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# LIGHTING CONTROL USER INTERFACE STANDARDS

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## DISCLAIMER

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# PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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- Renewable Energy Technologies
- Transportation

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For more information about the PIER Program, please visit the Energy Commission's website at http://www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

# ABSTRACT

A particularly egregious source of energy waste is that which occurs simply due to miscommunication between a human being and an energy-using device. At present, there is an absence of standards for lighting controls. This may lead to products that are unnecessarily confusing, and this problem may worsen as control capabilities rise sharply with the advent of digital and networked lighting control systems.

Over the past year, researchers from Lawrence Berkeley National Laboratory (LBNL) and the California Lighting Technology Center (CLTC) collaborated to document existing and emerging user interfaces for lighting control as a necessary prerequisite to creating a consensus among industry and policy makers on the need for a lighting control user interface standard, and a process by which to design and create it.

The CLTC and LBNL research team proposes to create a standard for lighting control user interface elements that encourage energy-saving behavior.

The Lighting Control User Interface Standards project is an initial investigation of the topic. It is intended to be followed by later phases that will conduct more detailed research, draw up possible content for one or more standards on the topic, and pursue adoption of those by appropriate organizations.

**Keywords:** electricity, lighting, user interface, controls, symbols, standards

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# EXECUTIVE SUMMARY

Lighting user interfaces have traditionally been largely simple, with most just an on/off switch, and most of the remaining complexity being three-way (multiple location) switches or those with dimming functions. However, we can expect the coming years to see increasing complexity in controls, with more use of sensors for daylight and occupancy, price responsiveness, integration with controls for other end uses, and with solid state lighting, even color control. As this occurs, in the absence of standards, we can expect two notable trends for the user interface. One is the traditional lack of visual cues on lighting controls for what lights are controlled, and what additional features are present and which are activated. The other is a diversity of elements presented for the same underlying concept — a pattern found in other energy-related user interfaces.

All of this points to a possible future of user confusion and energy waste that we seek to avoid. That future is not here yet, but waiting until that time would mean waiting a number of years, during which manufacturers and users would become increasingly committed to divergent approaches in product lines and installed hardware, and so become resistant to changing to a standard. Also, significant money would be invested in non-standard devices, which would serve as a source of confusion for many years to come. Thus, it becomes ever more difficult to get all important stakeholders onto the same path the longer we wait to create a standard.

The objectives of this project are to review relevant standards and literature, assess the nature of existing lighting control user interfaces, and to organize results into a detailed and comprehensive taxonomy of all the types of information present in the interfaces, and the ways that they are diversely manifested in current and emerging products. The taxonomy will offer a solid foundation of the wide range of lighting status information and control options and allow the identification of commonalities and differences towards the development of a global user interface standard for lighting control.

One goal for our review of potentially relevant industry standards was to confirm that there was no existing standard that covers this topic area, and we found none. We conducted an extensive review of related standards, including those covering symbols, indicators/actuators, generic user interface issues, accessibility, user interface content common to other energy concerns, and terminology. We found important relevant content around graphical symbols, associations for color and movement, use of indicators, and terminology.

We also reviewed relevant literature. We found nothing directly on our topic, but did find some articles that addressed closely related issues. The focus in the literature is most commonly on the overall structure of the interface, how users accomplish tasks, and how to develop and design interfaces.

We reviewed many existing products, from simple switches, to those with many buttons, to those using graphic display technology. From this we developed a classification scheme for the entire 'form' of the control, to organize data and conclusions about interfaces. We expect to see a continuing increase in the amount of complex control interfaces, as the controls themselves gain increasing capability. Another aspect of the research was identifying the use of specific "elements" in the interfaces, most prominently, the terms and symbols in use, but also colors and actuation methods. Finally, we extracted topics ("concepts") that embody meaning and are represented in collections of interface elements (example concepts include basic switching, dimming/brightness, dynamic controls, and scheduling).

Lighting controls are often in prominent places in rooms, so that there is pressure to keep them free of what can be seen as visual clutter. This, and the fact that most are relatively simple, has led to a tradition of very little in the way of visual cues. The need to retain clean, simple appearances will remain, but it seems likely that more use of visual elements will be needed to provide clarity for all, as well as accessibility to the elderly and other populations.

In other contexts, such as around automobiles, and particularly when safety is involved, user interface standards are used to ensure clarity and correct operation of equipment. This approach is relatively new to energy, having been applied previously to power control of electronics, and currently also to climate control (thermostats).

This project is the first step in a process expected to result in the great majority of lighting controls on the market having clear and consistent interface elements. Key aspects of this process are the standards context (organizations and individual standards), lighting control issues, "marketing" the idea to key people in industry and elsewhere, and developing specific content that could be part of the resulting standard. It is not necessary, or even helpful, to try to address all topics within lighting control in an initial standard. There will likely be some topics where it is not possible to get sufficient consensus, and these should not derail those for which general agreement is more readily achieved.

While it is always necessary to monitor changes in existing standards, new ones, and any important ones missed in our review, detailed understanding of the landscape of existing standards is sufficiently covered by the research done for this project. The major standards activity going forward will be to work with industry and standards organizations to drive consensus on the particular standards organizations and processes most suited to this topic. Our tentative conclusion is that developing a standard through a U.S.-based organization would be easiest to do first, then passed up to an international organization for adoption there. Likely organizations to be involved are NEMA (National Electrical Manufacturers Association) for the U.S., and CIE (International Commission on Illumination) for a global standard. The U.S. version would be constructed with the international scope in mind, getting international review and comment as much as feasible.

For the rest of the activity, we foresee an iterative process of gathering people committed to the concept, and having the content for the standard emerge from discussions with them, rather than be produced solely by a few researchers. This should help ensure that the content is widely acceptable, and critically help produce a sense of ownership of the content by all involved. We expect a series of iterations, that both expand and refine the content, and expand the number of people and organizations involved. Important standards always require intensive in-person meetings to ensure quality of the result and commitment to it. The work done on existing controls for this project lays a solid groundwork of material to get interest in this process, and organize efficient and productive meetings. It also provides material for soliciting interested people to participate. Our limited work with manufacturers to date has provided encouragement to us in our goals, process, and direction. Many people in industry see the merit of the final result just by a description of it. Others remain more skeptical in the absence of a draft standard, but we expect most of these would be won over once they see the actual content.

For future work towards the ultimate goal, the next near-term milestone we propose is a national workshop on the topic. The intended participants would include representatives from all major lighting control companies in the country, as well as those providing building automation systems covering more than just lighting. Others would include representatives from relevant standards organizations, trade associations, state and national government, and researchers. Most attendees would also present.

We foresee a bright future for this topic and believe that a standard is readily achievable and that it can lead to changes in the market and ultimately energy savings.

# CHAPTER 1: Introduction

Imagine entering a room and being uncertain as to how to switch on the lights because you don't understand the controls. This is a safety problem. Being unable to switch them off (or control them in other ways) is an energy problem.

User interfaces are communication mechanisms — languages — that allow human beings to interact with control devices that provide information about and allow changes to the status of energy consuming devices, such as electric lights. Having a single designed language for lighting controls will maximize opportunities for saving energy. The alternative is a profusion of different ways for people to understand lighting controls and for control systems to communicate back to people. Significant diversity of control interface elements is guaranteed to waste large amounts of energy, in addition to creating ongoing annoyances for literally billions of people in the coming decades.

A goal of universal consistency may sound audacious, but we are surrounded by internationally agreed-upon interfaces elements. For safety, the radiation ☢ and danger ☠ hazard symbols are globally recognized and understood. For energy, the "power" symbol "⏻" has quickly spread and is now present on almost all recent electronic products. Other widely used examples are traffic signal lights, many automotive controls, telephone keypads, tape transport symbols (play, pause, stop, rewind, etc.), and conventions related to documents and to the Internet.

Where universally accepted interfaces are absent, users are often confused, leading to incorrect operation; when the interfaces control energy consumption, then energy will almost certainly be wasted. For example, the confusing and non-standard interfaces on residential thermostats has led to the unexpected result that, on average, homes with "energy-saving" programmable thermostats use more energy for climate control than those relying on traditional manual-controlled thermostats.

It is actually probably easier to accomplish universal consistency than to be successful with multiple standards, with each suitable only for particular types of lighting, buildings, languages, or countries. Experience with phones, vehicles, electronics, and the Internet all show this.

A key point here is that having a standard will not mean that all lighting controls will be the same (any more than all automobile controls are the same), but only that individual elements will be the same or similar. Key elements are terms, symbols, colors, indicators, actuators, and metaphors. As an illustration of the current lack of standardization in lighting control user interfaces, consider the six examples elements used for dimming control that are shown in Figure 1. From right to left: 1) a single slider, with the convention that actuation upward is to brighten, and actuation downward is to dim; 2) Arrow buttons, with the convention that up brightens and down dims. The buttons are combined with LED feedback lights to indicate the lighting level; 3) An interface with no elements to suggest dimming capability; 4) A light bulb icon paired with an 'increase' symbol and indicator light, where actuation to the right brightens; 5) a icon with the letter M paired with text to indicate on/off status, and an 'increase' symbol, where actuation to the left brightens and 'increase' symbol with on/off text, left to brighten; 6) a light bulb icon paired with text to indicate on/off status, and numbers to indicate the level of brightness.

**Figure 1: Six interfaces for dimming control that illustrate the lack of standardization across user interface elements**


User interfaces are an assembly of elements, in the same sense that a sentence is a logical assembly of words. A standard for lighting control user interfaces will likely be a dictionary of user interface elements, and like a conventional dictionary, would not restrict the types of sentences or paragraphs that can be constructed from the words it defines. The goal is a universal language for lighting controls, not a highly wasteful Tower of Babel.

## Background – User Interface Standards

This project draws inspiration and some content from the PIER project on Power Control User Interface Standards, also conducted by LBNL. That project began in 2000, and a second phase concluded in 2004 with the final approval of a standard (IEEE 1621) of the Institute for Electrical and Electronic Engineers (IEEE). That standard was reaffirmed in December 2009 for another five years. The underlying proposition for both projects is the same: that better and more consistent user interfaces can improve usability of products and lead to energy savings. The consistency comes from standard elements of user interfaces, and the standards work best when they have the backing of a recognized standards organization.

For power control, we found a range of conventional standards (national and international), informal guidelines, and manuscripts on good user interface design. We did not find any standard which directly addressed the topic at hand, and so needed to write one. We did find many standards which addressed aspects of the topic and so needed to be taken into account.

We also needed to find a home for the standard that we developed. We used the same overall approach for this project.

Some of the standards assessed in the power control project spoke to general issues of user interfaces, not to power control specifically, and so are also relevant to lighting control, and other emerging energy-related user interface areas, such as climate control. These various areas share some content, such as for occupancy and scheduling. It seems plausible to have one standard for the "common content", with others for each major topic area.

For standards that address an aspect of our topic, sometimes the content may be a clear match, and resonate as solid content to incorporate (e.g. that 'on' or more is up, to the right, and clockwise). In other cases, there reasons for caution, such as differences in the intended audience, or creation of the standard prior to recent evolution in technology or products (e.g. color control). In some cases, standards are inconsistent with the usual practice in contemporary products, or the content has significant drawbacks compared to alternative approaches. In sum, standards in this area need to be embraced, respected, considered, or rejected, as determined by the details of their content; regardless, the choice will have consequences which must be understood, particularly when consciously deviating from an existing standard.

Another issue which came up in the power control exercise was the question of *when* to pursue a standard for the user interface. In general, we are usually served well for a new topic by an extended time of experimentation, to allow the topic to mature and to gain some empirical experience. That is, it is possible to try for a standard too soon. In the power control case, it would have been desirable to also cover battery charging user interface elements, but the time did not seem quite right yet. In other cases attempts at standardization can come too late. An example of this is electrical plugs in Europe, which have pointless physical incompatibilities even as they are electrically harmonized. Attempts to define a common plug have failed due to a too large base of installed products. The key is to do the standardization at the <u>right</u> time. For lighting, there are many topics in play, and some are at very different stages of maturity. Thus, we expect that the optimal time for some elements has already passed (which does not mean we should not try to rectify the situation, e.g. the use of "up is off" in the U.K.), for others this project will be coming at the best time, and some topics are best deferred. For example, dimming and occupancy sensing are probably ripe for standardization now, but color control may be best addressed after a number of years of experimentation.

The existing relevant standards and committees fall into several categories: graphical symbols, indicators and actuators, safety, accessibility, and terminology generally. These topics do not fall into the existing work areas of any single existing standards committee. This is because existing committees and standards are usually "horizontal" — apply to all applications but cover only a single interface element in isolation, or provide only vague, general principles for user interface design. This is in contrast to "vertical" standards which would specify many or all aspects of a particular application.

Vertical user interface standards are rare. Apart from IEEE 1621, the only other one we are aware of is a standard for vehicle controls. The content in this is familiar to anyone who drives an automobile, covering nearly all the symbols found on the dashboard, as well as color meanings, and guidance on applying the standard in practice. Thus, this standard is an important example being a vertical standard, being successful, and in addressing a buildings-like topic, as a vehicle is in many respects just a building on wheels (or with wings or a hull). Our goal is to create a vertical standard for lighting control.

In our standards analysis, we: reviewed entire organizations and particular technical committees and standards for their relevance; considered the content of select standards and what they say for lighting control user interfaces; and presented a review of selected literature relevant to the topic.

To be clear, there is no existing major standard clearly focused on lighting control user interfaces (based on extensive search and interviews with lighting experts).

## Lighting Standards

Lighting research occasionally touches on user interfaces, in deployment of specific installations of controls, but it is generally an ad hoc implementation detail and not understood in the standards context. Research on commissioning of controls sometimes touches on how this is done mechanically, which has a user interface dimension, but is not particularly informative as to how people generally experience controls.

Lighting research for energy efficiency typically focuses on improving the physical efficiency of equipment and functionality of controls (essentially, the interface between the control and the light source). Those involved are accustomed to these approaches and able to make progress without considering user interfaces. Limiting lighting research and efficiency programs to traditional approaches would be a barrier to progress.

Digital lighting controls are gaining momentum in new and retrofit construction, offering a very wide range of lighting control options and feedback mechanisms. These systems offer the potential for instantaneous and historical information about the status of lighting systems and control through predefined scenes and conditions based on sensor and occupant input.

Digital controls are expected to save significant energy through implementation of occupancy, daylighting and scene controls. Setting up and dealing with this increased functionality requires sophisticated user interfaces. Well-designed individual control products are not enough. Without a standardized approach, there will likely be confusion that would be a major barrier to widespread implementation and realization of efficiency benefits. Effective user interfaces will enable potential savings to be realized in practice.

Up until now, the energy consequences of not addressing lighting user interfaces have been modest; while many are quite confusing, most lighting is still covered by conventional controls. However, new digital control technologies have much greater savings potential than older methods, making them much more sensitive to how they are used. There are often unstated assumptions about energy systems, particularly: that controls will be used to their optimal potential; and that information about occupant preferences and system configuration and status will all be communicated perfectly. Any lack of transparency in the controls, or user confusion about what the controls can do or are doing, will result in differences between potential savings and those actually realized. Standardizing user interface elements is not a panacea, but is an essential component of minimizing the difference between the lighting services people want and what they get. The only way to get to an effective user interface standard is through a project like this one, and it is an expedient (simple and cost-effective) way to achieve significant reductions in lighting energy use.

Without a standard, manufacturers cannot produce products that are consistent with common expectations as those are not documented for control designers to reference. While this problem exists today, it will grow much larger in the coming years as controls and their capabilities become more complex. Now is the prime time to address the user interface problem as the possibility and nature of more complex controls is becoming much clearer than in the past, and the longer it takes to start the standards process, the more difficult it will be to redirect companies that have significant investment in non-compliant product designs.

The past focus only on lighting source efficiency and control functionality is no longer an acceptable limit on approaches to saving energy in lighting.

## Project Plan

As digital lighting controls are emerging from various manufacturers, it is important to address the issue of a standardized approach to developing user interface elements. The goal of the project is to initiate the process by laying a solid foundation of knowledge about lighting control devices and mechanisms in use today. This is intended to be the first step in establishing a global standard for user interfaces for lighting controls that extend across all lighting applications.

The project has three major tasks: a review of potentially relevant standards, a survey of existing products and categorization of them, and a proposal for logical next steps in the process based on findings.

### Standards Review

This plan for the Standards and Literature Review was to:

- Identify and obtain key standards.
- Identify and obtain selected literature.
- Review these and summarize them.
- Assess standards organizations.

Many standards for buildings or products directly address their energy performance, such as building codes and appliance standards; these are all out of scope for this discussion. Even those that specify the *existence* of a lighting control are still not in scope as it is only the details of the user interface that are important for this effort. In this report, "standard" refers to an industry or technology standard, of the type created by the organizations discussed below.

The project was intended to be an initial investigation of the topic. The strategy was to follow it with later phases that will conduct more detailed research (including working more closely with industry), draw up possible content for one or more standards on the topic, and pursue adoption of those by appropriate organizations.

We report on the scopes of organizations, committees, individual standards, the content of the standards, and standards processes that will become relevant to lighting control standardization in later phases of this project.

### Survey Plan

Any proposal for how future interfaces should be constructed must begin with a solid understanding of the design of current interfaces. For this project we surveyed existing lighting control user interfaces, with a particular emphasis on technologies and products that seem most indicative of their future trajectory. Examples of these are those that utilize rich user interfaces (e.g. displays), those that incorporate dynamic elements as with sensors, and those which enable the lighting to be interconnected with other devices in the room.

The survey is expected to reveal some elements that already have a strong thread of consistency across contexts and manufacturers (these likely initial components of the standard), and those for which there is great diversity (and so further research needed to identify the best solution if any).  The survey will be the basis for the taxonomy of user interface elements, which will cover both the structure of what is to be represented, as well as how it is commonly implemented.

In the survey, steps were to:

- Select a sample of products for review.
- Analyze user interface elements present in these products (explicit and implicit).
- Meet with lighting manufacturers to assess current and future user interface elements.
- Prepare a report on products reviewed including user interface elements and key attributes.
- Summarize the project, review key findings and recommendations, and determine the best next steps toward a user interface standard.

The scope of the project is controls commonly found in residential and commercial buildings, used by ordinary occupants (not those intended only for professional facility managers).  We planned to evaluate controls ranging from simple to complex (including with displays), both residential and commercial, and covering both hardware and software. A particular emphasis was to be placed on technologies and products that the team determines are most likely to gain market share in the near term. The primary focus is on specific elements in the interfaces, including those available over a network, and elements that are commonly found with user interfaces such as sensors and actuators

Our approach to the classification of interfaces is two-fold. One is top-down, for the overall "form" of the interface, to distinguish a traditional wall switch from screen-based interfaces. The second is bottom-up, to examine the presence and meaning of individual "elements" of the interface, such as words, symbols, colors, motions, or metaphors.

# CHAPTER 2:
# Standards and Literature Review

In the Standards and Literature Review task of this project, the scope was to:

- Identify and obtain key standards relevant to this project, including but not limited to U.S. and international standards, both lighting-specific, and for user interfaces generally.
- Identify and obtain selected literature relevant to this project, that which addresses the lighting user interface topic directly, as well as some on user interface design.
- Review these and summarize them individually, and collectively.
- Assess standards organizations for their relevance to this topic.

Many standards for buildings or products directly address their energy performance, such as building codes and appliance standards; these are all out of scope for this discussion. Even those that specify the *existence* of a lighting control are still not in scope as it is only the details of the user interface that are important for this effort. In this report, "standard" refers to an industry or technology standard, of the type created by the organizations discussed below.

Assessment in this report covers the scopes of organizations, committees, individual standards, the content of the standards, and standards processes that will become relevant to lighting control standardization in later phases of this project.[1]

In the following sections, we first review entire organizations and particular technical committees and standards for their relevance. Then, we consider the content of select standards and what they say for lighting control user interfaces. Finally, we present a review of selected literature relevant to the topic. To be clear, there is no existing major standard clearly focused on lighting control user interfaces (based on extensive search and interviews with lighting experts).

## Standards Organizations and Committees

This section reviews standards organizations that have a scope that overlaps somehow with lighting control user interfaces. Key committees might be actively consulted in the process of developing user interface standards for lighting, and individual members may have useful insight or information. It may be useful to make adjustments to their standards, and there could be committees that could ultimately host our standard.

A general problem with locating relevant content is that from examining the title of a standard, one only gets the major topic area it addresses. Even a paragraph-long scope for a standard (only sometimes available) may not list all the details it addresses (being certain would require purchasing all standards). So, for most organizations discussed below, we only reviewed committee and standard names, and so some possibility remains that some relevant details are

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1 For clarity, we have put into a different font the names of standards committees, standards, and items from standards such as the names of symbols or their definition. The standards organizations themselves are in the normal font.

present in standards we have not reviewed. However, we expect that the amount of relevant content missed is small.

## International Standards Organizations

There are three "top-tier" international standards organizations, the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and the International Telecommunications Union (ITU). In addition, there are other organizations that have international scope, but have less weight. It is common for standards to be developed at a national or regional level, then forwarded to the international level for wider adoption. The "second-tier" international organizations often do the same thing as national standards bodies do in forwarding their product for adoption by one of the top tier organizations. Some international standards are subsequently brought down to national status, for political purposes, or to allow for minor alterations for local conditions, and elements of standards can be imported into local documents (e.g. as is done referencing symbols). All standards organizations have a structure of committees and subcommittees.

The majority of the relevant standards and committees are international. The national committees cited below are all based in the United States. There are standards defined by technology industry consortia rather than by traditional standards organizations, but we find these more connected to existing products and so will review them as part of that task.

### *IEC*

The International Electrotechnical Commission (iec.ch) is the body that is seen as the highest authority for issues relating to electricity. It has a very wide scope, and naturally covers issues related to the production of light from electricity. The IEC has many standards that inform our topic, but none speak to it as a specific goal.

A key topic for lighting is symbols, and in the IEC this is controlled by SC 3C (a subcommittee of TC 3). The IEC symbol standard is IEC 60417. It is worth noting that one addition and one edit have been requested for power control of SC 3C, to date unsuccessfully. The key issue is that the U.S. is not a member of the committee so we don't have an official way to request changes. By the time we get to this stage, we will likely have partners in other countries working on this, and so could request their help on this.

TC 16 on "Basic and safety principles for man-machine interface, marking and identification" hosts a key standard, IEC 60073, which covers color meanings, and arrangement and "coding principles" of indicators and actuators.

There is an IEC committee on Lamps and related equipment which does include lamp controlgear necessary for a lamp to function. However, it appears that this committee only addresses electrical aspects of controls and so has relevant content. The committee on "Automatic controls for household use" (TC 72) also appears to have no relevant content.

A committee on Electrical accessories has a subcommittee on Switches for appliances: (TC 23 / SC 23J) has standards on Switches for household and similar fixed-electrical installations in general, and on Switches and related accessories for use in home and building electronic systems (HBES) specifically. No indication that these cover user interface issues; most likely they cover electrical, mechanical, and safety issues.

### *ISO*

The International Organization for Standardization (iso.org) covers a wide variety of topics such as materials, equipment, products, processes, and systems. Almost any topic is potentially in scope excepting those addressed by the IEC or the ITU. Like the IEC, it has standards that inform our topic only in a general sense.

Also like the IEC, ISO also has a graphical symbols committee, TC 145, which has SC 3 on Graphical symbols for use on equipment. The ISO process anticipates that symbol requests will come from other ISO committees that are expert in the relevant topic area. In many cases, it is not obvious why a symbol is in the IEC or ISO standard, and for some, the location is counterintuitive. TC 145 does have an official liaison with CIE (the IEC committee does not).

There is a subcommittee under the Road Vehicles committee on Ergonomics applicable to road vehicles with a working group on symbols. The secretariat for this is with SAE, and it appears that the core work is done within SAE.

There is a TC 205 on Building environment design that has the "indoor visual environment" as one of its main areas of work and a working group on Building control systems design. Their work plan notes "human needs" as something to address, the need to coordinate with CIE, and the value of having products be usable in any country. All that said, there is no indication of relevant content.

### *JTC1*

The IEC and ISO could not agree which organization would host Information Technology, and so set up a Joint Technical Committee 1 (jtc1.org). One of the eight topic areas in the JTC1 mission statement for standards development is "user friendly and ergonomically designed user interfaces". A few JTC1 standards inform our topic, but more from the direction of design principles rather than specific elements like symbols. Being grounded in IT, JTC1 is oriented to display screens as the core of user interfaces. While lighting controls increasingly use, they are still overwhelmingly dominated by more traditional mechanically-oriented controls, an area that JTC1 does not cover.

JTC1's work on this topic is focused in SC 35 on User Interfaces. In discussion with a long-active participant in SC 35 (Carter, 2009), it was made clear that the committee deals with general user interface methods, not with specific applications (e.g. lighting).

### *CIE*

The International Commission on Illumination (cie.co.at) deals with "all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology". At present it does not appear to have standards important for the user interface topic at this time. However, if in future our standards considerations get into technical details such as how colors are represented, then current CIE standards may become relevant.

The CIE until recently had no technical committee that seemed relevant to this project. However, in late 2009, a new committee was formed with the following description:

> **TC 3-49: Decision Scheme for Lighting Controls for Tertiary Lighting in Buildings.** To offer guidelines in order to balance lighting quality, user comfort and energy efficiency in lighting controls solutions for tertiary lighting in buildings (i.e. for commercial, institutional and industrial buildings). To work on a decision scheme with focus on the user requirements (visual comfort, performance, personal control) to determine the most applicable control solution, including the consequences for possible savings. In this, it needs to be assumed that there are no technological or financial hurdles. Chair: Peter Dehoff (AT)

This group is just getting started, and while the user interface does not seem central, it is plausible that their interest could be steered to this, or that individuals from the committee would find the topic of interest.

### *IEEE*

The Institute for Electrical and Electronic Engineers (ieee.org) has its origins in the U.S., but is international. The only connection it has to this project is sponsorship of IEEE 1621 on power control user interfaces, which informs this project as a principle example and model. 1621 was sponsored by the Microprocessor Standards Committee of the Computer Society, both of which are clearly distant from the lighting topic. No IEEE societies (the constituent bodies it is made of) cover lighting.

### *SAE*

The Society for Automotive Engineers – International (sae.org) covers vehicle standards for various domains. SAE has several committees for Comfort & Convenience that has a standard for user interface issues for lighting (J2402). It also has a Lighting Coordination Advisory Group, but this probably addresses only the emitted light, not the controls user interface.

SAE J2402 "specifies symbols (i.e. conventional signs) for use on controls, indicators, and tell-tales applying to passenger cars, light and heavy commercial vehicles, and buses, to ensure identification and facilitate use". It also indicates the colors of possible optical tell-tales, which inform the driver of either correct operation or malfunctioning of the related devices.

## National Standards Organizations

At this time, we only cover organizations for the United States.

### *ANSI*

The American National Standards Institute (ansi.org) serves as an umbrella organization for those who actually do the standards work, providing coordination and accreditation.

### *IESNA*

The Illuminating Engineering Society of North America (iesna.org) also covers Canada and Mexico, but functions like a national organization in relation to CIE. IESNA at present has no standards committees that clearly have the user interface in their scope. However, we do expect to find individuals within IESNA interested in the UI topic and should engage the organization.

### *NEMA*

The National Electrical Manufacturers Association (nema.org) is a trade association that also has standards activities. It is the primary trade organization for the lighting (and lighting controls) industry. At present it has no standards that from their title are likely to touch on user interface issues. However, like IESNA, we expect to find interest and help within NEMA.

There is an organization called CANENA (canena.org), the Council for the Harmonization of Electrotechnical Standards of the Nations of the Americas. It does not develop standards, but instead seeks harmonization among standards organizations in the Americas. NEMA is the lead U.S. participant.

### *HFES*

The Human Factors and Ergonomics Society (hfes.org) has two technical committees that in theory could encompass lighting controls (one on environmental design and one on product design), but it seems unlikely that in practice either would.

### *UL*

Underwriter's Laboratories (ul.com) is concerned principally with safety. It does have standards that deal with physical and electrical aspects of switches. It is not apparent that any deal with user interface issues.

### *AIGA*

The American Institute of Graphic Arts (aiga.org), founded in 1914, is a trade organization that offers recommended practices more so than standards activities that would be required for compliance. The AIGA has a AIGA Signs and Symbols Committee that would be helpful to consult in the event of the creation of a new symbol or set of symbols that was intended for widespread adoption in common interfaces. An example of the prior work completed by a committee within the AIGA is the set of 50 passenger/pedestrian symbols. The objective was to create a set of signs, in partnership with the Department of Transportation, that communicated the required range of complex messages, addressed people of different ages and cultures and were clearly legible at a distance.

*Interaction Design Association (IxDA)*

The IxDA (ixda.org) boasts over 17,000 registered members worldwide, was founded in 2004, and charges no membership fees. Modeled after the social networking and participatory culture communities that Interaction Designers serve, this relatively new collective may serve as a valuable resource when discussing the lighting interface components as they relate to software and mobile devices, a fast-growing segment of the lighting controls market.

## Standards — Process

This section addresses what to do with the standards content we expect to develop in future phases of this project. It would be helpful to have in mind a few standards organizations that could plausibly host a standard on lighting control user interfaces. Any official proposal to initiate a project is probably several years off, but talking about it informally with people involved in these organizations can help prepare the ground for such an eventual proposal, and confirm (or deny) our conclusions about the relevance of particular organizations and committees.

Ultimately this should be an international standard, though it often works best to first create a national standard, and then convert it to international. While ISO JTC1 does have user interfaces as one of its major areas of work, it does not appear to be a plausible home for a standard for this project. In addition, there is no existing committee or subcommittee in the ISO or IEC that is an obvious target, since it would need to be a lighting-oriented committee. So, the highest organization that seems like a reasonable goal is CIE, either developing it directly there, or first through IESNA or NEMA. Again, we are a long way off from proposing the initiation of any standards process, so there is no action soon from these conclusions, but it is worth floating the idea within CIE, IESNA, and NEMA to gauge interest and prospects.

## Individual Standards

This section covers existing standards that inform functionality that may be used in lighting control user interfaces.

### Symbols

The two most important set of symbol standards are IEC 60417: Graphical Symbols For Use On Equipment (IEC, 1998) and ISO 7000: Graphical Symbols For Use On Equipment (ISO, 1989). IEC 60417 was originally published in 1973 and updated frequently since, including in 2004.[2] In 2002 ISO 60417 was converted to an electronic database format so that it can be updated continuously. IEC 60417 defines over 600 symbols, the great majority of which have nothing to

2 We have the most recent ISO 7000, but the 60417 edition is from 1997; don't expect there were changes in the symbols we care about since.

do with energy use or lighting. A modest number have some definite or possible relation to this project. The ISO 7000 standard covers a similarly wide range of symbols as IEC 60417, though the IEC symbols are more oriented towards electrical, electronic, and medical equipment, and the ISO symbols include many designed for industrial equipment (e.g. handling cloth) and vehicles.

IEC 80416-1: Basic Principles For Graphical Symbols For Use On Equipment — Part 1 Creation of graphical symbols (IEC 2000) provides guidance on creating graphical symbols. IEC 80416-1 contains a pattern (a set of grid lines) upon which symbol originals are to be designed, and specific instructions for how to do this (another document of this type is ISO 3461: General Principles For The Creation Of Graphical Symbols). A second part of this standard, IEC 80416-3 Basic principles for graphical symbols for use on equipment — Part 3: Guidelines for the application of graphical symbols (IEC 2002), specifies how symbol originals can be adapted for use on products. Examples of application guidance for symbols are that line thickness can be changed, that outlined spaces can be filled in, and that color should be avoided unless where necessary.

IEC 11581 Icon Symbols and Functions is for those symbols used on displays. Some general symbols such as a clock symbol are relevant.

ISO 9186, Graphical Symbols — Test methods for judged comprehensibility and for comprehension (ISO 2001a) specifies procedures to be used in advance of establishing international standard symbols. Some of the principles can be extended to the other interface elements.

### Indicators/Actuators

The key indicator standard is IEC 60073 on Basic and safety principles for man-machine interface, marking and identification — Coding principles for indication devices and actuators (IEC 1996). It includes specifications for color assignments, audio indications, and flashing rates.

IEC 447: Man-machine interface (MMI) — Actuating principles (IEC 1993) provides many basic principles for user interface design, including concepts (e.g. error conditions), and physical indications or actuations.

### Generic UI Issues

There is a standard that provides general guidance on principles for designing interaction scenarios with software systems, though many of the principles can also apply to hardware (it goes by the name of ISO 9241-1, Ergonomic requirements for office work with visual display terminals (VDTs) — Part 1: General introduction and ISO 9241-10, Ergonomic requirements for office work with visual display terminals (VDTs) — Part 10: Dialogue principles).

### Accessibility

There is no question about the merit of having user interfaces accessible to those with some sort of disability; the question is what can be specified. In the power control project, extensive effort was made to identify accessibility content, but with only limited results.

Common disabilities we should consider are deafness, blindness, limited vision, limited motor ability, and special needs of the elderly and children.

The major accessibility topic that came out of the power control experience was to specify use of colors that best meet the needs of people with color-blindness. For example, common bi-color green/yellow LEDs use colors that are not distinguishable by many people who are color-blind (or color-deficient as the condition is officially called). Color specifications for traffic signal lights were cited, and this content can be directly moved over to lighting controls.

Another topic was conventions for audio indications of power state transitions, e.g. that a rising tone means a higher power state. This could also be specified for lighting (and would be strictly optional).

For key controls or for orientation, a raised "nib" can be applied to special keys. For example, keyboards often have these on the "F", "J", and "5" keys. How this might apply to lighting control is unclear.

Many aspects of lighting controls, e.g. placement on a wall, size of keys, etc., are well outside our scope.

Finally, there is an effort to develop Universal Remote capabilities, in which a device could export its user interface electronically in a standard schematic fashion, and then have it rendered to the user on the user's device in a way consistent with their needs and capabilities. This standard specifies the mechanisms, but not standard content.

## Common UI content

There are several types of user interface content that span across many energy-related contexts. These need to be considered for lighting user interfaces, but not likely part of a standard for lighting specifically.

One topic is general user interface content for any user interface. This includes concepts that have generic functionality (e.g. lock/unlock, help, scrolling, undo, etc.) and might be expressed as symbols, images, or words. It also includes many conventions for graphical user interfaces.

Another set of common UI content is controls that apply to several areas of energy-related controls, and should be harmonized across them. Examples include scheduling (clocks, timers, sweep systems), and occupancy sensors (e.g. audio, infrared, ultrasonic) and indicators. Supervisory control states such as low-power or demand-reduction status may also be common across energy-related controls.

The UI landscape in the lighting industry is quickly expanding to encompass devices that are no longer classified as hardwired. User interface standards developed for this project need to be flexible enough to cross from hardwired interfaces, to software, to mobile devices seamlessly. This will also need to take into consideration the way the end-user interacts with the device. There are current conventions such as buttons and dials that are quickly being superseded by multi-touch screens that have no moving parts, but keep the gestures to produce the desired result. Movements from left to right, up and down, single or double taps, and circular or horizontal gestures to scroll may retain popularity as the multi-touch screen industry grows and therefore be appropriate to use in this project.

## Other topics

IEC 61592: Household Electrical Appliances – Guidelines for consumer panel testing supports the idea of improved user interfaces. The panels of people to test devices are to be diverse on many criteria, and topics to address include "aspects that can be evaluated" as "legibility, visibility and comprehensibility of indications" and "simplicity of use of control panel and programming". IEC 61592 references other publications: ISO/IEC 37 (1995) and ISO/IEC Guide 37, both entitled Instructions for use of products of consumer interest and ISO/IEC Guide 71, Guidelines for standards developers to address the needs of older persons and persons with disabilities.

We assume that none of the user interface content for lighting controls is covered by **safety** regulations. This is an important point as safety regulations are often mandatory, or used as such by manufacturers, so could be a significant limitation on design options.

A topic apparently not covered by existing standards at all is issues of representations of non-trivial concepts (basic "on" and "off" being trivial). An example is levels of dimming. At present, some interfaces use a numeric scale that directly proportionally controls absolute light output. In others, there is a non-linear relationship between the user numbers and the light output.

### Terminology

The area of terminology is generally used in standards circles to include only terms used for technical purposes, not those terms used by ordinary people. As such, the topic is only marginally related to the User Interface Standard, though it is advantageous for internal and user terminology to be consistent. We can consider a number of terminology domains; these are not mutually exclusive: manufacturers, technical standards, designers, installers, building management, occupants, and organizations.

American National Standards Institute (ANSI) and Illuminating Engineering Society of North America (IESNA) have approved a document, Nomenclature and Definitions for Illuminating Engineering: ANSI/IESNA RP-16-05, as a standard by ANSI and a recommended practice by the IESNA. The document contains definitions of terms used in the U.S. lighting industry.

International Electrotechnical Commission (IEC) and Commission Internationale de L'Eclairage (CIE) have approved a document, International Lighting Vocabulary: IEC/CIE 017.4-1987 as a standard. The document also contains definitions of nearly 1,000 terms used in the international lighting industry.

Someone unfamiliar with the lighting industry can use these documents to become familiar with lighting terminology. We will use these documents to unsure the terminology we use is consistent with the U.S. and international lighting industries.

## Specific Interface Elements and Content

This section reviews specific content in existing standards that may be relevant to lighting control user interfaces. The goal is to present and discuss the content, not to come to conclusions. The content is organized by: symbols, (color) associations, indicators, terms, and physical mappings.

One basic use of user interface elements is safety, and when that is in question, there is heightened attention to and limits on how controls are presented. We assume that lighting control user interfaces do <u>not</u> raise safety concerns, so are not encumbered by mandatory prescriptions or restrictions. As an example, IEC 447 specifically notes that for non-safety interfaces, deviation from the standard is allowed.[3]

In designing interfaces and selecting elements, IEC 447 notes that users must have a workable "mental model" of the system being controlled. This raises the question of whether describing a

3 For several standards, we do not have the most current version, but have no reason to think that the content has changed in ways of concern to lighting. In some cases the names have changed: IEC 73 is now IEC 60073, and IEC 447 is now IEC 60447

standard mental model that we assume for people using lighting controls should eventually be part of the project.

This study is most focused on individual user interface elements rather than the entire control systems they are part of, but we note that IEC 447 specifies that the most important controls on a panel should be at the top or left of the control (and the least at the bottom or right).

## Symbols

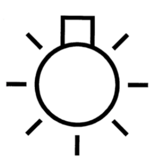
For communicating diverse concepts to people, there are two basic methods: words, and symbols (colors and sounds have a more limited range and use scenarios). Words are language-specific (and sometimes more specific than that) and so have disadvantages for communication meant to be international. In addition, words often take up more space than symbols do, and are often visually more obtrusive. There is always a need for a standard translation of each symbol to a word (or short phrase), so the two are complementary, not in conflict. We can be sure that symbols will be an important part of future lighting control user interfaces.

Appendix A includes a table of many symbols, including their number, name/definition, and the graphical symbol itself. The symbols are primarily drawn from ISO 7000 and IEC 60417, with a few drawn from SAE J2402 (vehicles). The SAE standard is notable as it primarily references the main standards, but adds a few of its own and adapts their name and representation as needed. It is also notable as a "vertical" standard covering multiple types of elements, in the amount of content it covers, and that it is intended for such a wide audience.

The discussion below is organized by the general purpose of the symbols, as they relate to this project. There are many hundreds in the IEC standard and several thousand in the ISO one. These are selected symbols that on initial inspection seem most relevant, but eventually may draw in more.

There are standard symbols for electrical drawings (IEC 60617), and for documenting audio/video and home automation systems (being updated by CEA R10 WG7). These are intended only for use by professionals in their field, so outside our scope. However, in other contexts terms and symbols sometimes move from one domain to another, so these standards should be assessed at some later time, in case some symbols should be drawn from these to this project, or proposed from this project to those domains.

### *Lighting in General*



A basic starting point for symbols is one (or more) that indicate to the user that lighting is in play. One of the early symbols in the IEC catalog (number 12, with its number of 5012) is for Lamp; lighting; illumination —  — defined as To identify switches which control light sources, e.g. room lighting, lamp of a film projector, dial illumination of a device. The core appears to be an abstracted ceiling light fixture or standard "A-lamp", with rays of light emanating from the light source. Both of these concepts seem solid and important, and there seems nothing problematic with this symbol. It could be argued that over time, the A-lamp shape of a bulb will disappear, as we move to more solid state lighting. While this may well be true, it is likely that the convention for the symbol of a light bulb will hang on for much longer.[4] The SAE standard renames the general lighting symbol  to mean Master lighting switch.

4 People have used the word "dial" for phones long after they stopped using any phones with actual dials; they also continue to refer to a phone "ringing" or use "ringtones" long after phones had mechanical bells.

There is an interesting general graphic resemblance between ☼, ⏻ - the lighting and power symbols. Both have a circle interrupted at the top by a vertical rectilinear element. To all appearances, this is strictly a coincidence, but one is the core symbol for one energy-related user interface, and the other might be.

Many symbols in the ISO standard use the convention of emanating rays for light, particularly for automobile controls. Emanating rays are used sometimes to show water, as a shower Detergent for dish washing ///\\\\ – and also for a Clear rinsing agent for a dishwasher ✳, but we would never expect to find these in close proximity to lighting controls. Sound and radio waves typically use a series of concentric arcs so are clearly different (this important as many display-oriented light controls also control sound). Heat tends to be shown as parallel wavy lines – e.g. .

Cars have distinct symbols for many types of lights: headlights (multiple types), parking lights, interior lights, and others. It is likely that we will need to have symbols for specific types of lights in buildings (e.g. emergency lighting, general lighting, and task lighting). The key characteristic should probably be the emanating rays. In fact, the lighting symbol ☼ does explicitly reference two variants: Low-intensity lighting and Indirect lighting .

One symbol which uses the emanating rays is Brightness, brilliance ☼, and its definition notes using it for a dimmer — To identify the brightness control, for example of a light dimmer, a television receiver, a monitor, an oscilloscope (a related symbol is for a combined brightness and contrast control). However, this is for a particular lighting function, not the general idea of lighting. In the context of ☼ on a TV, it is the only control highly related to lighting. However, in a lighting control, the question is what it means distinct for other lighting controls, and so it may be too similar to other lighting symbols to be very useful.

Sometimes symbols need to communicate two concepts and so combine them; the SAE standard does this frequently, including for light-relate symbols, e.g. P≤ for a Parking light, or for lighting of the instrument panel. The standard specifies for Low-level interior illumination (night driving); this could be applied in buildings, e.g. for a night light.

*Basic Control*

In basic control we cover those for switching between no light and some light. For most lights today, "on" is made apparent by a switch position (assuming not a 3-way switch) or the fact that the light in question is visibly on. There are basic IEC symbols for On — | — and Off — ○ — and this whole topic is well-covered in the research for the power control user interface project. The on and off symbols are most commonly used on appliances and electronics, usually on a rocker switch so that both symbols are shown.[5] For electronics, power control is usually organized around the Power symbol ⏻ for a control that changes the power state, and/or is adjacent to a power indicator. While the primary IEC document names this Standby, the SAE document calls this Power. The Power concept seems possibly applicable to an entire lighting control system, but not particularly to conventional control of an individual light sources. While | and ○ are not commonly used on light controls today, they may be in future.

5 This has the advantage that they collectively communicate that it is a power control, and people need not remember which symbol is which—they just change to the other one if needed. In fact, some people "remember" the on and off symbols reversed from their actual meaning, but don't encounter needs to correctly identify them, and only recognize them as a pair.

For labeling switch positions, there are the symbols “in” and “out” for labeling a bi-stable push control to associate the position with the corresponding function. There is no discussion of what functions might be associated with either state.

Another aspect of control is a specific sequence or ongoing behavior or activity. This is certainly more a likely feature of future or more complex control than what is usually used today. There are two sets of symbols which implement this in the international symbols. One is the familiar tape transport symbols of play, pause, stop, rewind, fast-forward, etc. These have been adapted for use on web pages and other contexts not originally envisioned for them, so not necessarily a stretch to use for lighting. Another set is Start , Stop , and Pause — these for an “action”. These are much less recognized, though widely seen (particularly on copy machines), though usually the name of the symbol is also on the key.

*Dimming*

Beyond simple binary on and off, we want to distinguish dimmed states in between. One possible symbol choice is Variability — To identify the control device by means of which a quantity is controlled. The controlled quantity increases with the figure width. It is the fourth symbol in the IEC catalogue (out of hundreds), suggesting its importance. There is an ISO version of this for rotary control: and versions for controls with specific steps in the control, , and for those with a maximum setting independently selectable, . Note that this is just a possible application of these symbols, as there is nothing in their names or definitions which refers specifically to lighting.

*Characteristics / Aspects of Light*

While the quantity of light (dimming) is likely the most important topic in the near term, there are other characteristics that should be addressed. One of this is color, and while today this is not commonly adjustable, it may be in future. There is a standard symbol for “Colour” which can be reproduced with red, green, and blue dots. This has been most widely seen on TVs.

There are two basic symbols for Colour temperature: one for natural light , and one for incandescent lamp . These were designed for cameras, not for light sources, and seem sufficiently close to the brightness and lighting symbols as to be confusing if used for lighting controls. There are symbols for Light and Dark but these are intended for photocopiers for the resulting printed image, not for light sources.

*Non-lighting symbols*

Some lighting controls also control entities other than light sources, so that symbols for those may be expected to show up on lighting controls. Common examples are exhaust fans, window shades, and switched outlets.

*Common content*

Common content is mainly found on more sophisticated controls, so only emerging in the general lighting context. One common action is to increase or decrease a quantity, and this is often done with + and — . However, these symbols are actually intended for use with dc power polarity (as found on batteries), though their use as ‘more’ and ‘less’ seem well established. Functionally this alternative use seems fine; the key is to ensure that no safety concerns identify this adaptation as a problem.

For scheduling, there is a symbol for Date, as well as a variety for time and timers: , , , and . However, the differences between the clock/timer symbols are subtle and quite likely many people would not differentiate between them. So, while we want to almost certainly use one of these, we may want to use *only* one.

Other useful symbols in common use are: Additional information on screen, , Locking , and Unlocking .

There are a number of general control symbols available that could in principle be applied to lighting but seem obscure. These include: Adjustment to a minimum - , Adjustment to a maximum - , Normal operation - , Return to an initial state - , and Principal control panel - .

This topic certainly needs revisiting, particularly after our examination of existing controls shows what common content concepts are widely used.

## Color Associations

The correspondence between particular colors and meaning has a very long history; even in nature, animals use color to communicate within and between species. Many color associations are common in contemporary life, such as temperature (red:hot; blue:cold), traffic signal lights (red:stop; yellow:caution; green:go), and power control keys on many mobile phones (red:off; green:on). Color was also important in the power control user interface project (green:on, yellow:sleep; off:off).

IEC 73 covers many user interface elements, including color associations. Table 1 lists the basic color associations for this standard and several other sources. In addition to these colors, blue has "mandatory significance" (not clear what that means), and white and grey (in addition to black) have no specific meaning.

**Table 1: Ideas associated with selected colors**

| **Color** | **IEC 73** (state of equipment or condition of process)[c] | **British Standard 4099**[a] | **Widely held associations**[a] | **Population Stereotype**[b] |
|---|---|---|---|---|
| **Red** | Emergency; faulty | Danger – alarm; action needed | Alarm, critical, disabled, emergency, failure, stop | Stop or danger |
| **Yellow** | Abnormal | Caution – impending change | Marginal condition (caution), standby | Caution |
| **Green** | Normal | Safety – proceed, equipment safe | Active, enable, normal, on, on-line, run | Go or on |
| **Black** | No specific meaning | | Off | |

Note: One source said that most commonly, audio/video recorders use red lights for recording, green for play, and yellow for pause. [a]From Flurscheim (1983). [b]From Eastman Kodak (1983). [c]Safety conditions omitted.

There are limits to how many colors should be assigned generic meaning, both for what people might remember, and for how they distinguish among colors.

### Other Associations

IEC 73 specifies other visual associations, and several for sound, and for tactile sensations. For visual cues, the corresponding shape to red (danger, faulty) is a hexagon, for yellow (caution, abnormal) a triangle, and for green (safe, normal) a square or rectangle. For the mysterious 'mandatory significance', the shape is a circle. The triangle is used in public signage for warnings, so seems logical. That a hexagon and not an octagon (as on stop signs) is used for danger seems odd. Aside from the triangle, these conventions don't seem especially useful for lighting.

For flashing, the standard specifies two ranges of speeds (slow and normal), so that they can have different meanings. It seems likely that having more than two speeds would go beyond what people would likely understand as meaningful distinctions. Flashing is identified as calling for attention.

For sounds, the standard speaks to ongoing sound, which seems not useful to lighting control. While some controls today are entirely silent, some make mechanical sounds which have the effect of giving feedback that a transition has occurred. Others generate sounds when user inputs are occurring. The power control standard specifies optional audio associations for powering up and down (rising and falling tones); it seems plausible to adapt this convention for lighting controls.

Detailed tactile associations seem beyond what lighting controls are likely to commonly use.

### Indicators

Visual indicators are most familiar as a single LED with a color and stable on, stable off, and flashing states. Any indicator can inherit the generic associations from color and flashing discussed above, as well as being in a particular context from where it is, or a term or symbol near it. In many cases, an indicator is only intended to communicate on and off, with no meaning attached to the color used. This is particularly an issue as for many years, only red LEDs were widely (and cheaply) available, and still today, there are price and energy use differences between different colors that inform design decisions In addition aesthetic design concerns drive many design decisions. So, a challenge is to distinguish when color matters, and when it does not.

So, while the color associations above should be referenced for possible meaning for lighting control indicators, a key for any lighting-specific standard is to define associations for particular concepts or functions. We are not aware of existing standards that do this, but any standards developed should be logically related to the existing color associations.

Indicators can also be audio or tactile, though neither is especially important for lighting controls. Technically, a switch position is a mechanical indicator.

### Terms

Most terminology is defined within some professional context, to enable people to communicate with precise meaning. The International Lighting Vocabulary and Nomenclature and Definitions for Illuminating Engineering contain definitions for lighting terms used in this document including fixture/luminaire, lamp, color, daylight, light source, dimmer, etc. Terminology that is critical to the project will be included in a glossary as an appendix to the final report. Terms included will be defined per the above listed sources.

### Physical Mappings

Physical actions of people with respect to controls manifest themselves in several ways: what they do with "actuators", and how mental models are manifested in metaphors, and affordances.

An actuator is something that allows mechanical motion of a person to be communicated to a control. IEC 447 catalogs these as a handle, knob, push-button, push-push button, push-pull button, roller, plunger, light pen, mouse, keyboard, touch sensitive screen. IEC 447 specifies a number of associations for common physical actions. These are summarized in Table 2.

**Table 2: Associations for common actions**

| Effect<br>Action | Increasing | Decreasing |
|---|---|---|
| **Vertical motion** | Up | Down |
| **Rotation** | Clockwise | Counterclockwise |
| **Horizontal Motion** | Right | Left |
| **Motion re: operator** | Away | Towards |

The term affordance refers to the perceived and actual properties of an object that provide strong clues about how it is used or operated [Norman 2002]. For example, a flat metal plate on a door affords pushing, and suggests that the door opens outward, while a grab-handle affords pulling, and suggests that the door opens inward.

In interface design, metaphors comprise a set of icons, images, actions, and processes that leverage a user's existing knowledge of how things work, to make interfaces understandable. A common example used to illustrate the concept of metaphors comes from personal computers, where the 'desktop', and folder icons are used to represent the operating system's file system. This is in contrast to non-GUI representations that rely upon text strings, with colons or slashes to indicate roots, directories, and file names and locations.

### Summary

There is a rich vocabulary of existing interface elements in standards that are or could be relevant to lighting controls. There are a range of element from those that will likely be adopted directly, those that might need some adaptation or application language, and some which should be rejected for use with lighting. We also expect to need to create some new elements, at least for symbols and words.

## Literature Review: Lighting Control User Interfaces

This section presents the results of a literature review concerning user interfaces for lighting control systems. The reported findings span a range of sources, including lighting industry and manufacturer reports, academic and trade research publications, design studies, and informal conversations with lighting controls researchers from Philips, UC Berkeley, and Lawrence Berkeley National Laboratory. In general, the public domain does not offer a large body of work dedicated to user interfaces for lighting controls. User interface design and closely related topics such as human factors and ergonomic design, form an entire field of study that are thoroughly documented in the literature, but rarely is the work explicitly applied to lighting systems. Therefore, searches over terms such as {lighting interface design study usability elements user} tend to generate results related to the DALI (Digital Addressable Lighting Interface) protocol, web and GUI design, electrical and controls design, patent applications, or manufacturer product ads. This is also the case within the lighting and HCI (human computer interactions) research literature. It is worth mentioning that lighting controls manufacturers do conduct user studies, and dedicate significant resources to switch and interface design, however their findings are not typically made public.

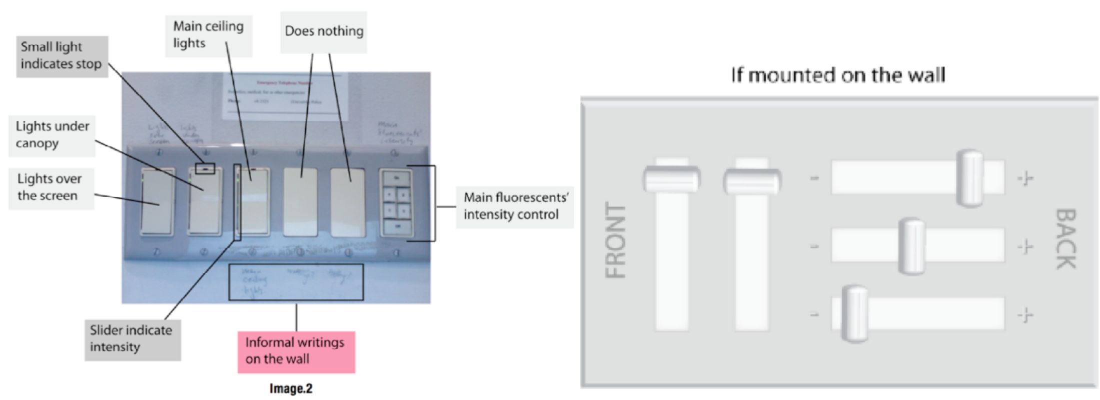
Four instances of lighting interface studies were found, two in the form of reports, and two from the peer reviewed literature. Relative to the interfaces standardization project, these studies are useful in drawing attention to pairs of lighting control tasks and interface elements that may lead to usability challenges.

- In (Morimoto et al. 1997) a three-part approach was adopted to design a control panel for lighting and air conditioning control: identification of tasks and terms; prototype concept generation; and usability testing with 13 subjects. The research concluded that the use of the 'parallel design method' (vs. iterative design) was more valuable from a usability standpoint. Usability was assessed according to operating time, error rate, and the need to consult manuals.

- A 2009 study reviews the design of an 'intuitive' interface according to a set of interface design guidelines, and it's comparison to a traditional interface (Boesten et al. 2009). Usability testing showed improvements relative to the traditional controls.

- In a 2007 human factors project a panel with an array of rocker switches and buttons was evaluated for usability (Sakizili 2007). Users were presented with a set of tasks, and human factors violations were identified based on the number and type of mistakes that they made. Principles from the text *An Introduction to Human Factors Engineering* were used as a guide to inform a suggested redesign of the lighting control panel.

**Figure 2: Left: Traditional switch panel evaluated in [Sakizili 2007]; Right: Suggested redesign.**

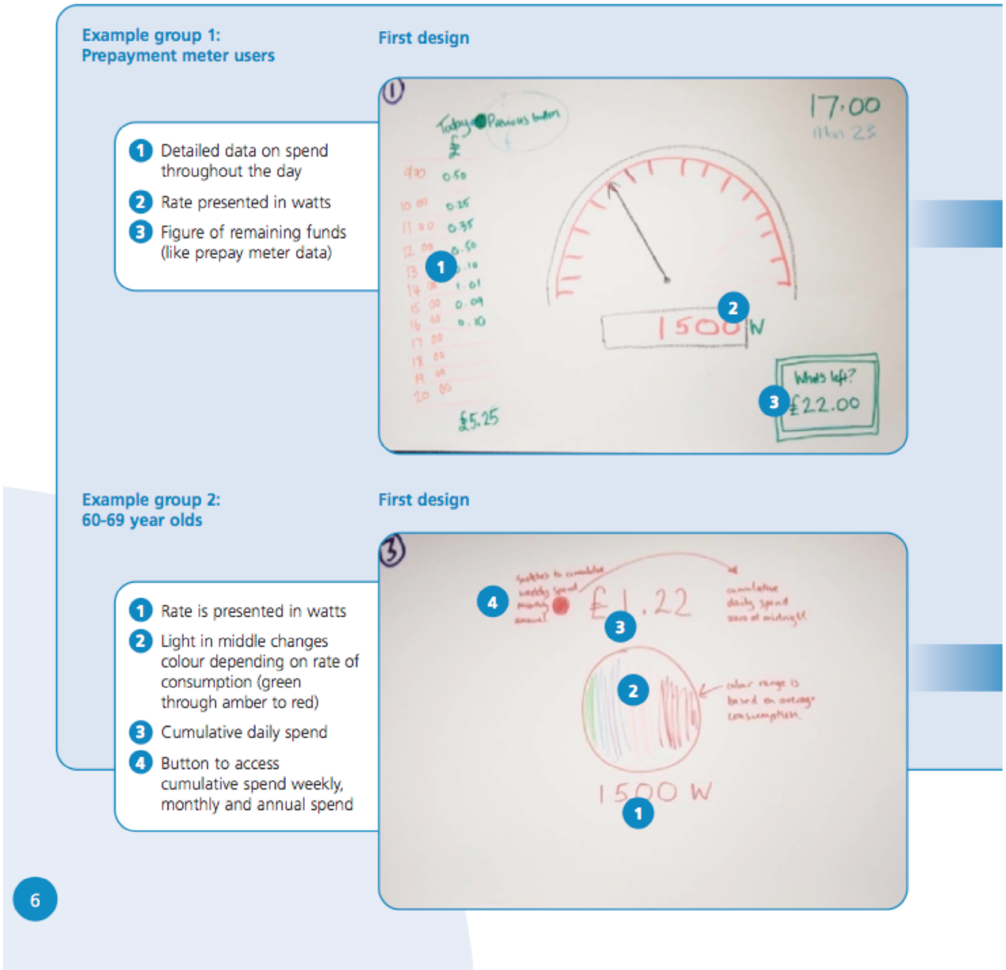



- Finally, the development of speech interfaces for naming and configuring DALI lighting control systems is presented in (Ramirez Chang 2008). The paper states that neither panels of wall buttons with scene names, nor touch screens with complex menu hierarchies are sufficient to address the issue of lighting in reconfigurable workspaces. In response, an alternative speech-based paradigm is investigated.

Moving beyond lighting controls, the literature also offers instances of interface design studies particular to energy efficiency technologies such as programmable thermostats design, and energy information displays. (Freudenthal and Mook 2003) present interface usability tests for a thermostat that included multimodal interaction dialog using speech, sound, graphics and touch. Relative high usability was noted especially with the task-based dialog and with automatic suggestions given by the thermostat. Age-dependent differences in usability were found for certain interface details, such as finding a hidden menu item. Usability problems that were observed were worse for the older group of users. (Peffer 2009) developed and tested an interface for a demand responsive thermostat and home energy display. Human subjects tests were performed to determine the behavioral effects of displaying energy versus price information, and of sponsorship – for example, utility vs. non-profit community groups. In this case, the context in which the interface was presented influenced behavior, but the information that was displayed did not. In the context of home energy displays, a September 2009 report (Energy Savings Trust 2009) explored the behavioral and efficiency impacts of the design of home energy displays. The authors note that little is known about the relative strengths and weaknesses of different display options, or what makes a good energy display. Literature reviews, and user interviews and focus groups were conducted, and ultimately the study concluded that a minimum specification is required to maintain critical energy management functionality. Specifically the specification defines: a set of default display elements (e.g. analog power indicator, expense metrics and units); push button interactions that should be supported (e.g. spend in last complete month); option to toggle between units of money and power; and support powering from mains, but also via internal battery to allow mobility.

Returning to the overall interfaces standardization project, the literature review suggests that the research will be strongly informed by vendor conversations, prior research in standards, and knowledge from the interface design, and human factors and ergonomics communities. Within interfaces and design, several key references and researchers are relevant. Donald Norman is a cognitive scientist who was one of the first to combine human factors and cognitive design principles to encourage a human or user centered approach to design (Norman 2002, 2004, 2007). Republished in 2002, *The Design of Everyday Things* explores instances of good and bad design, and establishes introduces a guiding set of design principles, with formal underlying structures that can be applied by designers. These principles are rooted in concepts such as providing visibility, meaningful conceptual models for users, mappings between actions and results, affordances, error accommodation, and feedback. Norman explicitly addresses switch design, noting that mapping and grouping are common challenges. With regard to arrays of light switches, he notes the common difficulty in determining which switch controls which light. Norman recommends a redesign in which switches are installed on horizontal planes, as opposed to vertical walls. In addition, he recommends overlaying a floor plan on the horizontal mount surface so that fixture/switch pairs are easily recognized relative to the location of the fixtures in the room (see Figure 4). In 2004 Norman focused on the role of users' emotions in product design, although with less emphasis on guidelines and methods, in *Emotional Design: Why We Love (Or Hate) Everyday Things.* More recently, *The Design of Future Things* was published in 2007.

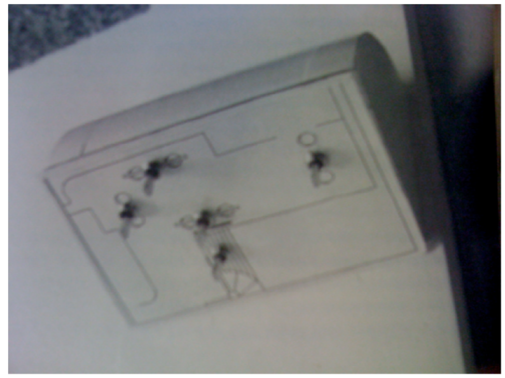
**Figure 3: Home energy display interface design study (Energy Savings Trust 2009)**




Web, software, and graphical user interfaces are a common focus of usability experts such as Jakob Nielsen. Nielsen is the founder of 'discount usability engineering,' a process that focuses on rapid inexpensive user interface improvements, based on four techniques: user and task observation, scenarios, simplified thinking aloud, and heuristic evaluation (Nielsen 1994). In 2006, *Prioritizing Web Usability* was authored with the intent of updating *Usability Engineering*, and identifying the most important guidelines from the interceding twelve years (Nielsen and Loranger 2006).

The methods first espoused by researchers such as Nielsen and Norman have since been modified, evaluated and applied by others, and are thoroughly documented in the literature. For example, the Interaction Frogger framework uses the concepts of information feedback and feedforward to characterize user action and product function, with the goal of intuitive interface design (Wensveen et al 2004). Based on six practical characteristics (e.g., time, location, direction) the designer is supported in linking user action and product response.

**Figure 4: Installed switch panel in [Norman 2002] (left), and redesign (right)**



As previously noted, the contemporary literature in user interface design is dominated more by the consideration of software GUIs than that of physical objects or machines. Search terms that include the words interface, human and machine quickly generate findings related to ISO standards, which are reviewed in Section 3.0. However the human factors, ergonomic, and industrial design literature offer valuable insights concerning user interactions with the tangible physical world ([Salvendy 2005; Wickens et al. 2003), and in automated systems (Nickerson 2006; Sheridan 2002; Woods and Hollnagel 2006).

In reviewing methodologies that may contribute to the design of a user interface, three areas were briefly explored: participatory design, design anthropology, and image schemata. Although all three of these areas could be expanded into research areas of their own right, as tertiary topics that will inform the project team in this effort they have merit.

Participatory Design methodology and practices center around the needs of the end-user rather than the researcher or manufacturer. This extends beyond the needs of the end-user that are directly connected to the use of the product or service being designed, and into the environment of the user, community values, and the larger system of objects and practices that the product or service will function within. Participatory Design practices involve end-users beyond focus groups and include them in activities that include workshops, story-collecting and story-telling through text, photography exercises, and games for analysis and design, and the co-creation of descriptive and functional prototypes (Muller, 2002).

Participatory Design practitioners vary in area of expertise, although the concept has gained significant popularity in the field of software and interface design. The exploration and potential adoption of Participatory Design methods in the development of future lighting controls interfaces may offer insight into the project that may not be afforded by other methods. Additionally, the interface components that result may be positioned for adoption within the community it is intended for even before the design is complete.

There are at least four main communities that a new lighting interface standard must serve for successful market adoption:

- Standards organizations.
- Lighting manufacturers.

- Specifiers (designers, architects, electrical distributors, contractors).
- End-users.

In the last three groups listed, there is an opportunity to involve the community in the creation or dissemination of the proposed standard. Digital tools for distributing community information are present and pervasive in each of these communities. While decisions regarding the proposed interface design will be made ultimately by the design team and the standards organizations who will adopt them, tools for participatory design can be used to inform and develop the standard.

If participatory design methodology is used to create products and participatory culture enables that product to circulate through a community where it is rejected, accepted, or evolves to meet the needs of the community, it makes sense to also look to contemporary anthropologists and market researchers that are working at the cross section of these areas. Their work is relevant to this project to provide methods for gathering information on both the design of an interface standard and what needs to be done to seed this standard in culture to assist in its acceptance. Without proof that there will be acceptance, manufacturers are less likely to adopt the standard and produce products that use it.

Dori Tunstall, PhD is a Design Anthropologist working and teaching in this area. She differentiates Design Anthropology from traditional anthropology or market research by noting that there has been a shift in what is studied by practitioners in the field from the study of exotic peoples and their practices to the study of global movement of people and practices, as well as the goods they produce and use. She employs practices from the design disciplines and anthropology to conduct her research. If her approach can be used as a representation of the community of anthropologists that she represents, the following define the approach of using design to determine information about the intended end users:

- Indirectly through abstracted representations of multiple values and experiences to inform designing by designers where the technical means are beyond the contextual knowledge of the people who might use the designs (this can be end users as well as corporate stakeholders).
- Directly by various people's co-participation in the design of objects, communications, and experiences at various levels of fidelity.
- Directly by providing various people additional shared tools of design production appropriate to their own contexts.

User interface design is a good example of an area that benefits from these approaches. The Bay Area design firm IDEO (ideo.com) practices both participatory design and design anthropology in the course of their product development. Although essentially a commercial venture selling a methodology as a product, the success of the products designed speaks to the methods used. The design of a lighting controls interface standard would benefit from examining IDEO's methods, since the end result would perform in the same arenas as the interfaces designed by such firms. Additionally, a standard would need support from the ID community in order to be successful, and firms like IDEO would benefit as well.

Although a new lighting interface standard would need to gain momentum with niche audiences in order to gain momentum, unlike devices like mobile phones and music software, the end user does not typically select the lighting control interface in buildings other than their homes, and not always even there. The successful implementation of a lighting controls standard would see to the ubiquitous adoption of the signs, symbols, gestural, and visual language elements it contained. The topic of image schemata, and the attempt to find categories of common metaphors that are found throughout the human landscape becomes relevant.

Two authors were reviewed for the purposes of this project to begin exploring this topic. Mark Johnson and George Lakoff worked to define and categorize commonalties through the analysis of language metaphors, and then took this one step further to generate a list of image-based schemata that serve as a building blocks for metaphors that provide the basis for relating to and understanding experiences. These basic concepts may prove valuable when mapping interface functions to cultural practices and the assignment of symbols to represent interaction. For example, a cycle schema indicates a beginning, transgression through a series of stages, and a return to the starting state. In a radial dial used to adjust lighting levels, the light cycles through stages of brightness to dim, and then into an off position and then to full brightness again. When users encounter the circular form of the radial dial for the first time, a preformed notion of what to expect from a cycle using the visual metaphor of a circle, assists the user in understanding how to use it. Other spatial motion image schemata include:

- Containment.
- Path.
- Source-Path-Goal.
- Blockage.
- Center-Periphery.

Design practitioners are cautioned against using these theories too literally, but image schemata theory does provide a foundation to consider when designing for the broader audience and is worth noting for the purposes of this project.

# CHAPTER 3: Existing Controls Survey

This chapter documents the approach to the Survey of Existing Controls conducted to collect information about existing user interfaces, and to identify interface elements that are important to consider in the development and deployment of the next generation of lighting controls. The scope of this task includes:

- Select a sample of products for review, ranging from simple to complex (including with displays), both residential and commercial, and covering both hardware and software. A particular emphasis will be placed on technologies and products that the team determines are most likely to gain market share in the near term. The primary focus is on specific elements in the interfaces, including those available over a network, and elements that are commonly found with user interfaces such as sensors and actuators.
- Analyze user interface elements present in these products, both explicit and implicit.
- Meet with lighting manufacturers (e.g., Lutron) to assess current and future user interface elements.
- Prepare a report on products reviewed including user interface elements and key attributes.
- Summarize the project, review key findings and recommendations, and determine the best next steps toward a user interface standard.

From simple toggle switches found in most houses to complex control panels in commercial office spaces, lighting controls employ a variety of interface components to cue the user to provide the appropriate light levels for the occupants of the space. The objective of this survey is to collect, document, and analyze the common elements found in residential and commercial controls that a typical occupant regularly comes into contact with.

This survey focuses on the elements of common lighting control user interfaces, including switches, dimmers, and scene controllers that are found in homes and office spaces. Portable light sources, such as table lamps and torchieres commonly found in homes, were audited to determine the basic categories of switching and dimming. Visual, tactile, and audio elements that serve as cues or feedback are also taken into account. This survey excludes control panels and software-based systems that are intended for use only by professional facility and energy managers, not the general occupants of a building.

## Survey Methodology

The California Lighting Technology Center (CLTC) has ongoing relationships with an extensive list of lighting manufacturers. Through this expertise, CLTC staff members selected a group of manufacturers that represents a large segment of the U.S. lighting controls market.

Product images were collected from manufacturers by reviewing online catalogs and through photographing samples at CLTC. Product images were collected and categorized based on the intended user (end user or professional energy/facility manager); interface complexity (switch, dimmer, scene controller, and automation); mechanical or screen (software-based) input; mobility; visual cues; and dynamic feedback elements.

The collection of samples was used to develop a taxonomy of lighting control interface forms and elements that represent the most common features of lighting control interfaces that are used in residential and commercial environments. The taxonomy reveals variation in the use of common elements and the representation of the functions associated with those elements. The structure of the classification system is to maximize utility and clarity, not necessarily rigor.

The majority of the items surveyed were selected because they can be found in either environment. The residential products were generally used as a baseline because they are typically less complex and sold at a lower price point.

Forty-four companies, including 28 lighting, eight home automation, three home improvement, two electric, and three other companies were surveyed (Table 3). Of the 30 companies that were surveyed online, 27 were reviewed through online catalogs, and three electric/home improvement companies were reviewed on one product only. Two-hundred eighteen products were collected by reviewing online catalogs and by photographing samples at CLTC. Sixty types of table lamps were collected from Target. Target was selected to represent portable lamps and torchieres currently available for sale to typical California residents. Target has locations in the majority of mid-sized to large California cities and represents a popular location for purchasing of affordable small household appliances.

Twenty companies submitted feedback on lighting control user interface standards during LightFair International 2010. This valuable experience afforded the survey team access to a significant portion of the manufacturers who are active in the US lighting industry at one location. It was also useful to participate in product demonstrations to see first-hand how the manufacturer would describe how to use the interface. The information collected from the interviews that took place LightFair 2010 will be included in the final report.

**Table 3: List of companies surveyed**

| Company | Company Type | Online data | Photo data | Interview |
|---|---|---|---|---|
| ACE | Home improvement | Product | - | - |
| Acuity (Lighting Control & Design) | Lighting | Catalog | - | - |
| Acuity (Sensor Switch) | Lighting | - | - | Light Fair |
| Anigmo | Lighting | Catalog | CLTC | - |
| Berkeley Lamp | Lighting | Catalog | CLTC | - |
| Blackstone International | Lighting | - | CLTC | - |
| CentraLite | Lighting | Catalog | - | - |
| Colorado vNet | Automation | Catalog | - | - |
| Control4 | Automation | Catalog | - | - |
| Cooper Controls | Lighting | Catalog | - | Light Fair |
| Crestron | Automation | Catalog | - | Light Fair, Company visit |
| Dialux | Software | - | - | Light Fair |
| Do It Best | Home improvement | Product | - | - |
| Douglas Lighting Controls | Lighting | Catalog | - | Light Fair |
| Easylite | Lighting | Catalog | - | Light Fair |

| Company | Company Type | Online data | Photo data | Interview |
|---|---|---|---|---|
| Echoflex | Lighting | Catalog | - | - |
| Encelium | Lighting | - | - | Light Fair |
| Feelux | Lighting | - | - | Light Fair |
| Future | Lighting | - | - | Light Fair |
| GE | Lighting | - | - | Light Fair |
| HAI | Automation | Catalog | - | - |
| Hubbell | Electric | - | - | Light Fair |
| IKEA | Home improvement | - | CLTC | - |
| LaMar | Lighting | - | - | Light Fair |
| Leviton | Lighting | Catalog | - | Light Fair |
| Lightolier | Lighting | Catalog | - | - |
| LiteTouch | Lighting | Catalog | - | - |
| Lumergi | Lighting | - | - | Light Fair |
| Lutron | Lighting | Catalog | - | Light Fair |
| Nedap Luxon | Lighting | - | - | Light Fair |
| Philips | Lighting | Catalog | CLTC | Light Fair |
| PulseWorx | Lighting | Catalog | - | - |
| RTI | Automation | Catalog | - | - |
| Savant | Automation | Catalog | - | - |
| Schneider Electric | Lighting | Catalog | - | Light Fair |
| Sylvania | Lighting | - | - | Light Fair |
| Smarthome | Automation | Catalog | - | - |
| Starfiel Controls | Lighting | Catalog | - | - |
| Target | Other | - | In store | - |
| Traxon | Lighting | Catalog | - | Light Fair |
| Tridonic | Lighting | Catalog | - | - |
| Vantage | Automation | Catalog | - | - |
| WattStopper | Lighting | Catalog | - | Company visit |
| Westek | Electric | Product | - | - |

Source: CLTC

# CHAPTER 4: User Interface Forms and Elements

The goal of this task is to organize and analyze the data from the survey to develop a taxonomy of lighting control user interface elements for major lighting applications. This will cover both the abstract concepts being represented, and the diverse ways that they are implemented in controls. The scope of this task includes:

- Analyze the data from the survey.
- Prepare a taxonomy of user interface elements.

This section begins with a list of terms for use in discussing lighting control user interfaces, to establish a common vocabulary, for this report and beyond. The discussion is organized into a sequential narrative that reflects the way a typical occupant interacts with lighting controls. In a typical situation, the occupant approaches the device, interprets the static visual cues, interacts with the device, and receives dynamic feedback (from the light and/or the control). This organization gives context to the collected data.

Two-hundred twenty one lighting controller images were collected from the Internet and on-site at CLTC. Complex controllers (e.g. scene controllers) are more prevalent in this survey, but the distribution in this chart does not reflect lighting controller prevalence in homes. The survey was not intended to reflect the current stock or sales of controllers, but rather be oriented to what is most useful for understanding future directions. The distribution represented in Figure 5 reflects controllers that manufacturers make available through sales and marketing materials, which tend to be more complex and expensive. Timers were found to be less prevalent, possibly because most of the timers are not targeted to residential usage. The controllers surveyed were not categorized according to the type of lamp they would be paired with, such as incandescent, fluorescent, or solid state lighting sources. As solid-state lighting products become more prevalent, this may be taken into consideration. Residential color control is an emerging technology typically associated with new solid-state products, so color controllers are still uncommon in the residential market.

Our analysis uses a variety of approaches to understanding and organizing lighting controls, specifically:

- A top-down assessment of the entire interface, which we refer to as the “form” of the device.
- A bottom-up assessment of each individual “element” of the interface and what it means (including meaning which may be implied but not specifically referenced by an element). An element is a unit of the interface that cannot be subdivided, such as words, symbols, colors, dynamic behavior, and metaphors.
- Organization of elements onto sets of related ones we call “concepts” which have correspondences amongst each other.

- A distinction between communication from the device to the user, and communication from the user to the device.
- A division between that content which is static (e.g. printed on the control), and that which is dynamic (e.g. indicator behavior).

These are all different ways of 'slicing' the topic, and none substitutes for any other.

## Terminology

Forms of lighting controls reviewed in this report include fixture-integrated switches/dimmers, wall-box switches, dimmers, programmable dimmers that control several scenes, and select home automation systems that control other systems (i.e., heat/air, audio/visual) along with the lighting. Controllers can be grouped into a number of major types, with subdivisions within them.

The following terms are a framework for discussing lighting controls. Although many of the terms listed below have other definitions when used in other (non-lighting) areas, this list defines them as they are used for lighting controls.

### Controller mobility

**Fixed:** Any lighting control interface that a user does not move regularly, even if the controller itself is wireless or moveable (e.g., a cord dimmer).

**Mobile:** Any lighting control interface that is intended for the user to move on a regular basis.

### Controller Forms

**Switch:** A lighting controller that primarily turns a light on or off.

**Dimmer:** Device used to control the intensity of light emitted by a luminaire (this from IES (IES, 2000) which adds "by controlling the voltage or current available to it").

**Scene controller:** A lighting controller capable of controlling multiple lamps, light settings, and/or lighting zones based on the wiring or the program of the controllers.

**Home automation:** A control system that also controls non-lighting systems (i.e., heat/air, audio/visual).

**Remote:** A handheld mobile lighting control device (excluding mobile phones) that the user moves on a regular basis in the home or in the workplace.

### Element types

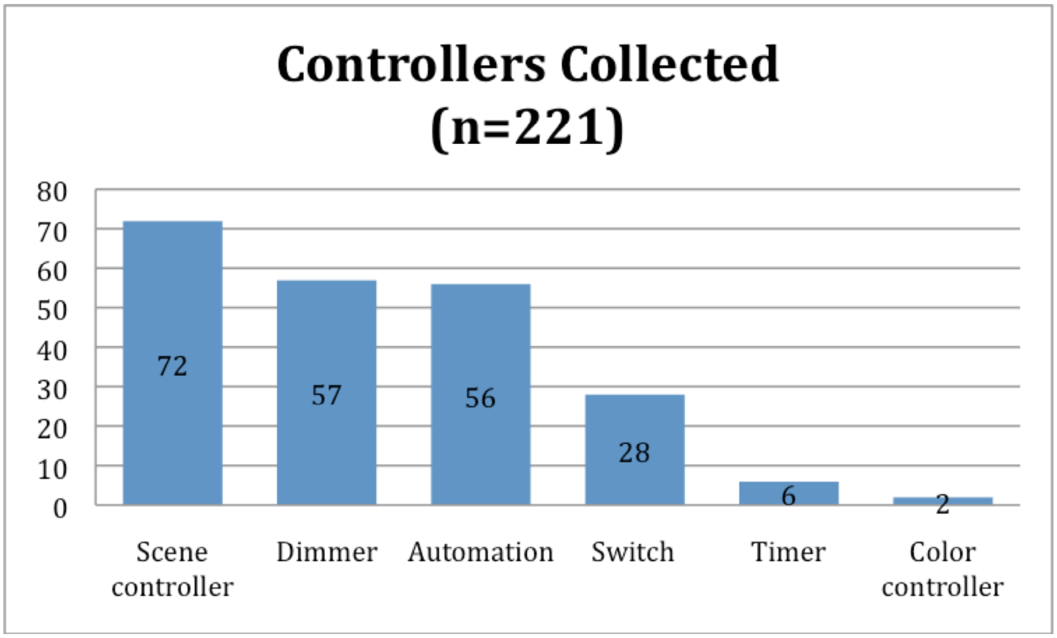
Elements can be static or dynamic and fall into one of three categories, depending on the sense they employ. Dynamic elements can provide feedback.

**Visual element:** Visual cue on a lighting controller that indicates the function of the control. Examples collected in this category include static elements such as words or symbols and indicator lights that flash specific colors. Observed position of a control is a visual element.

**Tactile element:** Tactile cues on a lighting controller include indications for the position of the control (e.g. an indentation, or position as felt), or haptic technology that provides motion feedbacks (e.g. pressure, force, and vibration).

**Audio element:** Audio cue from a lighting controller that gives feedback indicating a change of light level or a change in the conditions of the system (e.g. demand response signal).

**Figure 5: Controllers collected**




Rocker, toggle, and push-button controls offer the possibility of indicating switch state. Only rocker and toggle facilitate labeling with visual elements.

Left - Push switch on the base of a table lamp; middle - Rotary switch on the neck of a torchiere; right - rotary dial switch on the cord of a table lamp.

## Forms

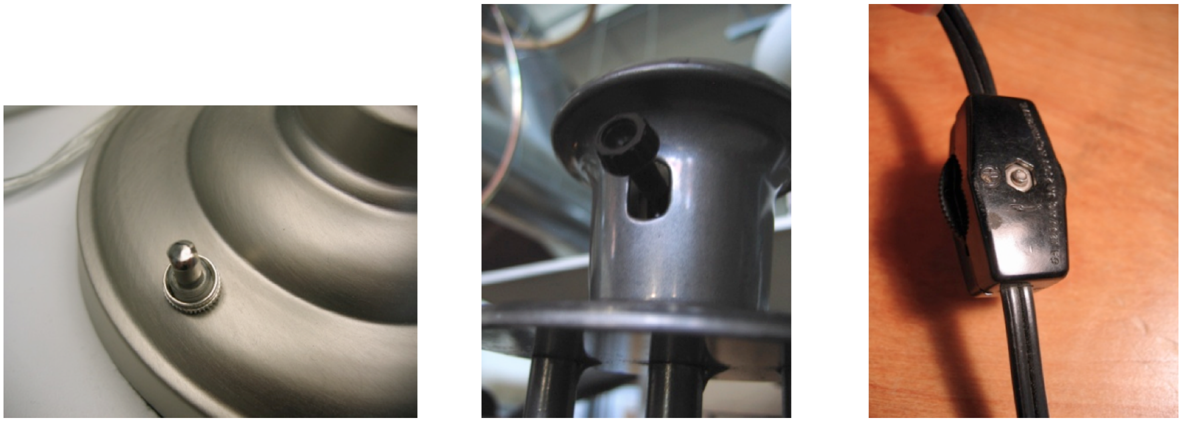
Our first way of organizing controls is a taxonomy of overall forms of lighting controls, beginning with the simplest, and ending with those with the most capability and complexity. We have presented our results as a traditional taxonomy, but with the wide variety and complexity of lighting controls, we need to consider in a future phase if it would be better to express some of this as characteristics framework rather than a formal taxonomy.

### Switches

#### *Fixture-integrated Switches*

On portable devices, such as table lamps and torchieres, switches are typically positioned on the base, the neck, or the cord (Figure 6). The base-affixed switches are mostly rocker, toggle, or push buttons. The neck-type switch includes rotary, rocker, line, and pull control. Cord switching most often uses a rotary dial or rocker. The movement of the switch toward the luminaire in the majority of the portables surveyed turned the device *on*.

**Figure 6: Left: Push switch on the base of a table lamp; Center: Rotary switch on the neck of a torchiere; Right: Rotary dial switch on the cord of a table lamp.**



Of the 60 samples collected from Target, a rotary knob on the neck of the lamp was the most common control for table lamps, representing 63% of the sample. Line, pull, and cord rotary control were significantly less common than rotary control.

**Figure 7: Control interface on Target table lamps**

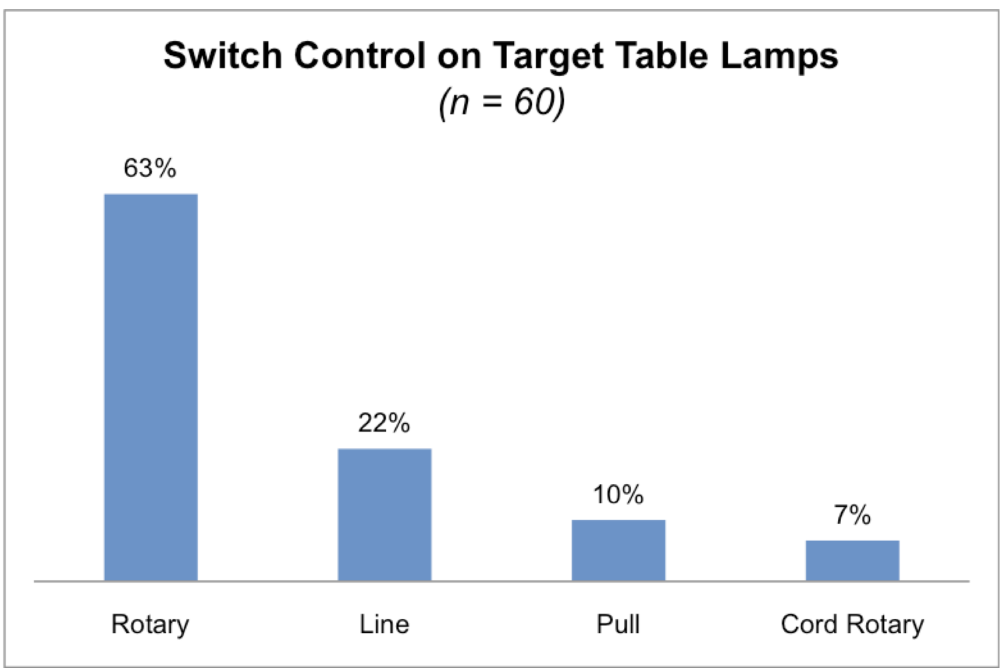
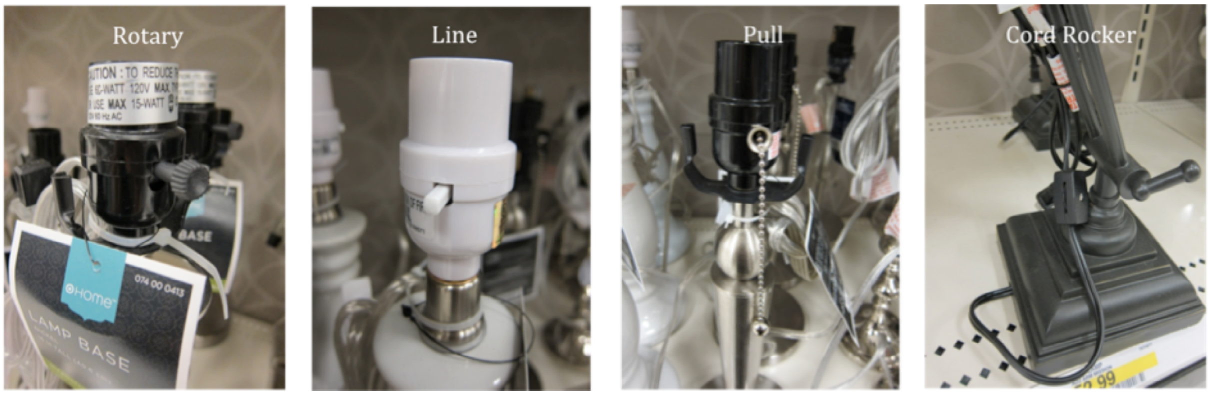


**Figure 8: Four table lamps control types found at Target**




*Wall Box Switches*

The most common control style for wall box switches is the toggle or rocker (Figure 9, left). In the U.S., the convention is that the top or "up" position will turn the light on and the lower or "down" extinguishes the light. Push-button controls with one button (on/off) switch or two buttons (on and off) also are available on the market. This type is usually a part of a scene control product series that controls multiple light settings with additional buttons. Visual cues such as labels or LED indicator lights are more common on push button switches. Of the 24 wall box switches sampled in this survey, 16 of them did not feature any visual cues beyond the assumed conventional cues (e.g. up = on).

*Foot Switches*

Foot switches control the light through push buttons or rockers and commonly operate floor lamps such as torchiers. Replacement foot switches (Figure 9) are available on the market. Neither typically features visual cues on the interface.

**Figure 9: Left: Rocker wall box switch (Echoflex); Middle: Replacement foot switch (Do It Best); Right: Dial dimmer on Berkeley Lamp II.**

## Dimmers

Dimmers come in two basic types: those in which the switch function is integrated with the dimming, and those for which the two functions are separate.

### *On-fixture dimmers, portables*

According to this survey, rotary dials are the most common dimming feature on portables, specifically table and task lamps. The dimmer either sits on the base or on the neck. On-fixture dimmers usually do not include visual cues. For example, the Berkeley Lamp II (Figure 9) has two dials: One controls the uplight and another controls the downlight. The uplight brightens by rotating the dial downward (toward the user); the downlight brightens by rotating the dial upward (away from the user).

### *Cord dimmers, portables*

Cord dimmers are either incorporated into the cord or sold as an add-on feature. Most cord dimmers have a slide or rotary dial. Some slide cord dimmers include locator lights to locate the controller in the dark. Similar to fixture-integrated dimmers, cord dimmers typically have no visual cue on the direction of the control. At first glance, occupants cannot infer which side will raise or lower light levels. However, occupants can learn the direction after a few uses, and it is not considered a complex task.

**Figure 10: Cord dimmer with slide control and locator light (Lutron, left); cordless dimmer with dial control (Levitoron, right).**

### *Wall box (conventional) dimmers*

Wall box dimmers include combinations of slides, toggles, rockers, buttons, rotary dials, and touch elements. Thirty-four wall box dimmers were surveyed. Current models of dimmers such as the Lutron Maestro “saves” the light output setting set by the occupant when they last switched off the lights (that is, the dimming setting is separate from the on/off status). When the light is turned on, the light output remains unchanged from the setting most recently used. In addition, select slide dimmers indicate the current lighting level with light emitting diode (LED) indicators. This feature doubles as a locator to find the switch in the dark.

**Figure 11: Left: Lightolier slide dimmer; Middle: Lutron Maestro digital dimmer with LED indicator; Right" touchless dimmer with decorative faceplate (Anigmo)**

*Decorative touch dimmers*

Decorative touch dimmers include few visual cues and are highly customized to occupant preference. Tapping the touch dimmer serves as the on / off switch, and applying pressure to the dimmer faceplate adjusts the light output. One touchless dimmer found by the survey team was designed to respond to an object moving in front of the dimmer to activate the on/off states, and pressure applied to the faceplate for dimming control. Although the control is simple, occupants with no previous knowledge of these products will need orientation to properly use the product.

**Figure 12: Foot dimmer (Westek)**

*Foot Control Dimmers*

Foot control dimmers use a wide slide design with traction elements on the pedal (see Figure 12). Of the ten user feedback posts on Amazon.com, three reported that they used their hand instead of their foot to control the dimmer, suggesting that foot control lacks fine adjustment ability.[6]

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6 Amazon.com, customer rviews of Westek 6089B 500W Full Range Foot Control Dimmer. <www.amazon.com/Westek-6089B-Range-Contor-Dimmer/product-reviews/B000FPCEGI/ref-cm_cr_dp_all_summary?ie=UTF8&showViewpoiints=1&sortBy=bySubmissionDateDescending>

## Scene controls

Scene controls enable multiple and complex settings of groups of light fixtures to be attained with few interactions. They fall into two primary categories: those for lighting only and those for other end uses as well. In addition, there are three types: hardware (switch/button) only, display only, and hybrid (which includes both).

### *Lighting scene controls*

Hardware keypads are the most common scene control interface (89% of the 70 scene controllers surveyed). Scene controller shapes and sizes from wall boxes to table top panels. Of the 16 companies with hardware scene controllers, all but one offer a custom engraving/labeling service for their hardware keypads. Features such as locator lights, dimmers, and occupancy sensors also are common on scene controllers. Multibutton keypads are available with to up to 20 buttons, allowing further customization. 79% of the scene controller samples had words as visual cues on the controllers, suggesting words are the most common label requested by the customers.

### *Home Automation*

Home automation typically includes multimedia (audio/video), climate, and lighting scene control. This category of products differs from commercial automation systems in that they are intended for users of various backgrounds with different interactive technology comfort levels, and usually out in the open and so used by many people. Commercial building automation systems are designed for users who have specific training in energy management, and are often out of plain sight, and so not used by the great majority of building occupants. Home automation systems are intended for smaller spaces, and the interface designs take cues from pre-existing residential devices associated with entertainment and communication. Currently, home automation systems are considered a luxury item and are associated with mid to high-end real estate.

Of the 49 automation controllers sampled in this survey, 63% are touch screens. More than half are touch-screen only. The remainder are screen/mechanical hybrids with peripheral hardware bordering the screen. Hardware keypads (24%) and LCD screen hybrid keypads (24%) are the other common interfaces. All of the scene controllers included words as visual cues. Many also included symbols, pictographs, or images for visual cues. Compared to keypads, touch screens offer more complex graphics and larger symbol size.

## Remotes

In this survey, handheld lighting controllers that the occupant relocates on a regular basis are considered a remote. Mobile phone software was not surveyed for this document; we only cover hardware with lighting control as a primary purpose. Lighting control remotes were the most varied in form factor and interface design. Lighting control remote design references well-established home control and communication devices: mobile phones, video game controllers, and TV remotes.

Note that there are remote control devices for use in commissioning lighting systems. Since these are for use only by building/lighting professionals, they are out of scope for this project.

## Software-only

Lighting control applications are now available for devices such as mobile phones and personal computers. Occupants either purchase a device with pre-installed software or purchase and install the software on a multifunction device such as a mobile phone. These lighting control applications are often offered as part of larger home automation systems.

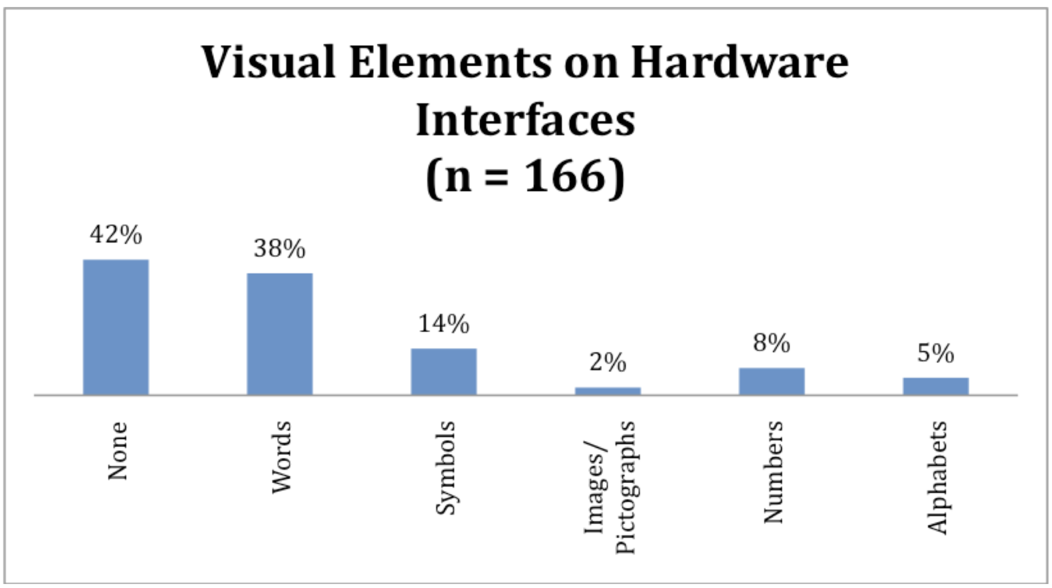
The key to this category is that the interface device was not created with lighting in mind; it is an added function (in contrast to lighting remote controls or home automation displays which have lighting as the or a core function).

## Static Visual Elements

Visual elements assist occupants in understanding lighting control functions before using the controller. Visual elements commonly include words, symbols, numbers, letters, images/pictographs, and indicator marks (e.g. for "on").

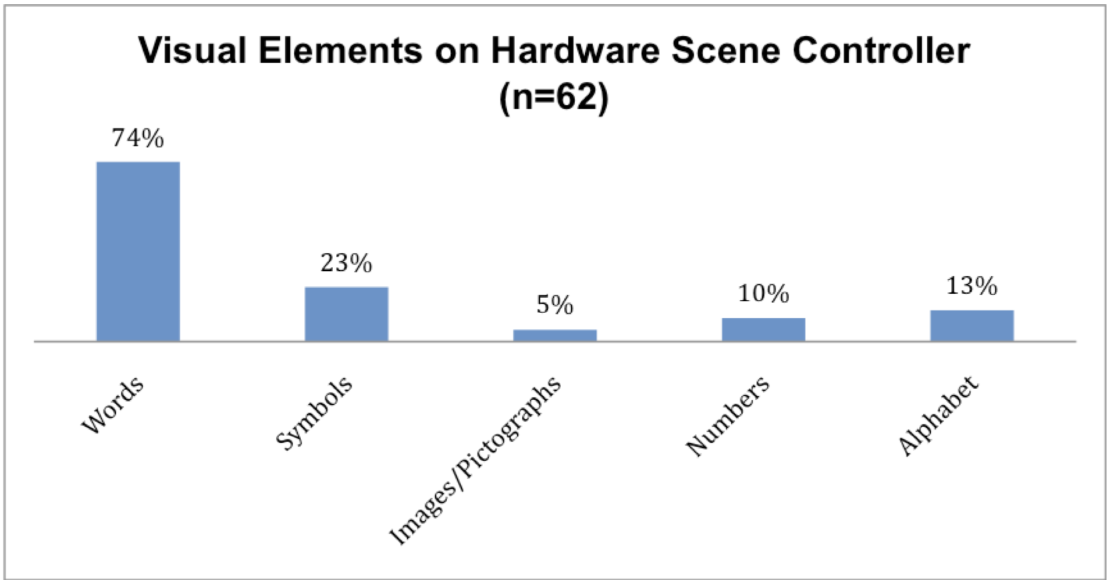
Software-based interfaces have multiple control "pages," so we were not able to review every page to collect all the visual cues used as we did not purchase and install such software. Future studies should include software-based lighting control user interfaces as any standards that emerge from this process will affect this product category. In this report, visual element statistical analysis focuses on mechanical interfaces.

**Figure 13: Visual Elements on Hardware Interfaces**
****Chart excludes color controller; total adds to > 100% as some had several elements**




Almost half of the mechanical interfaces did not have any visual cue available on the interface. The majority of the mechanical interfaces surveyed, as Figure 13 shows, are complex high-end devices with multiple scene control options. Seventy-eight percent of "plain" interfaces are switches and dimmers. If we narrow our focus to visual elements on scene controllers, words are significantly more prevalent than other visual cues. Symbols were slightly higher than numbers and letters, and images/pictographs were the lowest.

**Figure 14: Visual elements on Hardware Scene Controller**
***One interface may have more than one visual element**




## Words

Word labels were categorized into seven categories: command, location, fixture type, setting, time, and number/alphabet combo. Commands include switch (on/off) and other variations such as master switch (on/off), all on, and all off. Location labels range from one room (e.g., kitchen), to a specific part of the room (e.g., cabinet); foyer, hallway, and kitchen are some of the more common labeled locations. Fixture labels such as downlights, sconces, and cove also are common. Some word labels describe light setting for an activity (e.g., dining, reading, entertaining, party, and away). Lastly, some word labels distinguish different settings but do not allude to their use or area (e.g., scene 1, scene 2, scene 3, or room A, room B, room C). Engraved text can be anything that the customer requests, but it was noted in informal interviews with manufacturers at LightFair International 2010 that customers usually proceed with the default or recommended label. This default includes the typeface and placement on the interface, which are also customizable in most products. We also found automation company Control4 to have a text label "GREEN" indicating energy efficiency. Although this is the only energy efficient indication we found on UI, this may be a potential area to explore standardization.

## Symbols, Images, and Pictographs

Symbols are signs that convey meaning through various techniques of association, and may look nothing like the object or action they represent (e.g. a plus sign may indicate the addition of more light to a space but it does not actually look like an image of light). A pictographs is a stylized image that conveys meaning by resembling the object it represents, Fir example, a light bulb pictograph usually looks like an Edison-base incandescent bulb. Software-based interfaces include a much higher percentage of images and pictographs than other forms.

Power, lighting control mode, and brightness are the three controls that are commonly represented as symbols on lighting control interfaces. Power control is most commonly represented by the power symbol "⏻". Some include "|" for "on" and "○" for "off." Lighting /

lights are symbolized by an incandescent light bulb shape "☼"or a luminous ball. Generic lighting symbols are commonly found in home automation interfaces to distinguish lighting control from other home controls. Symbols used to represent brightness control include arrows, + and -, wedge-shaped ramps, and slide bars. Arrows are very common on hardware keypads, and slide bars are more common on touch screens. Few interfaces actually include a symbol for the concept of brightness, but instead imply it with those such as to increase/decrease (e.g. arrows, or a triangle to show a variable control).

**Figure 15: Indications on rocker switches**


### "On" Mark

For fixtures with a rocker switch, sometimes there is a dot or a line marked on the "on" side to indicate the direction of the switch. In the products surveyed, the "on" state results after moving the rocker towards the fixture or as is the convention, "up." This mark often includes a raised nib or raised text, which serves as a tactile cue. If the text is molded onto the switch but is not also printed in ink, the tactile feedback that "yes, this is the way to turn the device on" may be the only cue most users ever experience.

### Numbers and Letters

Number and letters are used to distinguish different settings, which could be different lamps, scenes, or zones. Numbers and letters sometimes also combine with words to create clearer descriptions than generic ones such as scene 1 and scene 2, or room A and room B.

### Printed Color

Lighting control wall units are designed to blend into the visual space of the room. The majority of the models are offered in neutral colors. Lighting controls include colored elements sparingly, often deferring color choice to the consumer.

Lighting control companies offer various colors and texture to suit users' customization needs. For example, Lutron offers four finish textures with more than 20 color choices. The survey team found only one example of a non-LED light color used on hardware, i.e., a scene controller from Acuity that included red for "on" and black for "off" (Figure 16). This is also a customizable product that allows users to choose colors for buttons or wall plates. The survey did not find that the color and finish of the wall plate served as a visual cue necessary to understanding the function of the lighting system.

**Figure 16: Red is on; black is off (Lighting Control and Design (Acuity).**


## Static Tactile and Audio Elements

Tactile and audio elements are essentially absent from lighting control user interfaces. When a user is not touching the control, they will not gain any tactile sense, and static audio indications are not common.

## Dynamic Feedback

Occupants receive feedback from lighting controllers via visual, tactile, and audio methods. Tactile and audio cues provide feedback during or after the interaction. Tactile elements include cues that can be felt through touch interaction with the surface of the interface. Audio elements notify the occupant that interaction with the device caused a change in the system (e.g. scene setting change). The lighting user interfaces surveyed used a combination of these elements, although some interfaces did not employ visual cues beyond the positioning of the control on the wall in an area where a light switch would commonly be found.

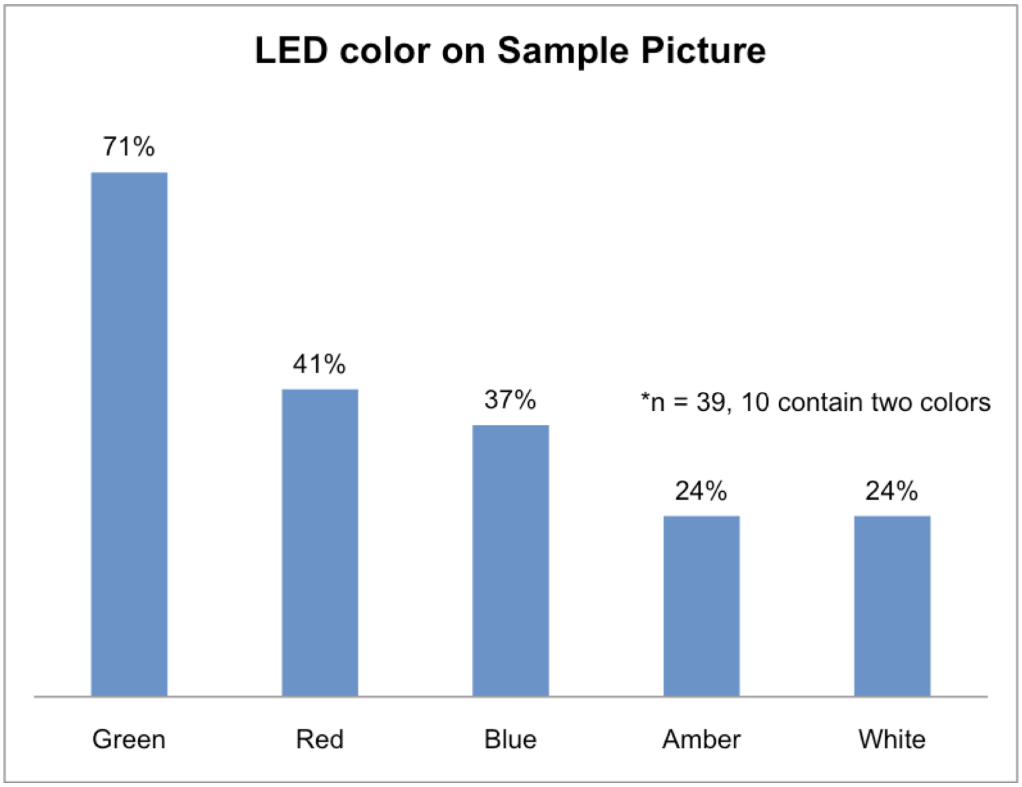
### Visual

The most noticeable way to observe adjustment of a lighting control device is not a visual feedback element at all, but simply the change in the light level of the room. However, when the action involves more advanced input such as setting scenes that will change the light levels at a time later than when the action is performed, feedback from the system assures the user that the actions taken did indeed adjust the setting and the system will perform as expected.

*Colored Indicator Lights*

Colored indicator lights frequently are used as lighting control devices. Digital wall box lighting controls use colored LED lights as locator elements, or as an indicator for brightness level. For wall box units with occupancy sensing, indicator lights show the system is working as it detects occupant presence. Blue and white lights are generally more prevalent on newer designed lighting control interface. Companies specify the number lights on the device, and the frequency and interval of blinking is not regulated by a standard. Currently, indicator lights are not customizable (though home automation company Crestron stated in an interview for this survey that consumers will be able to select preferred colors in the near future)

**Figure 17: LED color on controls**




According to lighting control company WattStopper / Legrand, customer's preference on LED color changed from red to green to blue and is now moving toward white. Red was first chosen because of its availability and cheap price. Blue light was adopted later because of energy efficiency and its long lifespan. There are questions on whether the use of blue lighting in residential lighting would disrupt circadian rhythm, but WattStopper suggested it will take 15 to 20 years for end users to have general knowledge on this topic. Although WattStopper stated blue was chosen because it symbolized high end, no other sources were found to back up this statement.

### *Colored Indicator Lights on Occupancy Sensors*

Occupancy sensors use colored lights to indicate the unit has detected presence in the room. The indicator lights are off during vacancy and triggered when the area is occupied. Feedback is given in the form of a blinking light. Common colors are red, green, and amber. Different manufacturers incorporate one or two lights into the sensor. There is no known standard on the connotation of the color or the frequency of the pulse.

Ceiling- or wall-mounted occupancy sensors that are not integrated into a luminaire or switch box also deliver feedback through colored indicators. Colored indicators are off during vacancy and active when the area is occupied. The most common colors include green, red, and blue.

In the example below (Figure 18), the red light indicates the passive infrared (PIR) sensor has detected an occupant and the green light indicates occupant detection using the ultrasonic sensor. This unit includes multiple sensor technologies and the manufacturer has selected color as a feedback mechanism to differentiate between the two. Without two lights, the occupant may not be aware of the two types of sensor. It was not been determined by this survey if this information is valued by the average occupant. However, if there are no lights on, this is an indication that the system is not functioning. This information is valuable if the lighting system no longer reacts the way the occupant expects it to.

**Figure 18: Dual Technology Occupancy Sensor (WattStopper)**

## Tactile

Tactile elements also serve as feedback to let the user know the light setting has changed. When an occupant touches an interface, haptic feedback felt after an action indicates that what touched should have an effect on the system; the changed position as felt (e.g. of a rocker switch) is an example of this (Figure 19). If the lights or settings do not change, it may be an indication that the action must be performed again.

**Figure 19: Left: Indentation on a sensor switch (WattStopper / Legrand); note that the indentation is marked to differentiate from the sensor. Middle: Indentation on foot control dimmer (Westek); Right: Digital dimmer with programmed audio feedback (Lutron).**

### Audio

Audio elements, such as a clicking sound, are used to tell users a certain light setting is reached. In rotary dimmers, audio, and tactile feedback are commonly used to indicate light is been turned off. In step dimmers or rotary switches, audio feedback indicates a different brightness level is reached. Because people are usually trained to understand the audio feedback in lighting controllers, newer technology such as the Vierti digital touch dimmer by Lutron mimics the clicking sound when lighting level is changed.

## Classification of Lighting Concepts

The notion of 'concepts' provides a useful platform from which to understand interface elements, and families of functionality that interfaces offer to users. Put another way, concepts cover collections of meaning or convention, that together form a coherent role. For example, in an automobile, dashboard controls encompass several concepts. The ventilation concept is served by a collection of symbols – fan (speed), vent outputs, recirculate – terms such as "AC", and colors to indicate hot and cold. Concepts are often separable from each other, and are commonly served by a collection of elements.

A "selector" allows the user to activate, or to use a term from software interfaces, "bring the focus to", a specific concept when more than one concept is accommodated in the interface. For example, on a whole-building control with a display interface, there might be a main screen with a symbol to select Lighting in general (as well as ones for climate, audio, video, security, etc.). Another example is a symbol for "Schedule", to bring up more detailed options for time-based controls.

A UI element for a given concept can serve one of several roles (sometimes at the same time):

- Presence of capability, e.g. that a sensor is present.
- Labeling of an indicator, e.g. an occupancy sensor showing presence.
- Labeling of an actuator, e.g. a dimming control.
- Name of a selector, e.g. in navigation on a touch panel to a different screen.

The same element can often be used for different purposes. For example, the word "Power" or the power symbol – ⏻ – can be used to label a switch, an indicator, or a selector for a control panel. This is similar to a single word being used as both a noun and a verb ("sleep" being an example of this).

Meaning can be spread across different types of elements. For example, the same idea may have a representation in a term, a symbol, and a color (e.g. the "sleep" term can also be indicated by a yellow indicator and by the moon symbol).

Sometimes a subsidiary element may indicate that the concept is "in play" even if the concept itself is not represented. For example, a control that has a timer function may show time increments like "10 min", "20 min", etc., but have no explicit element for the concept of timer.

One distinction among concepts is that some are primarily static, or manual, and others are more dynamic, or automatic.

The following is an initial classification of concepts around lighting. This can be expected to evolve in later phases of the project. An initial lighting user interface standard is likely to be organized around one or more of these concepts.

## Lighting in General

*The overall concept of lighting*

For controls that only cover lighting (with limited possible exceptions such as exhaust fans), the fact that lighting is involved is almost always implicit. For those that cover other energy services (e.g. climate or audio/video), the general concept of lighting comes into play. The most common symbol used is "☼" or some variant of it.

## Switching (Static)

*Basic turning on and off of a light source*

While this is the most basic aspect of lighting control, it isn't clear that there is a single word or phrase which well-captures the concept. While we do have the symbol for lighting in general "☼", it is more about the light, not the control of the light (though the auto standard does use this for a master lighting switch).

Some controls combine on/off control with dimming, e.g. a rotary switch with a distinct off position.

Some controls have three positions: on, off, and "auto", which engages an occupancy sensor. This raises the question of whether the "auto" is part of the On/Off concept or part of the occupancy sensing concept.

On/off includes the standard physical mappings that on=up and off=down.

This is most commonly used on actuators, since the presence or absence of light from the fixture serves as an indicators, but a few controls have separate indicators for on/off status (including locator lights that are on when the light is off).

## Dimming / Brightness (Static)

*Adjusting luminance*

"Dimming" derives from the way that this was introduced into lighting initially, from a reduction of the full-on level. This is in contrast to other types of linear control such as volume control for audio, or brightness of TVs, in which the "starting" level may be zero or arbitrary. Whether 'dimming' or 'brightness' or some other term is the best "handle" for this concept in the future remains to be seen.

Traditional dimming is a static adjustment by the user; dimming by automatic means (e.g. daylight sensing) falls into the dynamic control concept.

Dimming has the usual physical mappings for up, clockwise, etc. meaning "more".

Many symbols exist for showing control of a variable.

One aspect of dimming that deserves consideration is the relationship between the indicated level and light output. That is, on some controls the amount of light output linearly tracks the dimming control's numeric level (that is, setting the dimmer to half of the maximum level reduces lumen output to 50% of the maximum). DALI ballasts, on the other hand, have a non-linear relationship between the numeric level and lumen output. It would be helpful if all controls followed the same convention for this; this type of consistency should be easy to accomplish with digital controls.

## Schedule / Timer

*Control by time of day, or time since actuation*

These are not lighting-specific, but certainly useful for lighting. Climate controls (thermostats) are the place where these are most commonly seen in buildings, but they also show up in irrigation controls and security systems.

Schedules are most likely to be found on a screen interface, though mechanical clock timers have been around for decades.

Schedules can reference the concepts of a calendar or clock for metaphors or symbols. Timers are limited to a clock dial to show time dependency.

## Dynamic Control

*Controls that automatically change light in response to sensors or other information*

This is a category of concepts that determine how lighting controls behave automatically in response to signals from sensors. In the future, it could include price signals, and perhaps other types of sensors. They are grouped together because algorithms for determining light levels may be complex combinations of multiple sources of information.

### *Occupancy Sensor*

*Binary sensing of occupancy*

It may be worth distinguishing in terms/symbols between the sensor itself, and when it is used to control a light.

A traditional occupancy sensor only has two states: absence, and at least one person present. In the future, sensors may be richer, and be able to report the number of people in a space, who they are, and/or what they are doing. It may be helpful to have a different term for these, e.g. a "presence sensor".

Some controls change state not on someone entering a space, but when the sensor detects that no one is present any longer, and so call this "vacancy control". Thus, these may be referenced as a "vacancy sensor" even though the concept is the same, only the application different.

### *Daylight Sensor*

*Sensing of daylight or total light levels*

As with occupancy, we need to be able to label a sensor itself, as well as reference that one is being used to control light levels. In spaces with multiple sources of artificial light, these sensors may be sensing artificial light in addition to daylight, raising the question of whether the term will be accurate in the long term.

### *Transitions*

*Short-term states in between relatively stable light modes*

Automobiles increasingly ramp light levels up and down rather than simply have visibly instant changes between on and off (and also flash lights to indicate an action like "lock" or "unlock"). These transitory states are likely to become more common in residential and commercial buildings and so may become visible in user interfaces. This is a more speculative concept than the others.

## Color

*Determining specific color of light*

While this is a young topic area for lighting control (at least for general purpose lighting), it seems likely that the word "Color" and the symbol will be commonly used to indicate these controls.

## Scenes

*Presets for groups of fixtures*

A lighting "scene" is a set of control settings which often include different brightness levels for multiple different light sources.

Additional possible concepts include:

- Energy saving or consumption (to provide feedback to occupants).
- Collecting groups of fixtures into a set (this is related to scenes).
- Ventilation. Not a lighting feature, but sometimes present on lighting controls.
- Common content (not lighting-specific). Scheduling, and price (including demand response signals).

## Color Control

Tunable color, color saturation, and color temperature control technology are beginning to be more prevalent in the residential marketplace. New user interfaces also were created to accompany this new technology. This survey found only two companies that manufacture end-user level color control that is designed for "plug and play" use in the home (Figure 20). Other systems require professional knowledge to design for and training to operate. Both of the color controllers use iPod-like rotary control to adjust color. One controller takes design cues from audio control by incorporating "play" and "pause" symbols on the color controller. New symbols for color control, including a symbol for "white light" to indicate variability in correlated color temperature within the white light range, were used on these controllers. Two different symbols were used between the two units to signify the red, green, and blue (RBG) color mixing modes. Since end-user color changing lighting is new, symbols for color control

**Figure 20: Color changing lighting control**
**(Left: Traxon; Right: Philips)**

are even less standardized than the rest of lighting control. Future studies may further investigate color control interface as this technology grows and matures. It is also unclear if the average end user has a clear understanding of the LED RGB color mixing system and how it functions.

## Feedback from Manufacturers

Moving forward this project will require the active engagement and support of a critical mass of manufacturers. Thus, in our data collection and other efforts, we engaged individuals from lighting control companies in informal discussions at LightFair 2010 to understand their perspectives on the need for and desirability of a user interface standard.

Of the eleven companies that provided feedback on UI standardization, representatives from approximately half were either supportive of the study, or were of the opinion that the lighting industry could strongly benefit from the adoption of common interface standards. In general, this group acknowledged enhanced usability as a valid objective, with one vendor drawing an analogy to the utility of standard UIs in browser-based Internet applications. At the same time, approximately half did not favor the concept, for three reasons:

- misperception that standards would negatively constrain designers.
- belief that superior design was a competitive advantage for their company that standardization would eliminate.
- disbelief that lighting user interfaces are poorly understood by users.

It is important to note that this was not a rigorous survey – the project team noted that the degree to which standards were viewed favorably depended somewhat on the role of the representative. Presidents and CEOs tended to be more receptive than sales staff, perhaps feeling more freedom to speak openly, or desiring that the LBNL/CLTC project team view their brand favorably.  Suggestions offered by some of the more engaged representatives were to:

- Focus on front-end user controls, as opposed to interfaces that installers might encounter, and on dedicated, fixed implementations in which reconfiguration of the physical space is not a consideration (Traxon).
- Pursue a lighting control UI standard within a NEMA working group (Leviton).
- Explicitly connect manufacturers with end users, to demonstrate that lighting control UIs do in fact have usability shortcomings, and to communicate the value of a standard (Cooper).

Discussions with industry also indicated that for many vendors, a *learnable* UI is perceived as sufficient, in contrast to immediately understandable UI with high *usability*. Five companies shared their approach to product design:. Cooper Controls and Hubbell reported a formal process to collect feedback from end users to understand interface usability, and Lutron 's internal design group, Aesthetics Cognition and Ergonomics, ensures consistency in certain interface elements across their lighting products. Schneider noted that they determine UI design on a product-by-product basis, sometimes hiring 3rd party industrial designers. Douglas Controls uses internal staff for all interfaces designs, frequently drawing input from partners in the architectural community, and has based some decisions, e.g. LED indicator color, on historic norms in relay and motor feedback.

## Survey Conclusions

The variety of controls, lack of interface consistency, and minimal visual cues often result in user confusion over how to interact with a system. The manufacturers' controls examined in this study, while often having similar functions, often incorporate proprietary symbols and physical interfaces. As different as the interfaces may be, there is an importance in determining the core elements that cross over the myriad of products in the market. While this report begins to map out the fundamental aspects of controls, including static elements, user interactions, and dynamic elements, a further classification is necessary to clarify control interfaces. The ultimate goal is to develop an industry standard for select lighting control user interface elements to encourage increased energy-efficient behavior in residential and commercial buildings.

# CHAPTER 5:
# Summary and Next Steps

## Discussion

In general, our findings confirmed rather than challenged our expectations, but we are now on much more solid ground in asserting those points. From our standards review, we found no existing standard focused on our topic, but no barrier to creating one. A particularly plausible path forward would be to create a national U.S. standard under the auspices of NEMA, and then submit that to CIE for consideration as an international standard. An issue less clear is where to put "common content" that spans two or more energy-relevant user interface topics (e.g. both lighting and climate, as with scheduling and time); presumably this should be specified in one place rather than repeated for each end use.

The topic of existing standards is now well-covered and so may not need to be such a major focus of future work, though there is always a need to monitor updates to standards, new ones, or ones not identified in this project.

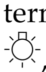
From our literature, we did not find any narrowly targeted on our topic, but rather it is oriented to entire interfaces in general or for other purposes. In particular, the literature does not much address individual elements. A topic that sometimes arises in user interface research (and in our standards review) is accessibility to people of various types and abilities. Particularly as our population is gaining many more elderly, the issue of accessibility should be an explicit component of future research.

From our survey, the approach proved to be sound, though a future phase should include a special focus on software-based interfaces that require extra effort to obtain screen-shots of. Understanding existing controls requires analyzing them with several different approaches: overall form, individual elements, distinct concepts, and the nature of the interaction (i.e. direction of communication between device and person, and whether elements are static or dynamic).

Most basic hardware-only interfaces have no visual cues at all; while this is justified for the most simple ones, this convention becomes problematic as they gain more and more capability. The screen-based interfaces not surprisingly have a much richer palette of elements they utilize than mechanically-oriented interfaces (not surprising as their total functionality is also usually much greater). In general, words are the most common element found, which may be problematic for internationalization of controls. The most variety of implementation comes in those elements which are dynamic, such as indicator color and flashing.

In general, we found this topic very amenable to our research approach and the results were of the form we were seeking.

## Recommendations

In terms of the content of a standard, some individual elements seem fairly solid already in terms of use on products, compatibility with existing standards, and clarity; lighting in general, , is an example of this. In other areas, particularly for symbols, it does not seem clear what to use, e.g. for occupancy sensing and daylight sensing. For concepts, the best targets seem to be lighting in general, dimming, and dynamic controls. Both color control and scene control probably need more development and experimentation in products before initiating standardization. Scheduling and timing probably would benefit from standards now, but should consider the full range of end uses and may end up in a different standard. A focus on specific tasks may help understand how error conditions affect user interface needs.

At some point it will become essential to host a workshop on this topic, to bring together key people from major manufacturers, relevant standards organizations, interested government/policy organizations, and the lighting research community (ourselves and others). This would serve to help refine the concept, gain support, and improve the project plan. This may be something to prioritize.

Elements of analysis that need to be deepened or added to future work include emerging software/display interfaces, accessibility, and internationalization. A possible line of research is to evaluate overall usability of specific interfaces (as is being done for climate control), to measure how effectively people can accomplish specific tasks; whether this should be part of the next phase of work on this topic is not yet known.

The project team will seek wider involvement and funding support for follow-on work, but expect continuing leadership of LBNL, CLTC, and the California Energy Commission (CEC). The first next step that is envisioned includes creating broad recognition of the possibility and need for a user interface standard. This project would be followed by research on UI topics particularly necessary for the first version of the standard. Then, a first draft of the standard would be prepared, and brought to the standards development process of the standards organization most suited to the topic. Throughout this there would be close coordination with manufacturers who are already actively working with both the CLTC and LBNL on lighting projects. A likely outcome of the project is one or more journal articles or conference papers for this project.

Bringing the content of the standard to the marketplace would be accomplished through several routes. One would be the direct influence on manufacturers as they work with us on developing its content, in initial stages and through standards organizations. Another would be through voluntary measures as through Energy Star and utility programs. Whether it is necessary or desirable to bring any of the standard content to mandatory regulations is not yet known, but certainly a possible approach. Again, the goal is to affect the entire market for lighting controls, with a commensurately large impact.

# CHAPTER 6: Conclusions

The goals of this project were to examine key aspects of the potential for lighting control user interface standards, specifically standards and aspects of existing controls. We reviewed existing lighting and user interface standards, to determine if there was any existing standard on the topic, and what others were particularly informative to it. As we suspected, we found no existing standard that addresses our concern directly, so there is a gap in what is available as a reference to manufacturers and policy makers. We did find an extensive set of standards which speak to aspects of the problem, and serve as important background and references for an ultimate lighting control UI standard. We also have a candidate process by which to work towards our ultimate goal of an international standard, by first working through U.S. standards organizations.

For existing controls, we reviewed many products on the market today, spanning from simple switches, to more complex button-oriented controls, to those utilizing display screens. We created a taxonomy of control “forms” to help organize and clarify our research and discussions. For individual elements on controls (terms, symbols, colors, etc.) we found that many of them are only implied and not explicitly shown. For those that are, we produced a classification of these. We also examined fundamental collections of meaning and function in controls as “concepts” that serve a further method of organization.

In discussions with manufacturers and others, we found a significant well of enthusiasm for this effort. While there are still some people who expressed caution or skepticism, we expect that most of can be won over once presented with an actual draft standard, to see that it does not unduly restrict design choices, nor overreach in the scope of what it attempts to address.

A path forward seems clear, to expand the process from just a few researchers, to one that formally includes manufacturers and other important stakeholders, and to begin to develop the actual content for a standard in a collaborative and open process.

Lighting control user interface standards offer a promising opportunity for energy savings not possible other ways, at very low cost, and with significant additional non-energy benefits. While final creation and deployment of them is still some time off, this project has moved the process forward significantly and sets the stage for the next steps.

# APPENDIX A:
# References, Glossary, Bibliography

## Chapter 2: Standards Review

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## Organization References

### *Lighting Organizations*

None of the following organizations are known to have standards content, though could be useful in promoting a standard once developed.

American Lighting Association (ALA)
http://www.americanlightingassoc.com/
2050 Stemmons Freeway, Ste. 10046
Dallas, TX 75342-0288

International Association of Lighting Designers (IALD)
http://www.iald.org/
The Merchandise Mart, Ste. 9-104
Chicago, IL 60654

Illuminating Engineering Society of North America (IESNA)
http://www.iesna.org/
120 Wall Street
Floor 17
New York, NY 10005-4001

Lighting Controls Association (LCA)
http://www.aboutlightingcontrols.org/
1300 North 17th Street, Suite 1847
Rosslyn, VA 22209

Lighting Research Center (LRC)
http://www.lrc.rpi.edu/
21 Union St.
Troy, NY 12180 USA

National Lighting Bureau (NLB)
http://www.nlb.org/
8811 Colesville Road, Suite G106
Silver Spring, MD 20910

### *Standards Associations*

American National Standards Institute (ANSI)
http://www.ansi.org/
1819 L Street, NW
(between 18th and 19th Streets), 6th floor
Washington, DC 20036

Human Factors and Ergonomics Society (HFES)
http://www.hfes.org/

1124 Montana Ave., Suite B
Santa Monica, CA 90403-1617

National Electrical Manufacturers Association (NEMA)
http://www.nema.org/
1300 North 17th Street
Suite 1752
Rosslyn, Virginia 22209

Underwriters Laboratories Inc. (UL)
http://ul.com/
2600 N.W. Lake Rd.
Camas, WA 98607-8542

*Architecture & Design*

Association of Collegiate Schools of Architecture (ACSA)
https://www.acsa-arch.org/
1735 New York Avenue, NW
Washington, DC 20006

The American Institute of Architects (AIA)
http://www.aia.org/
1735 New York Ave., NW
Washington, DC 20006-5292

AIGA, the professional association of design
http://www.aiga.org/
164 Fifth Avenue
New York, NY 10010

American Society of Landscape Architects (ASLA)
http://www.asla.org/
636 Eye Street, NW
Washington, DC 20001-3736

Interaction Design Association (IxDA)
http://www.ixda.org/

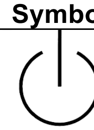
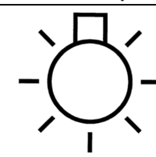
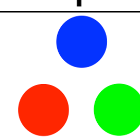
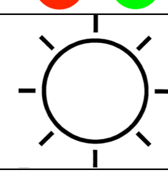
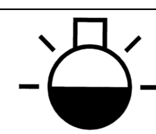
## Chapter 3: Existing Controls

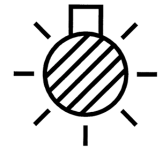
### References

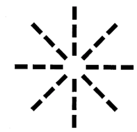
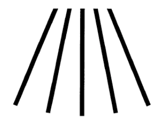
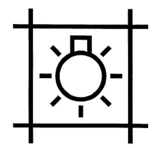
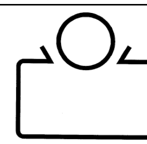
IES (Illuminating Engineering Society of North America). *The IESNA Lighting Handbook,* Ninth Edition. Illuminating Engineering Society of North America, New York, 2000.

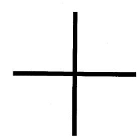
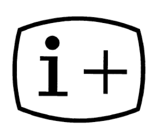
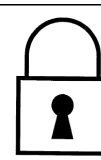
# APPENDIX B:
# Select International Standard Symbols

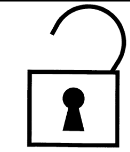
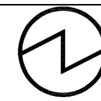
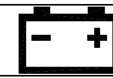
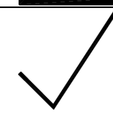
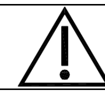
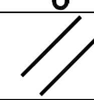
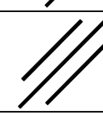
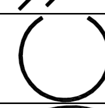
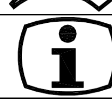
This appendix presents a selection of existing international standard symbols possibly relevant to lighting control  The number indicates the source.  All numbers below 5000 are from ISO 7000, and all above 5000 are from IEC 60417.  Those that begin with letters are from SAE J2402.

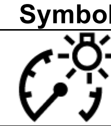
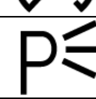
| Number/ Name | Directly Applicable<br>Definition | Symbol |
|---|---|---|
| 5009<br>Stand-by | To identify the switch or switch position by means of which part of the equipment is switched on in order to bring it into the stand-by condition.<br>*Note – see also symbol 5266.* |  |
| 5004<br>Variability | To identify the control device by means of which a quantity is controlled.  The controlled quantity increases with the figure width.<br>*Note 1 – Only the linear version is given since the radius of the base of the curved version depends on the diameter of the control concerned.  The curved version is shown in ISO 7000-1364.*<br>*Note 2 – See also symbols 5181 and 5183* |  |
| 1364 | Variability, rotational adjustment |  |
| 5012<br>Lamp; lighting; illumination | To identify switches which control light sources, e.g. room lighting, lamp of a film projector, dial illumination of a device.<br>*Note – See also symbol 5320 and symbol 5321* |  |
| 5048<br>Colour | To distinguish between the controls and terminals for colour from those for monochrome operation.<br>*Note – If this symbol is reproduced in colour, the colours of the dots shall be red (left), blue (top) and green (right)* |  |
| 5056<br>Brightness; brilliance | To identify the brightness control, for example of a light dimmer, a television receiver, a monitor, an oscilloscope. |  |
| 5181<br>Variability in steps | To identify the device by which a quantity is controlled.  The controlled quantity increases in steps with the figure width.<br>*Note 1 – Only the linear version is given since the radius of the base of the curved version depends on the diameter of the control concerned.  The curved version is shown in ISO 7000-1364.*<br>*Note 2 – See also symbol 5004.* |  |
| 5183<br>Variability, maximum step | To identify the control element by means of which a quantity, for instance speed, heating power, freezing temperature, depression, can be changed.  The maximum value of this quantity can be temporarily switched on by an additional operation.<br>*Note 1 – Only the linear version is given since the radius of the base of the curved version depends on the diameter of the control concerned.  The curved version is shown in ISO 7000-1364.*<br>*Note 2 – See also symbol 5004.* |  |
| 5320<br>Indirect lighting | To identify a control for low-intensity lighting if a distinction from the symbol 5012 is necessary, for example, dark-room lighting. |  |

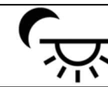
| | | |
|---|---|---|
| 5321<br>Low-intensity lighting | To identify a control for low-intensity lighting if a distinction from the symbol 5012 is necessary, for example, dark-room lighting. |  |

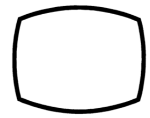
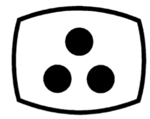
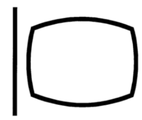
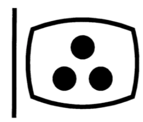
| | Possibly confusing | |
|---|---|---|
| **Number/Name** | **Definition** | **Symbol** |
| 5299<br>Clear rinsing agent | On Dish washers.<br>To identify the container for the clear rinsing agent, such as anti-spotting compound, and to identify the relevant step on the programme indicator.<br>*Note – The same symbol may be used on the selling package of the rinsing agent* |  |
| 5301<br>Detergent for dish washing | On dish washers.<br>To identify the container for dish washing detergent and to identify the relevant step on the programme indicator.<br>*Note – The same symbol may be used on the setting package of the detergent.* |  |
| 5384<br>Indication of radiation field by light | To identify controls for indication of the centre of the radiation field by light. |  |
| 5581<br>Save; economize | To identify a control whereby an economy programme becomes activated, for example, to save energy or water.<br>*Note – The percentage of economizing may be indicated in the figure.* |  |

| | Common Content | |
|---|---|---|
| **Number/Name** | **Definition** | **Symbol** |
| 5005<br>Plus; positive polarity | To identify the positive terminal(s) of equipment which is used with, or generates direct current.<br>*Note – The meaning of this graphical symbol depends upon its orientation.* |  |
| 5006<br>Minus; negative polarity | To identify the negative terminal(s) of equipment which is used with, or generates direct current.<br>*Note – The meaning of this graphical symbol depends upon its orientation.* | — |
| 5510<br>Additional information on screen | To identify the control to display additional information for the user, for example input source, selected function, warning, time, etc. |  |
| 5569<br>Locking | To identify on a control that a function is locked or to show the locked status. |  |

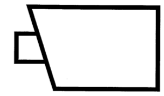
| | | |
|---|---|---|
| 5570<br>Unlocking | To identify on a control that a function is not locked or to show the unlocked status. |  |
| 5662<br>Date | To identify the control which sets and indicates the date. |  |
| 0232 | Electric energy |  |
| 0247 | Battery charging condition |  |
| 0422 | Ready (to proceed) |  |
| 0434 | Caution |  |
| 0435 | Assistance; query |  |
| 0641 | Fuel economy |  |
| 0717 | Call for maintenance |  |
| 1027 | Reset |  |
| 1028 | Cancel; delete |  |
| 1140 | Ready |  |
| 1364 | Variability, rotational adjustment |  |
| 2026 | Help |  |

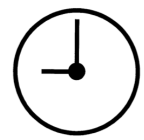
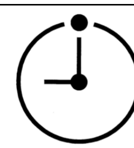
| | **Vehicles** | |
|---|---|---|
| **Number/Name** | **Definition** | **Symbol** |
| A.15 | Instrument panel illumination |  |
| A.08 | Parking light |  |

| | | |
|---|---|---|
| A.30 | Low-level interior illumination (night driving) |  |

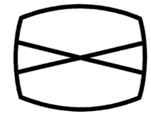
| | Video | |
|---|---|---|
| **Number/ Name** | **Definition** | **Symbol** |
| 5049<br>TV - Video | To identify the controls and terminals specifically meant for (mainly monochrome) video signal |  |
| 5050<br>TV – Colour | To identify the controls and terminals specifically meant for colour video signals.<br>*Note – If this symbol is reproduced in colour, the colours of the dots shall be red (left), blue (top) and green (right).* |  |
| 5051<br>TV - Monitor | To identify the terminals and controls for a television monitor. |  |
| 5052<br>TV – Colour Monitor | To identify the terminals and controls for a colour television monitor.<br>*Note – If this symbol is reproduced in colour, the colours of the dots shall be red (left), blue (top) and green (right).* |  |
| ISO: 2165<br>Light | |  |
| ISO: 2166<br>Dark | |  |
| ISO: 1943<br>Variable speed | |  |

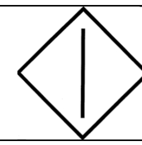
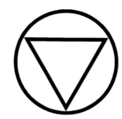
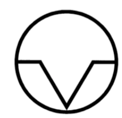
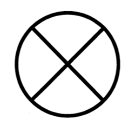
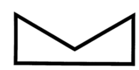
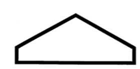
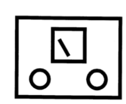
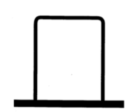
| | Occupancy | |
|---|---|---|
| **Number/ Name** | **Definition** | **Symbol** |
| 5082<br>Microphone | To identify the socket, terminals or switch for a microphone. |  |

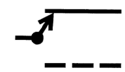
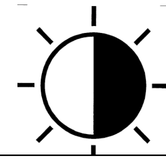
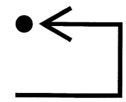
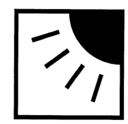
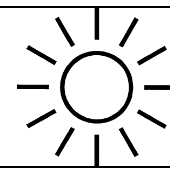
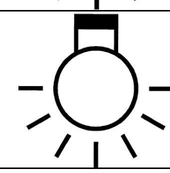
| | | |
|---|---|---|
| 5090<br>Telephone<br>Adapter | To identify the terminals to which a telephone adapter is to be connected, and to identify telephone booths. |  |
| 5116<br>Television<br>Camera | To identify terminals and controls for a television camera. |  |

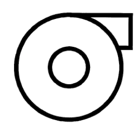
| | Scheduling | |
|---|---|---|
| **Number/Name** | **Definition** | **Symbol** |
| 5132<br>Elapsed time display, programmable timer | To identify the control for a display of the elapsed time from the beginning of an operation (such as cooking, washing, recording, reproducing, etc.).<br>*Note – This is currently under consideration* |  |
| 5184<br>Clock; time switch; timer | To identify terminals and controls related to clocks, time switches and timers. |  |
| 5417<br>Programmable duration | To identify the control of a programmable timer for the ON-condition of a part of equipment at a present point of time and for a determined duration.<br>*Note – This symbol is currently under consideration* |  |
| 5440<br>Programmable timer, general | To identify the control for a programmable timer, for instance the operating element for a programmed function.<br>*Note – See also derivatives from this symbol wherein the dot on the rim of the dial represents a preset point in the scale of time, e.g. 5417.* |  |

| | Possibly applicable | |
|---|---|---|
| **Number/Name** | **Definition** | **Symbol** |
| 5031<br>Direct current | To indicate on the rating plate that the equipment is suitable for direct current only; to identify relevant terminals |  |
| 5032<br>Alternating current | To indicate on the rating plate that the equipment is suitable for alternating current only; to identify relevant terminals. |  |
| 5033<br>Both direct and alternating current | To indicate on the rating plate that the equipment is suitable for both direct and alternating current (universal); to identify relevant terminals. |  |

| | | |
|---|---|---|
| 5055<br>Focus | To identify the focusing control(s), for example, of a television receiver, a monitor, an oscilloscope, an electronic microscope. |  |

| | Generic Control | |
|---|---|---|
| **Number/Name** | **Definition** | **Symbol** |
| 5072<br>Balance | To identify the balance control. |  |
| 5104<br>Start (of action) | To identify the start button.<br>*Note – See also symbol 5177.* |  |
| 5110<br>Stop (of action) | To identify the control device by means of which an action is stopped.<br>*Note 1 – This means stopping only by partial electronical disconnection.*<br>*Note 2 – See also symbol 5178* |  |
| 5111<br>Pause;<br>Interruption | To identify the control device by means of which the run (e.g. of a tape) is interrupted by means of a break mechanism and mechanical disconnection fro the driving mechanism which continues to run. |  |
| 5115<br>Signal Lamp | To identify the switch by means of which signal lamp(s) is (are) switched on or off. |  |
| 5146<br>Adjustment to a minimum | To identify the control by means of which a quantity is adjusted to its minimum value.<br>*Note – For example: “zero” control or balancing of a bridge device; rejection of an unwanted signal; minimum deviation of a meter, indicator, etc.* |  |
| 5147<br>Adjustment to a maximum | To identify the control by means of which a quantity is adjusted to its maximum value.<br>*Note – For example: tuning, maximum deviation of a meter, indicator, etc.* |  |
| 5263<br>Principal control panel | To indicate that the equipment is controlled from the principal control panel. |  |
| 5268<br>“IN” position of a bi-stable push control | To associate the “IN” position of a bi-stable push control with the corresponding function. |  |
| 5269<br>“OUT” position of a bi-stable push control | To associate the “OUT” position of a bi-stable push contract with the corresponding function. |  |

| | | |
|---|---|---|
| 5433<br>Normal Operation | To identify equipment that is normally used to provide service, or to identify the position of a change-over switch by which this equipment is selected.<br>*Note – The symbol 5433 shall be used in conjunction with symbol 5434* |  |
| 5435<br>Brightness/Contrast | On display equipment.<br>To identify a combined control for brightness and contrast. |  |
| 5495<br>Return to an initial state | To identify the control which returns a device to its initial state. |  |
| 5541<br>Background light | On a video camera or still photography equipment. To identify a background light compensation control. |  |
| 5552<br>Colour temperature: natural light | On a video camera or still photography equipment. To identify the correlated colour temperature selector control to suit natural light outdoors.<br>*Note – This symbol may be used in conjunction with symbol 5553* |  |
| 5553<br>Colour temperature: incandescent lamp | On a video camera or still photography equipment. To identify the correlated colour temperature selector control to suit incandescent lamp light indoors.<br>*Note – This symbol may be used in conjunction with symbol 5552.* |  |

| | **Climate control** | |
|---|---|---|
| **Number/Name** | **Definition** | **Symbol** |
| 5015<br>Air impeller (blower, fan, etc.) | To identify the switch or control which operates the air impeller, e.g. a fan of a film or slide projector, a room fan. |  |

# APPENDIX C:
# Lighting Controls
# User Interface Elements
# Taxonomy Charts

## Control Interface Visual Elements

### Visual Complexity in Mobile Lighting Control Devices

## Controller Interface Shape and Style

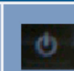
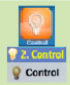
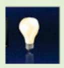
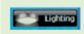
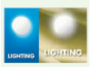
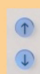
| | | VISUAL INDICATORS | BUTTON SHAPE | UNIT SIZE |
|---|---|---|---|---|
| A. |  Acuity | Six Buttons, Indicator Lights Left of Buttons | Horizontal Line | Small Wall Box |
| B. |  Lutron | Six Buttons, Indicator Lights Left of Buttons, “Up” and “Down” Dimmer Buttons | Horizontal Line, Small Rectangle | Small Wall Box |
| C. |  Control4 | Six Buttons, Indicator Lights on Buttons | Square | Small Wall Box |
| D. |  Watt Stopper | Four Rectangular Buttons, Indicator Lights on Buttons | Horizontal Rectangle | Small Wall Box |
| E. |  Leviton | Four Rectangular Buttons, Indicator Lights on Buttons, Text Labeled Buttons | Horizontal Rectangle | Small Wall Box |
| F. |  Crestron | (need to fill in full list) | Horizontal Rectangle, Vertical Rectangle, Line, Round | Large Wall Box |

## Combination Switch and Dimmer Interaction Types

| | TOGGLE ON/OFF | BUTTON ON/OFF | ROCKER ON/OFF | ROTARY ON/OFF | SLIDE ON/OFF | TOUCH ON/OFF |
|---|---|---|---|---|---|---|
| TOGGLE DIMMER | Lightolier | | | | | |
| BUTTON DIMMER | | Lutron | | | | |
| ROCKER DIMMER | | | Leviton | | | |
| ROTARY DIMMER | | Lutron | | Lutron | | |
| SLIDE DIMMER | Lutron | Lutron | Lutron | | Lutron | Lutron |
| TOUCH DIMMER | Leviton | | | | | Leviton |

## Residential & Commercial Controls

## Interface Symbols

| | Colorado vNet | Control4 | Creston | HAI | iLumin | Lightolier | LiteTouch | Lutron | RTI | Savant | SquareD | Tridonic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **POWER** | | | | | | | | | | | | |
| ⏻ | | |  | | | |  | |  | | |  |
| ⏻/I | | | | | | | | | | |  | |
| **LIGHTS/LIGHTING** | | | | | | | | | | | | |
| INCANDESCENT LAMP SHAPE | |  | |  | | | | |  | | | |
| DETAILED INCANDESCENT SHAPE | |  |  | | | | | |  |  | | |
| LUMINOUS CIRCLE |  |  | | | | | | | | | | |
| **BRIGHTNESS** | | | | | | | | | | | | |
| ARROW | | | |  |  |  | |  |  | |  | |
| +/- | | | | | | | | | | | |  |
| SLIDE BAR | | | | | | | | |  | |  | |

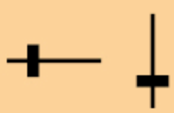
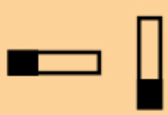
## Power Icons

| SYMBOL | USAGE | VISUAL METAPHOR |
|---|---|---|
| ⏻ (Sometimes ⏻ I) | ‣ Powering control system interfaces (Digital interfaces, remotes) | ‣ Circuit<br>‣ On / Off<br>‣ Up / Down<br>‣ In / Out<br>‣ Binary code (0=off, 1=on)<br>‣ Open / Closed |
| O I | ‣ Powering control system interfaces (Digital interfaces, remotes) | ‣ On / Off<br>‣ Binary code (0=off, 1=on)<br>‣ Open/Closed |
| ◑ | ‣ Powering control system interfaces (Digital interfaces, remotes) | ‣ On / Off<br>‣ Light / Dark<br>‣ Contrast |
| ● ○ | ‣ Powering control system interfaces (Digital interfaces, remotes) | ‣ Full / Empty<br>‣ Light / Dark<br>‣ Open / Closed |
|  | ‣ Powering control system interfaces, a symbol that is mostly used for hardware input devices, connoting its in / out push movement | ‣ Push/Pull<br>‣ Up / Down<br>‣ In / Out |

## Symbols That Indicate Time In Lighting Controls With Scene Setting Capabilities

| SYMBOL | USAGE | VISUAL METAPHOR |
|---|---|---|
| ☼☽ | ‣ Scene controllers<br>‣ Dimmers | ‣ Day/Night<br>‣ Light / Dark |
|  | ‣ Scene controllers<br>‣ Timer | ‣ Clock<br>‣ Passage of time |

## Symbols That Indicate Increase/Decrease On Dimmers

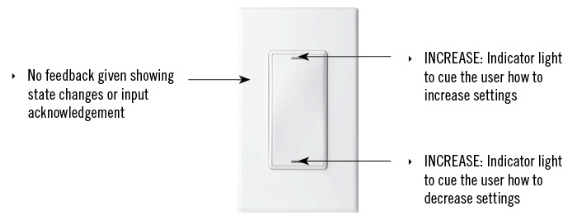
| SYMBOL | METAPHOR |
|---|---|
| + − | ‣ Addition / Subtraction<br>‣ Positive / Negative<br>‣ More / Less<br>‣ Left / Right<br>‣ Up / Down |
|  | ‣ Left / Right<br>‣ Up / Down<br>‣ Forward / Backward<br>‣ More / Less<br>‣ Past / Future |
|  | ‣ Stairs or ramp, incline<br>‣ Left / Right<br>‣ Up / Down<br>‣ More / Less<br>‣ Big / Small<br>‣ Stronger/Weaker |
|  | ‣ Left / Right<br>‣ Change in magnitude<br>‣ More / Less<br>‣ Big / Small |
|  | ‣ Changing levels<br>‣ Right / Left<br>‣ Up / Down |
|  | ‣ Progress, passage of time<br>‣ Start/Complete<br>‣ Left / Right<br>‣ Up / Down<br>‣ Full / Empty<br>‣ Big / Small<br>‣ This symbol is also used as the interface for digital input devices, usually to show quantity in percentages |

## Color Icons

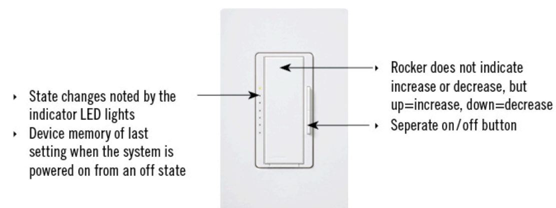
| SYMBOL | USAGE | VISUAL METAPHOR |
|---|---|---|
|  | ‣ LED color changing lamps | ‣ Adjustable<br>‣ Add/Subtract<br>‣ Additive color mixing |
|  | ‣ LED color changing lamps that can combine RGB into white light | ‣ Whole = sum of parts<br>‣ Set of objects or group |

## Dimmer Interface Anatomy

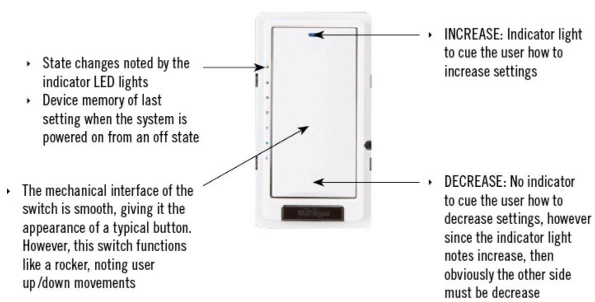
### ROCKER SWITCH/DIMMER



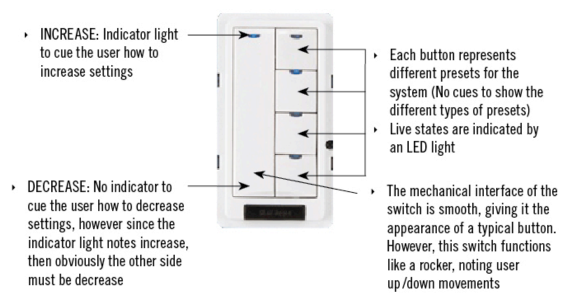

### ROCKER SWITCH/DIMMER



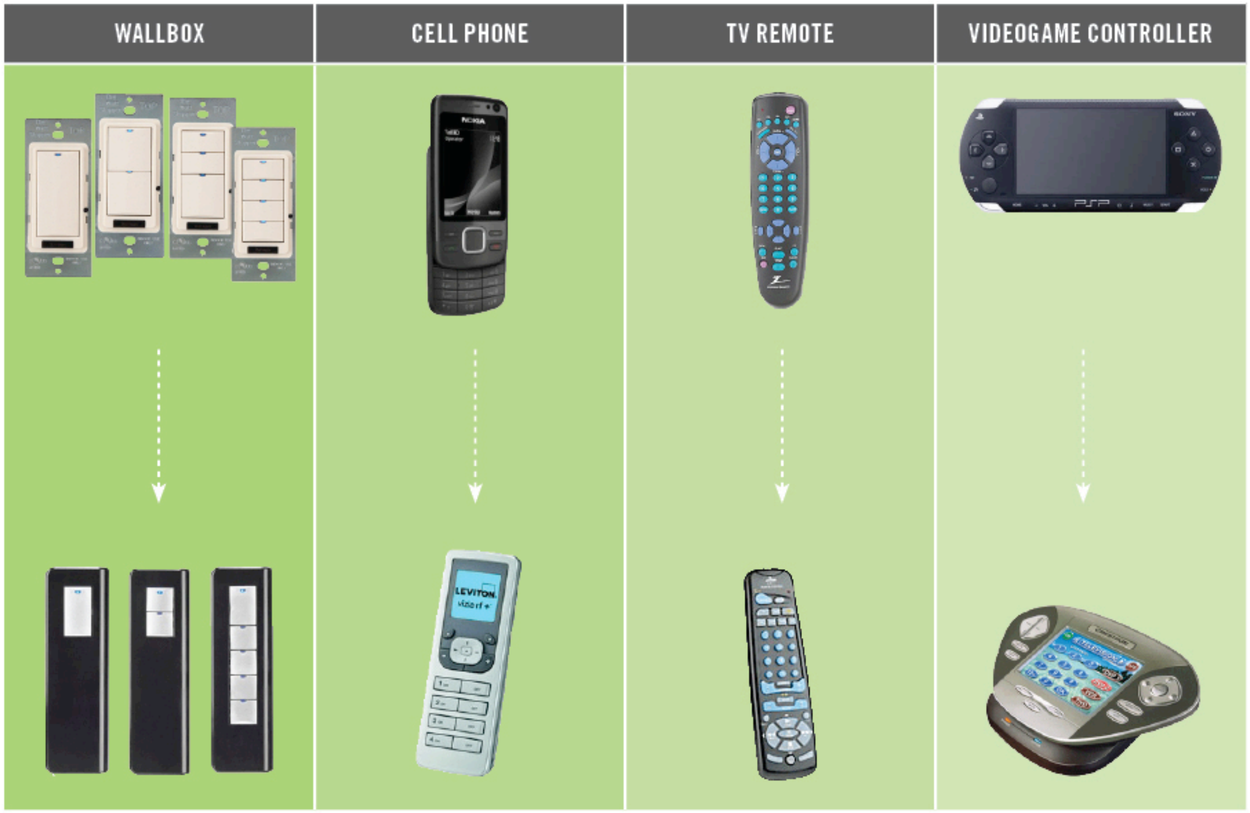

### ROCKER SWITCH/DIMMER




### PUSH-BUTTON DIMMER & SWITCH

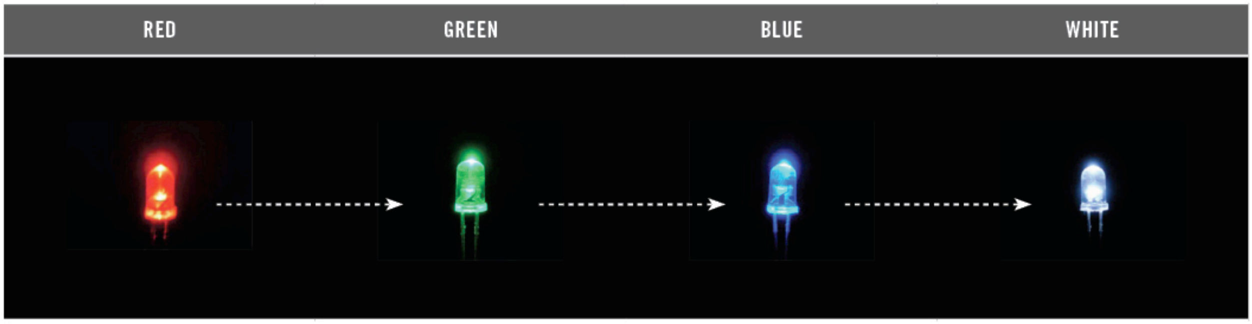


## Lighting Control Interface Shapes Compared to Other Control Devices Typically Found In The Home




## Common Brightness Adjustment Symbols

## LED Color Transition




## Interface Actions

### VERTICAL / HORIZONTAL MOVEMENT

Note: Characteristics listed for each interface type are representative of the general traits of that category, not just what example is shown.

| | SWITCH | | SLIDER | | |
|---|---|---|---|---|---|
| **INPUT** | MECHANICAL INPUT | | MECHANICAL INPUT | HYBRID INPUT | DIGITAL INPUT |
| **INTERFACE** | TOGGLE | ROCKER | DIMMER | TOUCH SLIDER | DIGITAL DIMMER CONTROLS |
| **MOVEMENT** | ‣ Move toggle up & down | ‣ Move rocker up & down/right & left to change states | ‣ Drag node marking the current level of the system up & down/right & left to increase and decrease | ‣ Drag node marking the current level of the system up & down/right & left to increase and decrease<br>‣ Tap different intervals to jump levels | ‣ Drag node marking the current level of the system up & down/right & left to increase and decrease<br>‣ Tap different intervals to jump levels |
| **APPLICATION** | ‣ Off/On | ‣ Off/On | ‣ Dimming, Off/On | ‣ Dimming, Off/On | ‣ Dimming, Off/On |
| **VISUAL CUES** | ‣ TEXT: On/Off<br>‣ TACTILE: Raised text | ‣ TACTILE: Raised nib, usually to signify on the "on" state, click for on/off | ‣ BUTTONS: One button + one slider<br>‣ TEXT: On/Off<br>‣ TACTILE: Click for on/off | ‣ TACTILE: Raised nibs indicating different levels<br>‣ Indicator lights for level | ‣ TEXT: Numbers noting different levels, text for increase/decrease<br>‣ SYMBOL: Increase/Decrease<br>‣ COLOR: Brighter colored node |
| **POSITION/STATE** | ‣ Two states locked at either on/off | ‣ Two states locked at either on/off | ‣ Slider position movable from 0% (off) to 100% | ‣ Slider position movable from 0% (off) to 100%<br>‣ User can jump to different levels instead of gradually changing levels | ‣ Slider position movable from 0% (off) to 100%<br>‣ User can jump to different levels instead of gradually changing levels |
| **FEEDBACK FOR STATE CHANGES** | ‣ TACTILE: Mechanical click, perceptible to touch<br>‣ AUDITORY: Soft click | ‣ TACTILE: Mechanical click, perceptible to touch<br>‣ AUDITORY: Click | ‣ TACTILE: Mechanical click, perceptible to touch | ‣ VISUAL: LED indicators showing dimmer levels<br>‣ AUDITORY: Beep, click | ‣ TACTILE: For some interfaces, there is no tactile feedback. Some systems include a vibrating feedback to show that the user input was acknowledged<br>‣ VISUAL: Marker node shows what level the dimming is on. Other systems, particularly online interfaces whose response time is dependent on internet speed, sometimes display an icon (i.e. hourglass, clock, spinning wheel) showing the passage of time, indicating that the system has registered the user input and is in the process of updating the system state to reflect the change.<br>‣ AUDITORY: Tone |
| **SYSTEM INDICATION OF ACTUATION** | ‣ Lights turn on/off<br>‣ The system indication is binary in this case, since it only allows for two states. | ‣ Lights turn on/off<br>‣ The system indication is binary in this case, since it only allows for two states. | ‣ Lights turn on/off<br>‣ Light level increases or decreases. However, a dimmed state might not be instinctively noticed if the user does not have a reference point for a lower dimmed state to full light output.<br>‣ Actuation is indicated if the node is not in its off position. | ‣ Lights turn on/off<br>‣ Light level increases or decreases. However, a dimmed state might not be instinctively noticed if the user does not have a reference point for a lower dimmed state to full light output.<br>‣ LED indicator notes at what level the system is set on. | ‣ Lights turn on/off<br>‣ Light level increases or decreases. While looking at the lights, a dimmed state might not be instinctively noticed if the user does not have a reference point for a lower dimmed state to full light output. However, the GUI slider shows what level the system is set to. |

# IN / OUT PUSH MOVEMENT

Note: Characteristics listed for each interface type are representative of the general traits of that category, not just what example is shown.

| | BUTTON | | |
|---|---|---|---|
| | MECHANICAL INPUT | HYBRID INPUT | DIGITAL INPUT |
| **INTERFACE** | <br>SCENE CONTROLLER | <br>REMOTE | <br>TABLETOP TOUCH PANEL CONTROLLER |
| **MOVEMENT** | • Push button to change states or increase and decrease | • Push button to change states or increase and decrease | • Select "buttons" or links to change states, select what aspect of the system to modify, or increase and decrease |
| **APPLICATION** | • Change states at set intervals (scene controllers, dimming) | • Change states at set intervals (scene controllers, dimming) | • Change states at set intervals (scene controllers, dimming) |
| **VISUAL CUES** | • TEXT: On / Off; POWER; numbered scenes; scene names (dependent on manufacturer naming conventions)<br>• TACTILE: Raised nib to highlight special keys<br>• SYMBOL: State changes | • TEXT: On / Off; POWER; numbered scenes; scene names (dependent on manufacturer naming conventions)<br>• TACTILE: Raised nib to highlight special keys<br>• SYMBOL: State changes | • Shape: Buttons on digital interface often aesthetically look like a physical button (shading) to carry over metaphor<br>• In this case, "Links" or words that are selected can also be seen as a button in its in / out movement<br>• TEXT: On / Off; POWER; numbered scenes; scene names (dependent on manufacturer naming conventions) |
| **POSITION/ STATE** | • The physical interface of a button can only be in two states — pressed down or not pressed (no action for half-depressed button)<br>• Multiple buttons (combined with visual cues) can prompt the user to increase / decrease states at set intervals between 0% and 100%, or to change states. | • The physical interface of a button can only be in two states — pressed down or not pressed (no action for half-depressed button)<br>• Multiple buttons (combined with visual cues) can prompt the user to increase / decrease states at set intervals between 0% and 100%, or to change states. | • Depending on the visuals of the interface, "buttons" often have an appearance of a push movement, indicating user input was registered |
| **FEEDBACK FOR STATE CHANGES** | • TACTILE: Mechanical click, perceptible to touch<br>• VISUAL: Indicator lights showing power on / off (sometimes increase / decrease)<br>• AUDITORY: Tone, click | • TACTILE: Button pressed down, tactile feeling of state change from rest to pressed down<br>• VISUAL: Indicator lights showing user input was registered. IR light turns on for remotes that rely on IR to transmit user input.<br>• AUDITORY: Tone, click | • TACTILE: In some cases, Vibration signifying change in state<br>• VISUAL: "Button" changing appearance (color, bolded text, highlighted, etc), mimicking a pressed-down button. Other systems, particularly online interfaces whose response time is dependent on internet speed, sometimes display an icon (i.e. hourglass, clock, spinning wheel) showing the passage of time, indicating that the system has registered the user input and is in the process of updating the system state to reflect the change.<br>• AUDITORY: Tone, click (reminiscent of a clicking hardware button) |
| **SYSTEM INDICATION OF ACTUATION** | • Lights turn on / off<br>• Lighting scenes change<br>• Some scene controllers have indicator lights showing which scene the system is set, or the active scene button remains depressed until a different scene is chosen. However with most interfaces, there is no indication if a state is already active, often warranting re-input of user commands to determine system activity. | • Lights turn on / off<br>• Lighting scenes change<br>• If the interface includes a screen, text or symbols on the screen will indicate what state the system is in.<br>• Button does not remain depressed once a scene is selected, so there is no indication if a state is already active or if the input was or was not registered, which often warrants re-input of user commands to determine system activity. | • Lights turn on / off<br>• Lighting scenes change<br>• The GUI of the system indicates which actions are active. |

# ROTATIONAL MOVEMENT

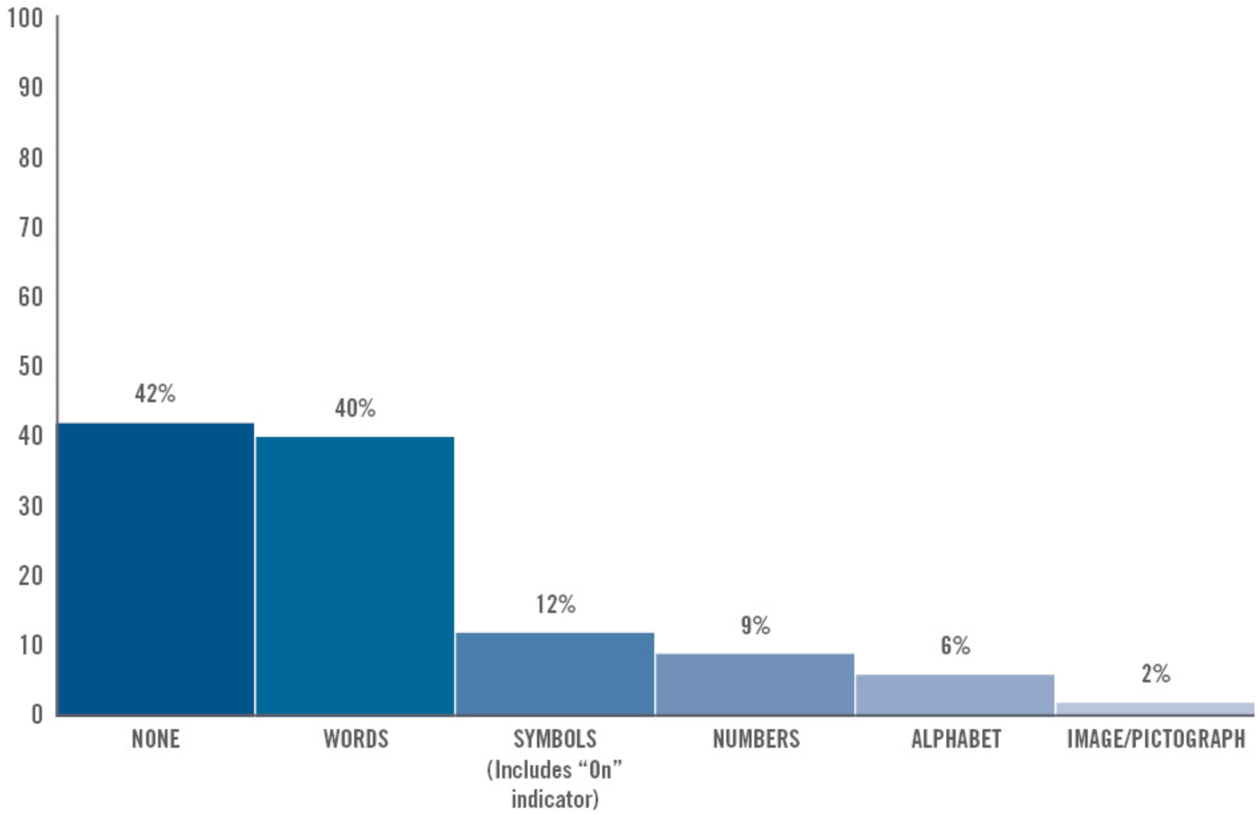
Note: Characteristics listed for each interface type are representative of the general traits of that category, not just what example is shown.

| | ROTARY WHEEL | | |
|---|---|---|---|
| | MECHANICAL INPUT | HYBRID INPUT | DIGITAL INPUT |
| **INTERFACE** |  DIMMER |  CIRCULAR DIAL REMOTE | |
| **MOVEMENT** | • Rotate clockwise or counterclockwise to increase or decrease | • Rotate clockwise or counterclockwise to increase or decrease | • Rotate clockwise or counterclockwise to increase or decrease |
| **APPLICATION** | • Dimming (usually gradual change) | • Dimming (usually gradual change ) | • Dimming (usually gradual change ) |
| **VISUAL CUES** | • TEXT: On/Off; POWER; numbered scenes; scene names<br>• TACTILE: Raised nibs indicating different levels<br>• SYMBOL:Variability | • TEXT: On/Off; POWER; numbered scenes; scene names<br>• TACTILE: Raised nibs indicating different levels<br>• SYMBOL:Variability | • TEXT: On/Off; POWER; numbered scenes; scene names<br>• TACTILE: Raised nibs indicating different levels<br>• SYMBOL:Variability |
| **POSITION/ STATE** | • Full rotation movable from 0% (off) to 100%<br>• Increase/decrease at set intervals between 0% and 100% for some dial interfaces<br>• Dimmers often have the push functionality of a button for on/off | • Full rotation<br>• For hybrid inputs that rely on signals from a remote to a system, there is often not a start and stop point for the rotation, so the user has a full 360 degree flexibility for movement | • Full rotation movable from 0% (off) to 100%<br>• Increase/decrease at set intervals between 0% and 100% for some dial interfaces<br>• User can sometimes jump to different levels instead of gradually moving from 0% to 100% |
| **FEEDBACK FOR STATE CHANGES** | • TACTILE: Kinetic click<br>• VISUAL: Indicator lights showing increase/decrease (sometimes showing power on/off)<br>• AUDITORY: Tone (sometimes increasing in volume), click | • TACTILE: No tactile feedback<br>• AUDITORY: Tone (sometimes increasing in volume), click | • TACTILE: Mostly no tactile feedback, although some systems simulate a vibrating "click" when states are changed<br>• VISUAL: Indicator lights. Unlike vertical/horizontal and in/out push movement interfaces, rotational movement<br>• AUDITORY: Tone (sometimes increasing in volume), click |
| **SYSTEM INDICATION OF ACTUATION** | • Lights turn on/off<br>• Light level increases or decreases. However, a dimmed state might not be instinctively noticed if the user does not have a reference point for a lower dimmed state to full light output. | • Lights turn on/off<br>• Light level increases or decreases. However, a dimmed state might not be instinctively noticed if the user does not have a reference point for a lower dimmed state to full light output.<br>• Color change for color mixing systems.<br>• For systems that have a flush rotary interface that does not include mechanical parts to change the levels, there is no indication of actuation unless the user inputs commands. | • Lights turn on/off<br>• Light level increases or decreases. However, a dimmed state might not be instinctively noticed if the user does not have a reference point for a lower dimmed state to full light output.<br>• The GUI of the system indicates which actions are active. |

## Device Mobility

## Visual Cues Analysis Graphs

### **Visual Elements on Hardware Interfaces** (n = 62)




Note: A single hardware interface may have more than one visual element