);
3. Highest ranked duplex-ARC from Survey 1 (#2) to non-ARCs (#6 – 9); and
4. Lowest ranked duplex-ARC from Survey 1 (#4) to non-ARCs (#6 – 9).

Figure 5 presents the percent of respondents that correctly identified the ARC (or lack of ARC) per analysis.

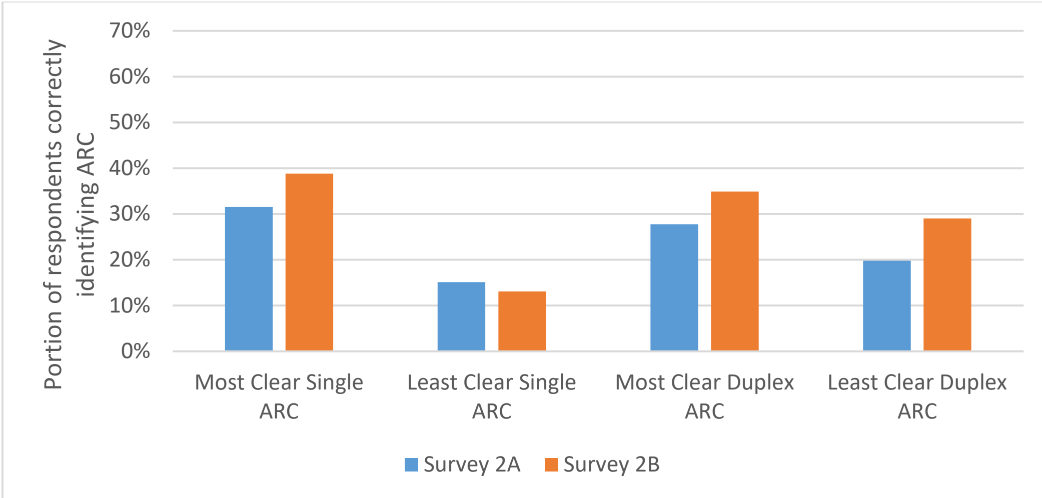


Figure 5. Results from Survey 2.

The ARCs with the highest ranking for clarity in Survey 1 also resulted in the highest number of respondents identifying correctly identifying ARCs n Survey 2, these are shown in Figure 5 as “most clear” single and duplex respectively. In survey 2A, users were not presented with information about ARCs, and the ARC that was ranked as the most clearly marked single ARC option was correctly identified as the ARC receptacle by more than 30% of respondents . In Survey 2B, respondents were presented with pre-information about ARCs and guidance that an ARC receptacle would explicitly contain the term “controlled.” Only when users were explicitly directed that ARC would contain the term “controlled” (Survey 2B, orange columns) and coupled with the ARCs that were deemed most clearly marked did more than 1/3 of the respondents correctly identify the ARCs (orange columns in most clear ARCs). In summary, respondents struggled identifying the ARCs even when explicitly provided with information to identify the ARC. In fact, guidance on ARCs and informing respondents to look for the wording “controlled” did little to improve ARC identification (compare 2A (no guidance) and 2B (guidance) in Figure 5).

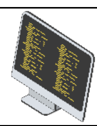
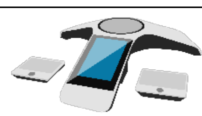
Survey 3 – Device Selection

After a duplex ARC is installed, a user identifies which receptacle contains the ARC (Survey 2), and then within the duplex receptacle which receptacle(s) is controlled (Survey 1), a user then must choose which device to plug into the ARC (Survey 3). Survey 3 presented to 122 survey respondents different common office devices and two receptacle options. A survey respondent had to choose whether to plug in the device to either an always-on receptacle or to an ARC. After choosing the receptacle, the survey respondent entered the rational for their choice. After the devices presented, they presented again with different amounts of information (*e.g.,* device power options; energy saving settings; and start-up time) about each device to survey respondents to determine if information about the device affected the decision.

Devices include a laptop, computer tower , space heater, AV/conference system, fan, task light, computer monitor, personal printer, and networked printer. Table 3 lists the devices and options that were presented to the survey respondents. Most devices were presented with an isolated variable (i.e., fan/task light/monitor – power options; personal printer/network printer –

start-up times, etc.). In contrast, the laptop was presented with all permutations of options. In total respondents were asked which receptacle to use up to 30 times for the 8 devices first presented with no information and then then presented again with the different information provided.

Table 3. Devices included to determine which receptacle type the occupant chooses to power the device for Survey 3

Device	**Image**	**# of Power Options**	**# of Start-up Time Options**	**# Energy Saving Mode Options**	**Total # Options**
#1 Laptop		180 W or 460 W	15 sec or 40 sec	Enabled or Disabled	6
#2 Task light		9 W or 40 W			2
#3 Fan		35 W or 60 W			2
#4 Space Heater				Thermostat: On Thermostat: Off	2
#5 Monitor		72 W or 245 W			2
#6 Networked printer			30 sec. or 3 min		2
#7 Personal printer			30 sec. or 3 min		2
#8 AV / Conf system				Idle Mode: On Idle Mode: Off	2
All eight devices					8
Total					28

Findings from Survey 3

Figure 5 presents the results from the initial questions. Roughly half the survey pool opted to power each device with the ARC. Reducing energy ranked high on the survey pool's background questions. In Figure 5, the darker color bars represents the survey respondents who selected to power the device with the "ARC" and the lighter color bars represent the respondents who selected to power the device with the "always-on" receptacle.

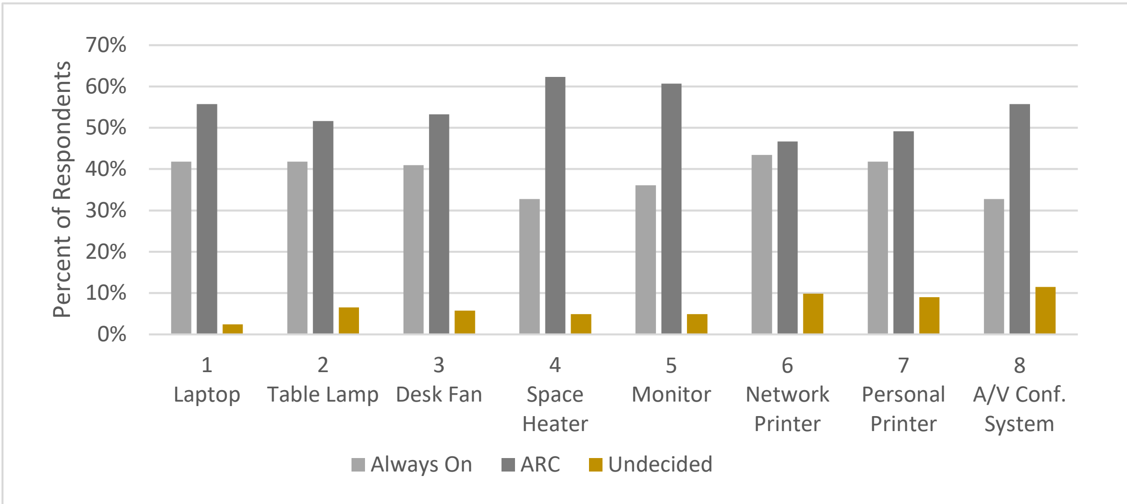


Figure 5. Survey respondents selected either always-on or ARC receptacles for the 8 devices.

After the respondents selected their desired receptacle with no information provided about the devices, the questions were repeated this time with information presented about the devices.

The laptop, space heater, and A/V conference system were presented again informing the respondents that it could either have energy-saving mode enabled or disabled and they were asked how that information affected their choice. When an energy-saving mode was enabled, respondents selected roughly the same choice with half opting to power the devices with ARCs. However, when the energy-saving mode was disabled, the majority of respondents opted to power the devices on the "always-on" receptacles.

The laptop, network printer, and personal printer were presented again informing the respondents that the device could either have a short (e.g., 15-second or 30-second) start-up time or a long (e.g., 40-second or 180-second) start-up time. Respondents selected ARCs in the same proportions (roughly half) when presented with the short start-up time as when not presented any information. For both printers, users selected to power the printers on the ARCs in greater proportions when presented with the long start-up time than when not presented with any information at all.

The laptop, table lamp, desk fan, and computer monitor were presented again informing the respondents that either low or high-power versions of the device could be available and they were asked how that information affected their choice. For the table lamp, desk fan, and computer monitor, more respondents selected ARCs for the "higher wattage" option than the "low wattage" option. See Table 3 for the wattage options. In contrast, more users opted for the "low wattage" option for the laptop than "high wattage."

Summary

Metzger et al. (2011) demonstrate that occupant behavior plays a critical role in energy savings with plug loads. In that report, the methods that relied on occupants changing their behavior resulted in the lowest amount of energy saved, and automatic methods that turned off plug loads saved more energy. ARCs require occupant to make multiple choices that affect the effectiveness of the technology. Behavior plays a role in all technologies, but behavior may have an outsized effect on ARCs. The results from our research in Survey 1, 2, and 3 all demonstrate the limitations of the user's behavior.

The results of Survey 1 indicate that three potential changes to ARC markings may be necessary, either through voluntary standards by industry or mandated by NEC, to improve occupant understanding and application of ARCs. First, contrast requirements are critical. Contrast is necessary for detection and reading. Second, NEC mandating "controlled" and the power symbol without either a contrast requirement or orientation requirement has limited value. NEC requires contrast and conspicuity in other requirements (e.g., orange triangle for isolated ground or green circle for hospital grade). Third, both a border requirement and an orientation requirement of the term "controlled" may be necessary.

Energy savings from ARCs relies on occupants correctly identifying the ARC. Respondents could not consistently identify ARCs when compared to other receptacles that they might encounter in a space. Respondents mostly performed better when informed that the ARC would contain the term "controlled", but how often can that information be provided to building occupants is unknown. However, if the low ranked markings from Survey 1 are used for the single ARC (#2 from Table 2), respondents performed the worst. Survey 2B respondents performed the worst with receptacle #2. On receptacle #2, "controlled" appeared in the top 1/3 of the device but did not include a border. Survey 2B respondents incorrectly selected both top and bottom at twice the rate of correctly selecting the top receptacle. Survey 2B indicates that if informed and presented with ARC #2 from Table 2 more users would select the wrong receptacle. Survey 2 indicates that successful energy savings from ARCs requires ARCs with borders and for the building occupants to be informed about the "controlled" aspect.

Table 1 (Metzger, Cutler, and Sheppy, 2012) demonstrates that once a device enters a low-power state and then turns off, less energy is saved than the time-based event. It is not obvious in Table 1 if the devices connected to the time-based controls also had low-state power options. Survey 3 demonstrates that survey respondents will select ARCs more than always-on receptacles for devices 40 W – 250 W. Limited options were presented, but the high wattage (>400 W) laptop resulted in fewer users selecting ARCs than "always-on". To best determine the potential of the technology, it might be necessary to understand if there is a wattage limit on devices in which users might connect to ARCs.

Users do not appear to understand the benefits of energy-saving modes. When the energy-saving mode was disabled, more users selected the "always on" receptacle. With the mode disabled, the device never enters a low-power or energy saving state. This is the exact scenario where a user should seek out the ARCs, but users did not select this receptacle type.

Per survey 3, start-up time did not seem to affect users' choices. Survey 3 presented the ARC as turning off after working hours and just before the start of work. Respondents may have assumed that start-up time would not be affected by this operation.

In summary, survey 1 demonstrates that the different receptacle markings used by manufacturers likely achieve varied success rates in terms of users identifying ARCs from non-

ARCs. Survey 2 demonstrates even when using “most clear” receptacles from Survey 1 and reminding the respondent that it would say “controlled”, only 1/3 of respondents could correctly identify ARCs. Finally, survey 3 demonstrates that users only select ARCs ½ of the time when presented with an ARC and an “always-on” receptacle. Surveys 1 – 3 demonstrate that users play a critical role in the success of ARCs playing a significant role in energy savings. Survey 1 demonstrates that the standardized markings may be necessary. Markings on the plug to help remind users that it may be good for use with ARCs is recommended. Survey 2 demonstrates that users are often confused by which receptacle is the ARC. Methods to reduce user confusion are necessary.

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