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Identifying the Impact of Energy Efficient Lighting Strategies for Use in Historic Preservation

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A Thesis in Historic Preservation Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements for the Degree of Master of Science in Historic Preservation 2007.
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IDENTIFYING THE IMPACT OF ENERGY EFFICIENT LIGHTING STRATEGIES FOR USE IN HISTORIC PRESERVATION

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A THESIS

In

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CHAPTER 1: INTRODUCTION

In recent years, the topic of "green" or "sustainable" architecture has received considerable attention. Both ideological and practical reasons have brought to the foreground the importance of the energy consumed by buildings, and subsequently, methods for decreasing that consumption. Therefore, one significant problem facing the continued use and re-use of historic buildings is their perceived, as well as actual, inefficient use of energy. Whether actual or merely perceived, energy inefficiency is often given as justification for the alteration—often irreversible—of historic buildings. This problem is compounded by the reality that much of the knowledge and attention of the energy efficiency industry is focused on new construction and energy efficiency retrofits that frequently do not take into account the values and goals of historic preservation. The consequence for preservationists attempting to improve the energy performance of historic buildings is that they face a dearth of resources and references that can help them evaluate and make informed decisions about pursuing energy efficiency within the larger framework of their preservation projects. This information gap stands as a major obstacle to achieving greater energy efficiency in historic preservation projects while maintaining fidelity to the principles and values that drive those projects. Additionally, this information gap poses an active threat to historic buildings. Without an understanding of the impact of pursuing various approaches to improving energy efficiency, preservation professionals under outside—or inside—pressure to improve energy efficiency may consequently choose deleterious courses of action that could have been avoided. Likewise, energy efficiency professionals face a similar problem. This information gap could prevent them from being able to discover how the impact of pursuing particular approaches to improving energy efficiency may or may not be appropriate for a particular historic building.

Lighting is only one portion of the energy consumption of a building, but it presents an ideal first step in addressing this information gap.[1] Lighting is one of the most obvious sources of energy consumption in a building, and as a such, it is more likely to contend with the principles and motives at work in the preservation of a historic building. Additionally, as the literature review that follows in Chapter 2 reveals, lighting for historic buildings and energy efficiency has been especially neglected. And finally, lighting is a relatively clearly defined area of building technology that can be addressed within the context of a thesis. A treatment of lighting should then be able to address one of the largest parts of the energy efficiency / historic preservation information gap and provide a model for addressing the other parts.

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[1] "Since … only 7% of our energy resources are used in lighting, why is lighting a primary target for energy conservation? Because lighting is "visible." We don't often stop to think about the enormous amounts of energy used in manufacturing processes, but lighting is before us continually. "Turn off the lights" seems a simple and obvious approach to conservation. A second reason why lighting is targeted is that it represents 30-50% of the operating cost of a building. Thus lighting is an important concern for building owners, and therefore to the entire economy. As utility rates continue to increase, the impact of lighting on operating costs will become painfully apparent."

Ronald N. Helms and M. Clay Belcher. Lighting for Energy-Efficient Luminous Environments (Englewood Cliffs, NJ: Prentice-Hall, 1991) 270.

Additionally, as Henderson and Barna relate, under-representation by the lighting industry on the committee responsible for updating the national energy code during the 1980s contributed to lighting being targeted as the source as an untoward amount of the energy savings in new buildings: "The standards require that the lighting industry produce approximately 75% of the energy savings in new buildings, with only 10% coming from HVAC and the balance from changes in glazing." While the standards have since been updated and balanced, this historic focus on lighting has lingering effects.

Justin Henderson and Peter Barna. "DOE Standards," Interiors Apr. 1990: 40.

In developing a methodology for bridging this gap and identifying the potential impact of various approaches to improving lighting energy efficiency in historic preservation, it is tempting to work with the goal of simply classifying the available approaches as "good" or "bad," or even more diplomatically as "appropriate" and "inappropriate." It would be convenient for both preservation and energy efficiency professionals to have the breadth of possible approaches parsed out into columns labeled "acceptable for preservation" and "unacceptable for preservation." However, such an approach would fail in three important ways.

First, not all historic buildings possess the same qualities or the same level of historic integrity. Therefore, from one project to the next, there will be variation in which parts of a building are to be preserved and which parts, if any, can be altered. But this variation is not limited to just the parts, but extends to what could be termed the aspects of a building, not just the material or fabric, but also the form and the function of the building.[2] Preservationists are concerned with both which parts of the building will be affected and how the aspects of those parts will be affected.

Second, not all preservation projects have the same goals. A preservation professional endeavoring to restore or engage in the ongoing preservation of a historically significant building, where it is important to maintain that quality of a "snapshot in time," will have a set of driving goals that is very different than a preservation professional engaged in a project where an old building with certain historical or architectural significance is being purposefully altered in order to accommodate new uses or is being

[2] For a more detailed explanation of the concept of "form, fabric and function," see Chapter 3: Methodology.

purposefully altered in order to allow it to more ably fulfill its current use. Both of these kinds of projects fall under the umbrella of historic preservation. Both enable buildings to find continued use, and therefore existence, in contemporary society. However, the means pursued, the standards for the appropriateness of retention and alteration, and the end result are different. The former project will likely have much higher standards of retention and historic integrity than the latter, and the latter will therefore likely tolerate interventions that are more invasive and altering.

Third, the field of historic preservation is not ideologically monolithic. Different preservationists can vary considerably in opinion about the appropriate standards and goals for the same project. This is not a new situation, and therefore it is not one that we should assume is likely to change in the near future.

The reality is that all of the approaches to improving the energy efficiency of lighting parse into a single column: "might be appropriate for preservation … depending on the circumstances." Therefore, any approach created in order to aid in identifying the impact of pursuing energy efficient lighting must be able to be used in projects with different historic qualities, in projects with different preservation goals and by preservationists with different preservation ideologies if it is going to be truly useful. The solution to this problem lies in avoiding value judgments such as "good" and "bad" or "appropriate" and "inappropriate," and focusing instead on the impact of pursuing those approaches. Preservationists already have the tools with which to assess when interventions are and are not appropriate for a particular preservation project. What preservationists generally lack, as is demonstrated by the literature review that follows in Chapter 2, are sufficient references and resources with which to engage those decision-making tools. They do not lack a methodology for evaluating whether the impact of a particular approach to energy efficient lighting is acceptable, but rather information about what approaches are available and what exactly the impacts of pursuing those approaches are, especially in the context of historic preservation. A resource that can offer a preservationist a better understanding of what approaches to energy efficient lighting are available and the extent and nature of their impacts would then serve as the basis to engage the decision-making processes already used to evaluate the appropriateness of all other interventions.

CHAPTER 2: LITERATURE REVIEW

Although many professionals have begun to see, or to be forced to confront, both the conflicts that can arise and the synergistic congruencies between the goals of historic preservation and those of energy efficient lighting, there is currently available little literature that directly addresses this confluence of topics. Within the body of preservation writings, energy efficiency is occasionally discussed, but typically as a peripheral issue within a larger context or in reference to the cost savings of energy efficiency. Attention to the larger subject of energy efficiency focuses on space heating and cooling and makes little mention of lighting. Within the body of writings on sustainable architecture and energy efficiency, historic preservation is occasionally addressed; however, these occurrences are most often passing references or involve defining how historic buildings are to be excluded from a set of energy efficiency requirements. And while there are few examples of writings that address the conflicts between the goals of energy efficiency and historic preservation, there are even fewer that address how those goals can be complementary.

THE NATIONAL PARK SERVICE AND THE STANDARDS

In the United States, the National Park Service and *The Secretary of the Interior's Standards for Rehabilitation* frequently serve as the default source for information, guidelines and regulations for historic preservation. Many state and local regulations defer to these standards and federal regulations are often built upon them. The gaining prominence of the issue of energy efficiency can be seen in the inclusion of a topic devoted specifically to energy efficiency issues in the latest revision of the Standards (1995). However, while this new section of the Standards addresses issues of insulation, awnings, windows, heating and cooling equipment, etc., it is completely silent on the subject of lighting.

The National Park Service also releases "Preservation Briefs," a series of technical note-style works that address particular topics within historic preservation. Fourty-four briefs been produced since they began in 1975. Energy efficiency was the topic of one of the first briefs to be released, but it too is silent on the specific topic of lighting. With *Conserving Energy in Historic Buildings*, Baird Smith and the NPS addressed the strengths of historic buildings and goals of historic preservation within the context of the lingering aftermath of the 1970s energy crisis. And while the content is not technologically specific, it was released in 1978 and is therefore dated in many ways. This can be seen in two of the early assertions in the brief:

> Studies by the Energy Research and Development Administration (see bibliography) show that the buildings with the poorest energy efficiency are actually those built between 1940 and 1975. … High thermal inertia is the reason many older public and commercial buildings, without modern air conditioning, still feel cool on the inside throughout the summer.[3]

In the three decades that have passed since the brief was written, those buildings characterized in the former (those built between 1940 and 1975) have begun to make their way into the stock of buildings that can be considered historic, and consequently those buildings characterized in the latter (those built before 1940) have come to constitute a smaller percentage of the stock of historic buildings. Additionally, the

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[3] Baird M. Smith. Preservation Brief No. 3: Conserving Energy in Historic Preservation (Washington DC: National Park Service, 1978).

emerging concern of preserving the recent past brings only more of those buildings built between 1940 and 1974—and even later—into consideration. Further, the increasing sophistication of the energy efficiency requirements of various building codes has lead to greater energy efficiency in new buildings,[4] which has in turn eliminated or reduced much of the inherent efficiency advantage possessed by many of those pre-1940 historic buildings.

The National Park Service is not the ultimate authority on all things relating to historic preservation, but as compliance with the Secretary of the Interior's Standards is such a common goal and benchmark in the United States, the NPS is frequently the place that professionals begin their search for information for any unfamiliar topic pertaining to historic preservation.[5] And, for the busy professional working in a field where budgets are often tight and billable hours scarce, the NPS may also represent the end of their search as well. On the other side of the issue, energy efficiency professionals and advocates are frequently unfamiliar with historic preservation, unfamiliar with the values and philosophies that drive the field, and unfamiliar with the resources available to guide them. Due to the prominence of the Secretary of Interior Standards, it is reasonable to assume that NPS resources are those that energy efficiency professionals are most likely to find. Lacking a foundation in the principles of historic preservation, these

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[4] The California energy code, Title 24 of the California Building Code, is probably the most sophisticated energy code in the United States and has been on a three-year revision schedule since about 1995, with each revision pushing for ever-greater efficiency in new construction.

[5] This actually raises another problem for preservationists and those advocating energy efficient lighting in historic structures. Since compliance with the Standards is at the heart of so many preservation regulations and institutions, from Historic Tax Credits to Section 106, professionals may therefore be reluctant to take any action that, although not in violation of the Standards, is not endorsed by the Guidelines that NPS publishes with them. This means that NPS's relative silence on this issue can be seen as not just failing to promote energy efficient lighting in historic structures, but actually hindering it.

professionals are even less likely than preservation professionals to be able to distill principles from the Standards and Preservation Briefs and apply them to the various energy efficiency approaches that they have available to them.

ENERGY EFFICIENCY AND LIGHTING FOR HISTORIC PRESERVATION

Energy efficiency is typically only addressed obliquely within the larger discussion of lighting for historic spaces. Usually this is done within the context of the tension that frequently exists between the goals of historic preservation and contemporary lighting demands. For example, the historic interpretation and the protection of historic fabric can easily be at odds with contemporary ideas about minimum light levels and concerns about life-safety. In *Lighting for Historic Buildings*, Roger Moss addresses one specific concern within this tension:

> Unfortunately, the requirement of adequate lighting is too often an argument for installing excessive levels of ambient (overall) illumination, usually in the form of recessed ceiling fixtures. […] each opening concealing a 150-watt bulb that assails the visitor with unnecessary and unhistorical light.
>
> Whatever supplemental lighting that is required for safety in public buildings should be sensitively introduced in a manner that will neither deface the architecture nor alter the way in which the original builder or architect expected the space to be seen. To reproduce faithfully fabrics and wall colors selected originally to be viewed by natural light or by the low levels of nighttime illumination provided by candles, mantel lamps, wall sconces or hanging fixtures and then to flood these surfaces with modern light levels adequate for an operating theater grossly distorts the interpretation of these colors and finishes.[6]

Here, Moss offers a concrete demonstration of the tension that can arise between contemporary lighting requirements and interpretation and the protection of historic fabric. But while the caution of sensitivity that he advises here, and other

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[6] Roger Moss. Lighting for Historic Buildings: A Guide to Selecting Reproductions (Washington DC: The Preservation Press, 1988) 12-13

recommendations offered throughout the book, can be adapted to and inform energy efficiency pursuits, such recommendations must still be adapted and do not directly address the topic of energy efficiency.

Similarly, the tension between the different lighting needs driving lighting design in historic buildings that house objects was the focus of a 1998 symposium "Light and Lighting in Historic Buildings that House Collections," and led to the publication of a set of guidelines.[7] However, these guidelines do not address energy efficiency directly. And, just as is the case in *Lighting for Historic Buildings,* the principles that the guidelines do espouse would need to be distilled and then adapted if they are to be used to guide the pursuit of energy efficient lighting.

Even when energy efficiency is more directly engaged, it us usually within the larger context of the tension between historic preservation and a larger spectrum of contemporary lighting concerns. In a special report for *Traditional Building,* Gary Behm specifically mentions energy efficiency when he suggests that balancing the myriad different, and at times contradictory, needs that influence the design of lighting in a historic building requires the services of a lighting professional:

> Driven by both governmental codes requiring the use of more energy-saving lighting systems and owner-driven requirements for cost savings and low maintenance, good lighting design in historic interiors requires at least a consideration of the use of energy-efficient lamp sources rather than the original incandescent sources.[8]

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[7] "APT/AIC Guidelines for Lighting and Lighting in Historic Buildings that House Collections," APT Bulletin 31.1 (2000): 11.

[8] Gary H. Behm. "In Luce Veritas: Or Why You Should Use a Lighting Consultant on Your Next Historic Project," Clem Labine's Traditional Building Nov.-Dec. 2002: 158.

Behm continues to identify some of the concerns encountered when using more advanced energy efficient lamps in the place of incandescent lamps, including UV decay and color rendering. However, the replacement of an older, less efficient lamp technology with another, more efficient lamp technology is only one approach that might be employed by a preservationist seeking to improve lighting energy efficiency. As it is a relatively short article and the author's point is to assert that these issues require the attention of a lighting professional, it is understandable that Behm does not go into what principles or techniques might be employed to evaluate the acceptability or mitigate the impact of the consequences of pursuing energy efficient lighting; however, it leaves the professional with no more tools than "hire a professional."

Historic Preservation within the Realm of Energy Efficiency

Shifting perspective to the field and perspective of energy efficiency, the barriers to information are even greater. Economics have forced historic preservation professionals to begin to pursue energy efficiency. Energy efficiency is not just a matter of ideology, but of practicality. The aftermaths of energy crises—both the national crisis in the 1970s and the more regional crisis in California in the summer of 2000—and rising energy rates have made greater energy efficiency a necessity. Rising energy costs are, of course, even more of a concern for the non-profits and municipalities who are often the stewards of historic structures and frequently operating with limited budgets and requirements for financial accountability. However, there has not been the same kind of outside impetus that might force energy efficiency professionals to gain familiarity with historic preservation.

Energy efficiency regulations are typically a part of building codes and building codes primarily address new construction. Unless the building code is specifically used to regulate historic preservation, the regulation of existing buildings is typically limited to issues of life safety. Using the California Energy Code again for an example, the legislative response to the difficulties that arise from the potential conflicts between the goals of the code and the goals of historic preservation is simply to exempt historic buildings from the energy efficiency requirements of the code. In fact, in the case of California, the code goes so far to call out lighting specifically.

> Exception 1 to §100(a) states that qualified historic buildings, as defined in the California Historical Building Code Title 24, Part 8 or California Building Code, Title 24, Part 2, Volume I, Chapter 34, Division II are not covered by the Building Energy Efficiency Standards. Building Energy Efficiency Standards §146 (a) 5.Q clarifies that lighting systems in qualified historic buildings are exempt from the lighting power allowances only if they consist solely of historic lighting components or replicas of historic lighting components. If lighting systems in qualified historic buildings contain some historic lighting components or replicas of historic components, combined with other lighting components, only those historic or historic replica components are exempt.[9]

The exception is not absolute, but it is quite broad. Additionally, a historic structure would have to undergo significant construction for the code to be activated to begin with, by which point the historic integrity of the building is likely to be considerably less of an issue.

Building codes are not the sole source of standards and regulation for energy efficiency. For example, the Green Building Council has established the Leadership in Energy and Environmental Design (LEED) system for rating and certifying buildings that are built in accordance with defined principles and standards of sustainable architecture.

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[9] California Building Code. Title 24, Chapter 1, Section 7.1

It is a voluntary system—although some municipalities, such as Seattle, have adopted the system for all municipal buildings—that gives buildings a ranking based on a cumulative score system. The inclusion of certain sustainable techniques, technologies and materials each carry point values. These point values are combined in order to give an overall score for the building. Different awards, such as Silver, Gold and Platinum, are given to different point ranges. One remarkable thing about LEED is that it actually does do a little to bridge the gap between historic preservation and sustainable architecture.[10] Recognizing the energy embodied in the fabric of existing buildings, LEED gives points for re-using buildings. However, even in this case, the primary method for dealing with the other implications of historic buildings is avoidance. Since LEED is a points-based system, any individual points area can be avoided in favor of other, more easily met point areas. Further, the section of LEED that deals with energy performance is based on the Environmental Protection Agency's (EPA) Energy Star program. The Energy Star program is also point-based, and to receive LEED credit, a building needs only to achieve a score of 60 out of 100.[11] In the case of a historic building, lighting could be written off while other areas received greater focus and the ranking of 60 might still be achieved. And even if a score of 60 were not possible for the building, the LEED points for energy efficiency could be written off while other areas received greater focus. The consequence is that while LEED does offer a set of energy efficiency standards that could be applied to lighting in historic structures, these standards are fairly easily avoided within the system.

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[10] Sustainable and energy efficient are not synonyms. Energy efficiency is one aspect of a sustainable approach to architecture.

[11] LEED-EB, 47.

The result is that energy efficiency professionals have not had an outside impetus that has forced them to deal with the concerns and principles of historic preservation. This leads not only to a general lack of familiarity, but a lack of resources tailored to their profession to which they can turn when particular circumstances lead to a need to address the potential conflicts between the goals of energy efficiency in lighting and historic preservation.

For professionals in both the fields of energy efficiency and historic preservation, there is a pronounced lack of resources that can be used to make use of energy efficient lighting strategies in historic structures. The available resources that address the topic of energy efficiency within the context of historic preservation—for professionals working in either energy efficiency or in historic preservation—are few and generally do not directly address the specific topic of lighting. Similarly, there are few resources that address the topic of historic preservation within the context of energy efficiency and almost none specifically within the context of energy efficient lighting.

Chapter 3: Methodology

The literature review in Chapter 2 suggests two primary components to the information gap that exists between historic preservation and energy efficient lighting. The first is the lack—in the literature of both preservation and energy efficiency—of a systematic way to categorize and conceptualize the large, diverse and ever-growing body of approaches that can be employed to improve the energy efficiency of lighting. The second is the need for information about the impacts that those approaches could have, especially on historic buildings.

Categorizing Energy Efficient Lighting Approaches

Few preservationists will have the desire to become experts in energy efficient lighting, and so they need a way to be able to concisely conceptualize a body of approaches to energy efficiency that is both large and significantly diverse. Some approaches make use of user intervention in the operation of a lighting system; some make use of design solutions in the construction or retrofit of a lighting system; some make use of design solutions in the arrangement of the space itself; and then there the are thousands of technological devices that are designed to improve the efficiency of lighting systems. Therefore, attempting to identify the impact of energy efficient lighting approaches individually would present a couple of distinct difficulties.

The Problem of Identifying the Impacts of Approaches Individually

On the most basic level, identifying the impacts of this large number of approaches individually would be an unwieldy task. And, while that level of specificity could be useful in some cases, sifting through all of that information would also be daunting for preservationists. Culling the body of available approaches down to a list of those found to be most effective or practical has typically been the solution to the problem of presenting energy efficient lighting to an audience that lacks expertise in the field. For example, in 1972, the Illuminating Engineering Society (IES) prepared a list of 12 recommendations for improving lighting energy efficiency without sacrificing lighting quality. These recommendations were meant to apply to both new and retrofit construction, and were intended to be a comprehensive treatment of lighting that would cover the operation, maintenance and selection of equipment. Those 12 recommendations were:

1. Design lighting for expected activity (light for seeing tasks, with less light in surrounding nonworking areas).
2. Design with more effective luminaries and fenestrations (use systems analysis based on life cycle).
3. Use efficient light sources (higher lumen per watt output).
4. Use more efficient luminaries.
5. Use thermally controlled luminaries.
6. Use lighter finish on ceilings, walls, color and furnishings.
7. Use efficient incandescent lamps.
8. Turn off lights when not needed.
9. Control window brightness.
10. Utilize daylighting as applicable.
11. Keep lighting equipment clean and in good working condition.
12. Post instruction covering operation and maintenance.[12]

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[12] Helms, 273.

For most of those seeking to improve the energy efficiency of buildings, such a list is very useful, laying out effective simple and straightforward measures. However, preservationists need to be able to evaluate the full range of possibilities available, not just the most widely used. Both the constraints of preservation projects and the reality that preservation goals will frequently take priority over other goals such as energy efficiency frequently require preservationists to be more creative with their energy efficiency plans. This, in turn, requires the consideration a larger body of options than just the most common or most effective.

The rapid pace of technological development in energy efficiency is also an issue. Technological approaches are being continuously, and often rapidly, developed, refined and made obsolete; therefore, identifying the potential impacts of individual technologies would make the information only as timely as a specific technology. Each new technology, each evolution of a particular technology, and each technology passing out of use would decrease the usefulness of any body of information about potential impacts. The body of information would also lack all of the advances that would come to follow and would be cluttered with the impacts of technologies that obsolescence had eliminated from consideration. Non-technological approaches may not have the same kind of dynamism, but the same problem exists: if approaches are treated individually, then preservationists will be less able to assess the impact of new approaches as they are developed.

The large body of available approaches presents another problem. Many of these approaches, especially in the case of technological approaches, employ variations on the same concept. For example, fluorescent lamps and high intensity discharge (HID) lamps are two different technologies that convert electricity into visible light more efficiently than typical incandescent lamps. However, while they are very different lighting technologies, they both save energy by supplanting a lamp that consumes more energy. Another, more diverse example is photocontrols and occupancy controls. Both automatically switch lights on and/or off under certain circumstances. However, photocontrols are triggered when ambient light levels reach certain predefined levels and occupancy controls when a person is detected in a room. The end result of automatic switching of lights is the same, but the means very different. In fact, even within occupancy controls, different technologies or even combinations of technologies are utilized to achieve the same end. Infrared motion detectors and ambient noise detectors are very different technologies, but employed for the same purpose, to detect the presence of a person in a space. If the impacts of all of these approaches were identified separately, the resulting body of information would have a considerable amount of redundancy, making it all the more unwieldy to sift through.

The Solution

Grouping the approaches into categories of approaches avoids these problems. The similarities can be used to advantage by grouping different energy efficient lighting approaches by their similar characteristics. Rather than addressing each approach individually, the common underlying strategy that different approaches employ can be the focus. For the examples offered above, HID and fluorescent lamps pursue the common strategy of using more efficient light sources, photocontrols and occupancy controls pursue the common strategy of using controls to automatically turn lights on when needed and off when not needed. In the same way, all approaches that make use of "active user intervention" can be grouped together in a common strategy, all approaches that use better spatial design to reduce energy consumption can be grouped together in a common strategy, etc. The advantages of such a grouping go beyond just making the body of approaches more manageable. It also addresses energy efficient lighting approaches on a more conceptual basis, allowing it to deal with the dynamism in the creation, evolution and obsolescence of individual approaches. For the preservationist using this system, each approach is conceived not by the particulars of the approach, but by the fundamental strategy employed. Therefore, with this kind of grouping as the fundamental conceptual framework, the strategies that underlie new approaches can be easily discerned and associated with other approaches that employ that same strategy.

Different Strategies and Different Eras of Lighting Technology

Categorizing energy efficient lighting approaches by underlying strategy would be beneficial for educating any group of people pursuing energy efficient lighting who are not experts in the field. But, it presents an additional advantage for historic preservation: the opportunity to define the categories specifically for use in preservation projects.

Historic preservation engages a scope of lighting technology that is broader than that which the contemporary field of energy efficiency typically engages. The discipline of energy efficient lighting can effectively make the assumption that electric lighting is the existing condition and the baseline from which impacts are evaluated. While, for the time being, preservation projects will almost always be dealing with electric lighting, preservationists must be able to contend with the reality that lighting technologies from another era may constitute the baseline. In *Lighting Historic Buildings: A Guide for Selecting Reproductions*, Roger Moss identifies five divisions or eras of lighting technology and arranges his chapters along those divisions: Candle Holders: 1620-1850, Oil Lamps (Whale, Lard, Burning Fluid): 1783-1859, Kerosene: 1854-1934, Gas Lighting: 1817-1907, and Electric Lighting: 1879-1930. While few preservation projects are going to include the reintroduction of a lighting system from a past era, preservationists frequently need to be able to evaluate the impact of an intervention relative to the conditions of those past eras and not just existing conditions.

The literature review in Chapter 2 reveals that the use of high efficiency lamps is one of the more prominent approaches currently employed to improve energy efficiency in historic preservation, and serves well to illustrate this point. Replacing existing lamps with modern, high-efficiency lamps is an intervention that has very distinct and specific consequences. It is likely to change the look of the lamps themselves, it is likely to change the lighting quality in terms of brightness and color rendering, and will certainly require altering the authentic historic function of the light source and even removing historic fabric. However, this circumscribed list only applies if the lighting system that constitutes the baseline for evaluating the impact is electric lighting. If the baseline lighting system is from an era other than that of electric lighting, then this intervention would have a much more extensive impact. It would require more than just replacing the lamp, but replacing the entire lighting system. Candle holders, oil lamps and gas lighting fixtures would have to have their historic technologies removed and replaced with electric lighting technology—or have to be replaced entirely—before those high-efficiency lamps could be installed. Therefore, if the energy efficient strategy were defined as "install high-efficiency lamps" then the consequences of pursuing the strategy would be very different when applied to the technology of different lighting eras.

This difficulty could be dealt with through replicating the identification of the impacts of each strategy for each era of lighting technology, but such a solution would create the kind of complexity and unwieldiness that was one of the reasons to categorize the approaches by strategy to begin with. A better solution is to build into the definitions of the strategies a level of specificity and clarity so that each strategy addresses in the same manner all eras of lighting technology to which it can be applied. The example of utilizing high-efficiency lamps can be used again to illustrate this. The problem with defining the strategy as "install high-efficiency lamps" is that, while it applies to many different lamp technologies, it is still specific to the lighting technology of the era of electric lighting. However, if the strategy is defined only slightly differently as "install high efficiency light sources," the strategy no longer exclusively engages a specific component of a specific era of lighting technology.[13] In reality, this solution to the problem is just an extension of the principle of developing a methodology that is strategy-focused instead of technology- or approach-focused.

The evolutionary nature of lighting technology makes the issue of eras of lighting technologies even more important. Electric lighting, with its electricity-based distribution systems and point-of-use light production, is ubiquitous, but it is not likely to stay that way. The history of lighting technologies is one of a series of one technology being replaced by another.[14] At some point, electric lighting will most likely be

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[13] Conceivably, this example could also be applied to other eras of lighting technology, such as through the installation of burners that more efficiently combust the oil in an oil lamp or the gas in a gas fixture. However, considering that the primary motivation behind the retention of a historic lighting technology is almost always the value of authenticity, these kinds of upgrades would likely be inherently excluded.

[14] Melissa L. Cook and Maximillian L. Ferro. "Electric Lighting and Wiring in Historic American Buildings: Guidelines for Restoration and Rehabilitation Projects," Technology & Conservation 8.1 (1983): 28-48.

succeeded by another lighting technology. Many believe that the lighting technology of the future is already on the market in the form of fiber-optic lighting, a technology that still uses electric lamps, but light rather than electricity is distributed to the point of use through fiberoptics. Through making the methodology reasonably independent of the lighting technology of a particular age, when and if a new era of a new lighting technology begins, this approach to conceptualizing strategies and their impacts will still be applicable.

The Strategies

From the body of available energy efficient lighting approaches found in the review of literature, twelve underlying strategies emerge: (1) Conservation, (2) Vigilant Maintenance, (3) Lux/Footcandle Reduction, (4) Automatic Controls, (5) Multi-Level Lighting, (6) High-Efficiency Light Sources, (7) High-Efficiency Luminaires, (8) Parallel High-Efficiency Lighting Systems, (9) Replace the Lighting Technology with a More Efficient Technology, (10) Increasing the Reflectivity of the Surfaces in the Space, (11) Daylighting and (12) Efficiency Elsewhere / Average Efficiency. The following chapter will be divided into twelve sections for these twelve strategies, each describing these fundamental underlying strategies as well as the approaches that are built upon them.

IDENTIFYING THE IMPACT OF ENERGY EFFICIENT LIGHTING STRATEGIES

The other component of the information gap that exists between historic preservation and energy efficient lighting is the need for information about the impacts that could result from pursuing certain energy efficient lighting strategies. For preservation projects, the list of impacts that may be significant can be far larger than it is for non-preservation projects. Non-preservation projects, the criteria for retaining components or features of the building will usually be dominated by whether its looks and/or functionality are sufficient for the owners, users or use. However for preservation projects, architectural, historical and social significance are frequently added to that list of criteria and can even dominate it. Therefore, preservationists must have a view of impacts to the building that is more granular—a broader definition of impacts with which they must be concerned, and a view of the building that considers its components and features in finer detail—than that of other architecture professionals. In a non-preservation projects there may be little concern about replacing existing lighting systems beyond cost of labor and materials or disruption to current users, while the loss of a historic luminaire or even a historic switch could be significant in a preservation project. In a non-preservation project there may be little concern about the architectural details beyond whether or not they look good or are fashionable, while in a preservation project, not just the loss of historic detail, but even the loss of the material from which the detail is constructed could even be significant.

The Components of the Lighting System

The most basic response to this need for a granular perspective is to break lighting systems down into their component parts. Even though they might come from different technological eras of lighting, most lighting systems include essentially the same components. (However, it should be noted that not all of these are actually physical components.) The components are the fuel source/storage, the fuel distribution system, the means of operation/control, the light source, the luminaire/fixture, [15] the placement/position of the luminaire in the space, and the characteristics of the space. Figure 1 shows which physical parts of each lighting system correspond to these component designations. The last two components, placement/position and characteristics of the space, are not physical parts of the lighting system, and apply to all eras of lighting technology the same. They describe where the light source is located in the space and the characteristics of the space such as finish colors and spatial configuration.

Lighting Technology	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire
Candle	wax	wick	manual ignition	wick	candle itself, candle holder, or luminaire
Oil Lamp	oil (whether whale, lard, burning fluid, kerosene, etc.)	wick	manual ignition	wick	whole lamp
Gas Lighting	gas	piping	gas cock	burner	luminaire
Electric Lighting	electricity	wires	switch	lamp	luminaire

Figure 1: Physical Components of a Lighting System

The Aspects of the Lighting System

In several places,[16] Frank Matero has offered a "Construct Model of Cultural Heritage" (Figure 2). In this model, cultural heritage—of which buildings are one kind—can be viewed in terms of its form, its fabric, and its function. When a preservationist embarks to "preserve" something that is deemed to have historic value of some kind,

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[15] "A luminaire is a complete, functional lighting unit, including the lamp(s), housing, electrical components required to power and operate the unit, and control media to direct and enclose the lamp housing. The old term for luminaire is a "fixture." A luminaire is the total lighting unit while a fixture is a plumbing unit (emphasis original)." Helms, 5.

[16] See for example "Loss, Compensation and Authenticity in Architectural Conservation" in the March 2006 edition of Journal of Architectural Conservation.

these are the aspects of the thing that is being preserved: the shape of the thing, the actual material of which the thing is composed, and the way the thing operates. Frequently, the interventions of historic preservationists favor one or two of the corners of the triangle at the expense of the others.

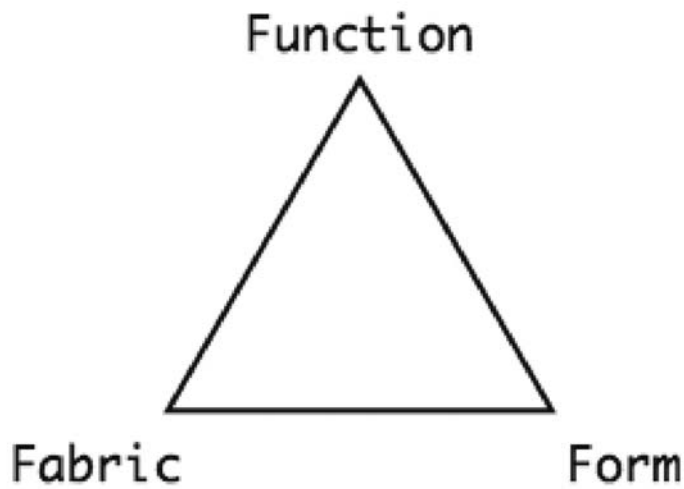

Figure 2: Matero's "Construct Model of Cultural Heritage"

For example, replacing deteriorated brick with newly manufactured brick that matches the historic brick will maintain the historic function and form of the brick, but will sacrifice the historic fabric. Conversely, an intervention can be pursued that will stabilize the brick and retard the deterioration. This will save the historic fabric, but does nothing to remedy the loss of the historic form to deterioration. Additionally, if that means of conservation includes rerouting compressive stress around the brick, that aspect of its historic function will have been sacrificed as well.

In the same way, an intervention that is meant to improve the lighting energy efficiency of a lighting system can affect that lighting system and its parts in different ways. In order to truly gauge the impact that pursuing a particular energy efficient lighting strategy would have, the impact on the form, fabric and function of each component needs to be considered. We can consider as an example an electric chandelier. The fixture itself may have some particular historical significance imparted by the manufacturer, the owner, the setting in which it was used, etc. Or, it might not be the particular fixture itself, but its style or design that is significant. Or, it might not be something about the fixture itself, but the way it was used within the space that is significant. These different situations could lead to different preservation priorities. Sacrificing historic fabric through replacing worn or broken parts in order to re-establish the historic form might be appropriate in the case of the second, but completely inappropriate in the case of the first. Likewise, retaining deteriorated fabric, even if it meant that the fixture could not be used as it was historically intended, may be appropriate in the case of the first, but inappropriate in the case of the third. These are the kinds of situations that preservationists face. The particular circumstances of different projects will place these aspects in differing orders of importance, and being able to see the impact of the strategy on each is essential to making an informed decision as to what strategy is most appropriate.

The Nature of the Intervention

In order to make an informed evaluation about the appropriateness of a particular energy efficient lighting strategy, the preservationist also needs to know more than just whether it will have an effect but also what the nature of that effect will be. For example, replacing a gasolier with an electric luminaire is a considerably different impact than simply electrifying the gasolier. Specifically categorizing the extent of the impact of each strategy is not really feasible considering that each strategy contains multiple approaches and/or technologies. However, differentiating between alterations and replacements, as in the example above, is basic enough to be feasible and is a very important consideration for the preservationist concerned with the retention of form, fabric, or function.

Identifying the Impact of a Strategy: The Intervention Matrix

In the following chapter, an intervention matrix (Figure 3) is used as the means of both identifying and summarizing the potential impact of each strategy on the historic building. As an accompaniment to the longer discourses on primary advantages and concerns in pursuing each strategy, it serves as a quick visual representation of the impact of each strategy. Although the representation of the matrix is two-dimensional, the matrix itself has three dimensions, one for each of the considerations identified above: the components of the lighting system, the aspects of those components and the nature of the intervention. The first axis—the row across the top—contains the components of the lighting system. The second axis—the column down the left side—contains the aspects of those building components with which preservationists may be concerned. The third axis—represented by a series of letter designators where the rows and columns intersect—contains the nature of intervention that the strategy will require; "R" is for replacement, "A" for alteration and "N" for none.

Strategy							
	Fuel Source	**Fuel Distribution**	**Operation / Control**	**Light Source**	**Luminaire**	**Placement / Position**	**Characteristics of the Space**
Form	R / A / N	R / A / N	R / A / N	R / A / N	R / A / N	R / A / N	R / A / N
Fabric	R / A / N	R / A / N	R / A / N	R / A / N	R / A / N	R / A / N	R / A / N
Function	R / A / N	R / A / N	R / A / N	R / A / N	R / A / N	R / A / N	R / A / N

Figure 3: The Intervention Matrix.

Chapter 4: The Energy Efficient Lighting Strategies

Conservation

This strategy should be the most obvious and where everyone responsible for the energy consumption of a building should start. And, thinking it through will help with implementation, a task much harder than the simplicity of the concept would make it seem. Conservation requires the active participation of the building users. It is straightforward, but dependent on people, not technology. It means training the users of a historic space to use the controls already present. This strategy is, in many ways, a more sophisticated version of the 70s-era parent telling their children to turn the lights off when they leave a room. The savings that can be found by pursuing this strategy are tied directly to the wastefulness of current practices.

Training is the center of the strategy. The users of a historic building are trained how to operate the lighting controls already present in the building. This means more than just training them which controls go with which luminaires. For the strategy to be truly successful, the users need to be taught not just how to turn off the lights, but more importantly when to turn off the lights. This may additionally involve signs or postings that remind them to do so or remind them how to do so, since the users' vigilance is of vital importance to the success of the strategy.

Turning the lights off when leaving a room is only the beginning. Eliminating waste through such simple means is a powerful step, but is not where the strategy need stop.

An aggressive conservation plan would also involve such measures as rescheduling activities so that uses could overlap and thereby share lighting energy, or rescheduling usage patterns to maximize daylight hour use when the artificial lighting—or as much artificial lighting—may not be necessary.[17]

Primary Advantages

The greatest advantage to the use of conservation in a historic preservation project is that it involves absolutely no impact on the form, fabric or function of the lighting system. The change is made instead to the users and their use patterns. Preservationists do not have to worry about losing something that may be significant or may later turn out to be so, or making changes that may be irreversible. Posting signs and notices about the conservation plan and how it works is the most extreme physical intervention that may be involved.

Another advantage is the reality that conservation requires little capital expenditure. There is some cost in terms of the time required to devise the conservation plan and then train the users—and realistically, sometimes to retrain the users. There also may be some material cost involved in producing any educational materials or signs and postings for the building. However, considering that pursuing any strategy will require planning and execution time, the relative cost is rather small.

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[17] This overlap that emerges between the strategies of conservation and daylighting shows how many of these strategies can and sometimes even must work synergistically.

Primary Concerns

Preservationists have common cause for concern with anyone pursuing this energy efficient lighting strategy: conservation only works as well as the people doing the conserving. In its discussion of this approach to energy efficient lighting, *Energy Efficient Buildings* relates an assertion by engineer Larry Spielvogel—a frequent contributor to professional magazines in the 1970s such as *Record*—that "careful operation of buildings is the single most effective way to conserve energy, that the 'single most effective tool for energy conservation is a screwdriver in the hands of an intelligent man.'"[18] Spielvogel's confidence in conservation is hinged on that "intelligent man." The ability for conservation to save energy is entirely dependent on the users' ability to turn off the artificial lighting, their ability to determine when to actually do so, their willingness to do so, and their vigilance in doing so. If any of these are missing, the success of the strategy will be compromised.

Additionally, the success of conservation is predicated on the idea that lighting energy is currently being wasted in the building, specifically through lighting being on when it could be off. Even if not in the form of a formal plan, conservation is already at work in many buildings simply because many users are already conservation minded. Whether Depression-era frugality or 1970s energy-crisis conservation, many users have an ingrained sense of saving energy through conservation. Additionally, due to the fact that conservation hinges on turning off the lighting when it is not needed, it has a very limited potential for saving energy when the lighting actually is needed.

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[18] Walter F. Wagner, ed. Energy Efficient Buildings (New York: McGraw-Hill, 1980) 11.

For many preservation projects, this strategy presents problems beyond those facing more recent buildings. Older buildings may have confusing lighting controls. Those rare buildings with historic, non-electrical lighting present users with lighting controls from another era, controls that may very well be quite foreign to them. Gas cocks, wick adjustment screws and the fact that snuffing a candle does not mean putting it out but trimming the wick so that the flame burns clearer and with less smoke present a whole new arena of lighting control to the typical user who has only ever used electric lighting. Even in the more common case of electrical lighting, many of the buildings with which preservationists work did not originally incorporate electric lighting. Even if they did, each passing year presented an opportunity to alter the lighting, adding switches, circuits and luminaires. And this is exacerbated by the common reality that these alterations are frequently done in the most expedient rather than the most sensible manner.

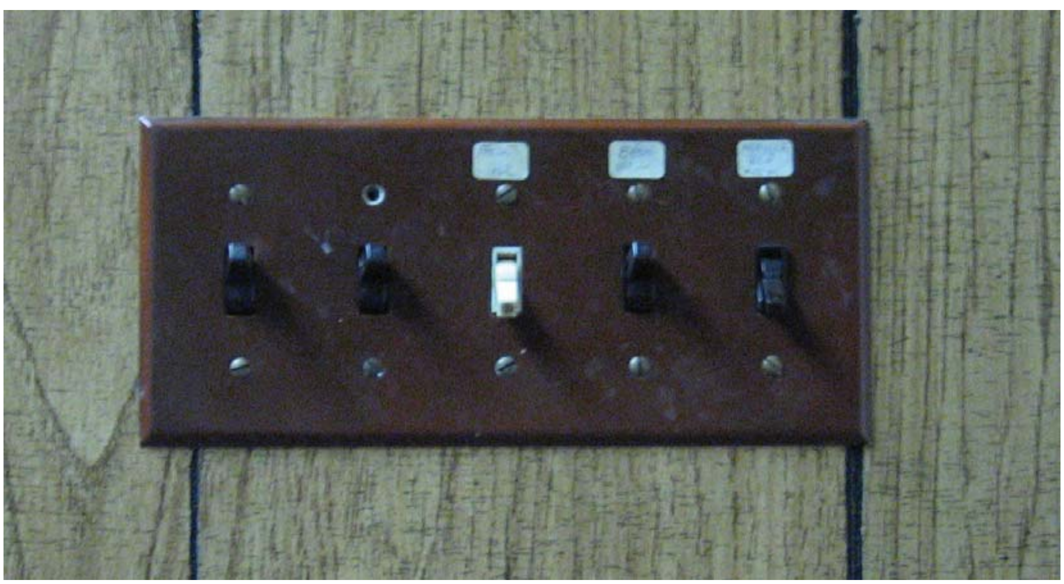

Figure 4: A confusing bank of light switches in a late nineteenth century residence in West Philadelphia.

Figure 4 shows an example of this from a residential twin in West Philadelphia. This bank of light switches is on the second floor at the top of the stairs and outside what historically would have been the family parlor. From right to left, the switches control the lights in the family parlor, the front half of the second floor hall, the rear half of the second floor hall, the living room below on the first floor, and the front half of the hall on the third floor above. Adding to the complexity, with the exception of the family parlor, each of those lights are controlled by two or even three additional switches in other locations. And things could be even more complex; sometimes switches are located with no logical connection to the lights they control, or in places that are very inconvenient to reach. Larger buildings may have all of the lights controlled not by standard switches but from a single circuit breaker panel, oftentimes with the luminaires controlled in no logical manner. This is frequently the situation in historic buildings like churches (Figure 5) and is the kind of situation that the users of historic buildings may face. Good training of a permanent staff can overcome even the most confusing lighting controls, but buildings with a transient user base and confusing lighting controls face a significant barrier to the successful implementation of conservation as an energy efficient strategy.

Figure 5: A circuit breaker panel in St. Agatha-St. James Roman Catholic Church in Philadelphia. Most of the luminaires in the church are controlled from this panel, but many are controlled from other isolated switches, including one located just above the floor in one of the side altar areas. Note the diagram to help make sense of which switches control which luminaires, and the electrician's tape covering some of the switches as a way to keep them either always on or always off.

Summary

Conservation							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	N	N	N	N	N
Fabric	N	N	N	N	N	N	N
Function	N	N	N	N	N	N	N

Pros:

- No impact on the form, fabric or function of the lighting system.
- Requires no or only minimal investment in materials.

Cons:

- No energy savings when the lighting needs to be on.
- Requires active intervention; if the users aren't switching the lighting off when not needed, there will be no savings.
- Savings limited to the wastefulness of current practices: if the users are already good about conservation, there is very little additional savings potential.
- The confusing lighting controls found in many historic buildings can be a barrier to successful conservation.

VIGILANT MAINTENANCE

In *Strategies for Saving Energy Used for Lighting*, Haden McKay points out that "lighting systems are over-designed by as much as 25 to 30 percent to account for long-term degradation of the lamps and dirt accumulation on lamps, fixtures, and room surfaces." Modern designers of electric lighting systems, recognizing the significant negative impact of lamp deterioration and dirt accumulation on lighting, have responded by increasing lighting power—and therefore energy consumption—in order to compensate for these consequences of neglected maintenance. Even in spaces where the lighting has not been purposefully over-designed, a neglect of maintenance can still lead to increased energy consumption; it can cause users to introduce additional lighting—and therefore energy consumption—into the space in order to compensate for the deterioration of the lighting. A vigilant maintenance schedule can be used to avoid both the practice of intentional over-design and the tendency to introduce more lighting into the space in order to compensate for the decreased lighting performance. The simple reality is that "good maintenance will require fewer luminaries by increasing the utilization of the light entering the space."[19]

In and of itself, the strategy does not actually save energy. Instead, it is a preventative strategy that makes it possible to avoid the over-design of new lighting systems or the addition of auxiliary lighting into a space with an existing system compromised by neglect. It can therefore be engaged either to prevent future compensatory overlighting or as part of a plan to reverse existing compensatory

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[19] Helms, 274.

overlighting. In the case of prevention, there will be no impact on form fabric or function. Some preservation projects do include the introduction of a new lighting system, and through making Vigilant Maintenance a part of the preservation plan, that lighting system need not be over-designed. In preservation projects with existing systems, Vigilant Maintenance can be used to avoid the introduction of additional lighting into the space. In cases where Vigilant Maintenance is being used to reverse existing compensatory overlighting, impact on form fabric and function will be determined by whatever means are pursued to reverse the existing overlighting.[20]

An easily overlooked aspect of this strategy is that maintenance does not stop with the lamps and luminaires. Not only the cleanliness of the luminaires, but also the cleanliness of the surfaces and even the freshness of the paint in the space can have an impact on the effectiveness of the lighting system.[21] Dirt and grime on light sources and luminaires are not the only culprits of lighting system deterioration, but dirt and grime and even clutter in the space as well.

Primary Advantages

As with Conservation, the primary advantage of the strategy of Vigilant Maintenance is the potential for the strategy itself to have absolutely no deleterious impact on form, fabric or function.[22] In fact, the strategy can have several positive impacts. A vigilant maintenance schedule will improve the appearance of the lighting itself as well as the

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[20] Lux/Footcandle Reduction, a strategy discussed later in this chapter, is one very likely means of eliminating overlighting.

[21] "Maintenance should include not only spot relamping, but also room surface cleaning, painting, luminaire cleaning and group relamping." Helms, 274.

[22] See the following Primary Concerns section for a discussion of how some situations that make Vigilant Maintenance an energy saving strategy may have an impact on form, fabric or function.

spaces. Dirt and grime in a luminaire can obscure decorative detail or color; dimmer, degraded light sources—including electric lamps—can cause luminaires and spaces to appear differently than the way they were designed to appear. Through the more frequent inspection that it entails, vigilant maintenance schedule also makes more likely the discovery of problems before they become serious.

Primary Concerns

Although the strategy itself will have no impact on the form, fabric or function of the historic building, many of the strategies that it may be paired with to reduce energy consumption can. In many situations, Vigilant Maintenance must be coupled with a means of eliminating compensatory overlighting in order to actually save energy. Although the maintenance may have no impact on the form, fabric or function, it is likely that the means taken to eliminate the compensatory overlighting will. For this reason, the negligible impact of the maintenance cannot be considered in isolation, but must be considered along with whatever means are pursued to eliminate compensatory overlighting.

Vigilant Maintenance also shares one of its primary concerns with Conservation: it requires active and consistent user participation. It is one thing to state during the design phase or the planning phase of a campaign to eliminate compensatory overlighting that Vigilant Maintenance will be a part of the preservation project, but quite another to actually make it happen and, even more importantly, make it continue to happen. If the maintenance schedule breaks down and the cleaning and maintenance of the lighting system are neglected, the lighting performance will deteriorate, which can easily lead to the addition by users of compensatory auxiliary lighting and the loss of the energy savings that the strategy was intended to garner.

Summary

Vigilant Maintenance							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	N	N	N	N	N
Fabric	N	N	N	N	N	N	N
Function	N	N	N	N	N	N	N

Pros:

- The potential for no impact on the form, fabric or function of the lighting system.
- Requires limited material investment.
- Vigilant Maintenance will improve the appearance of the lighting system and space as well.
- Vigilant Maintenance can provide early warning for potential and emerging problems in the building.

Cons:

- Savings potential is limited to the amount degradation of the lighting system has resulted in compensatory overlighting.
- Savings either contingent on reducing the lighting in response to the improved performance of the lighting system or are preventative savings.
- Requires on-going, vigilant attention; the savings are lost if the maintenance is neglected and decreased performance causes users to introduce more lighting.

LUX/FOOTCANDLE REDUCTION

Lux and footcandles are two units used to measure illuminance, the amount of light that reaches a surface.[23] Over the years, design guidelines and standard practice have varied considerably as to what light levels are appropriate for certain spaces. *Mechanical and Electrical Equipment for Buildings*—a standard reference volume for all kinds of mechanical systems used in buildings—addresses this phenomenon:

> The "energy rich" decades of the 1950s and 1960s saw a dramatic increase in recommended levels of heating and lighting for buildings. The evolution of higher recommended indoor temperatures is shown in Table 1.3. Lighting levels rose even more rapidly, as a look at past editions of this book (Table 1.4) (Figure 6) reveals. [...] These lighting levels have been reassessed, as shown by later scaled down recommendations of the Federal Energy Administration. These recommended increases and their impact on energy consumption reached a peak in the years around 1970, which could be called the "pre-energy-awareness" period in recent U.S. history.[24]

To illustrate how high light levels have historically climbed, *Mechanical and Electrical Equipment for Buildings* goes on to describe one somewhat extreme example, an electric utility headquarters building that was renovated and enlarged in the mid 1960s. The light levels in the building included 300-350 footcandles in the offices, up to 550 footcandles in display areas, up to 600 footcandles in conference and demonstration rooms and 500-watt luminaires in 228 of the window sills for nighttime façade lighting.[25]

The evolution of attitudes about what lighting levels are appropriate for different kinds of spaces is one of many reasons that spaces can end up being overlit. And, as Roger Moss points out in his *Lighting for Historic Buildings,* the degree of overlighting

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[23] Helms. 16.

[24] John Reynolds and Benjamin Stein, eds. Mechanical and Electrical Equipment for Buildings 8th ed. (New York: Wiley, 1992) 19.

[25] *Ibid*., 19-20

can be even greater from the standpoint of historically authentic lighting levels.[26] If even today's standards of appropriate lighting levels, which are often far lower than those of previous decades, far exceed those historically found in spaces, then the potential for overlighting is even greater. This presents a rich opportunity for reducing the amount of energy being used to light a space.

TABLE 1.4 **Trends in Recommended Minimum Lighting Levels (footcandles)**

	From Mechanical and Electrical Equipment for Buildings		Federal Energy Administration (1976)
Category	*2nd Edition (1945)*	*5th Edition (1971)*	
Offices			
Accounting, bookkeeping	30	150	
Regular office work	20	100	50
Conference rooms	10	(Not listed)	30
Corridors, stairs	5	30 (But not less than one fifth the level of the adjacent area)	10
Schools			
Auditoriums	10	30	
Classrooms, regular deskwork	20	70	
Drafting, drawing	30–50	100	
Sewing	50–100	150	
Libraries			
Reading room	20	70	

Figure 6: Table 1.4 from *Mechanical and Electrical Equipment for Buildings* (MEEB) illustrating the increase in historically recommended light levels.

Light level reduction can be achieved through a handful of different approaches. Light sources can be replaced with light sources that produce less light and therefore consume less energy. For example, in the case of electric lighting, this would entail replacing higher wattage lamps with lower wattage lamps. Adjustable light sources can

[26] cf. Chapter 2.

be tuned down, such as through the use of dimming switches on electric lights.[27] Fewer of the luminaires—or light sources in the luminaires—in the space can be illuminated, either disconnecting them or through using existing controls. Space planning can also be a means of Lumen/Footcandle Reduction. Users with similar schedules and lighting needs can be grouped together, making it possible to group the uses that need higher illumination together and easier to reduce the illumination levels elsewhere.[28]

Primary Advantages

Foremost among the advantages for the preservationist is the limited impact of the strategy and the easy reversibility of what impact there may be. Light sources—especially electric lamps—that are exchanged for lower consumption light sources can easily be exchanged back. Adjustable light sources that have been tuned down can be just as easily tuned back up. Luminaires that have had their light sources partially removed can just as easily have those light sources re-installed. Luminaires that have been turned off can be turned back on. Even if luminaires have been disconnected—such as by disconnecting the wires of an electric luminaire—they can easily be reconnected if the disconnection was done with forethought and reversibility in mind. An additional advantage is that, unlike Conservation and Vigilant Maintenance, Lux/Lumen Reduction can potentially be a one-time intervention. As such, it requires attention in the planning stage, but does not require the same kind of on-going vigilance for the energy savings to continue to be realized.

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[27] Although not very likely, conceptually this approach could even be applied to historic lighting technologies. Candle wicks can be trimmed (snuffed), gas cocks can be tuned down, etc.

[28] Hayden McKay. "Strategies for Saving Energy Used for Lighting," Architecture: The AIA Journal 76.4 (1987): 111.

There are also several non-energy advantages to this strategy. With Roger Moss's caution about the inappropriateness of overlighting in many historic spaces in mind, the reduction of light levels can lead to a more appropriate and accurate rendering of historic spaces. In fact, Lux/Footcandle Reduction can be an integral part of a lighting restoration project. As Cook and Ferro relate in "Electric Lighting and Wiring in American Historic Buildings,"

> As fluorescents and suspended ceilings are removed, many times a new world of ornate plaster cornices and ceilings, floral medallions, and intricate stenciling is discovered.
>
> In most cases, the replacement of this most recent lighting scheme with one approximating the original will result in drastically reduced ambient lighting.[29]

And the potential advantages for preservation projects go beyond just historical accuracy. Appropriate levels of illumination can vary from one style to another. In "Interior Lighting Systems for Historic Churches," Viggo Rambusch offers an example specific to church interiors:

> Generally, a Romanesque or Gothic interior calls for a much lower level of light than a Colonial or Georgian interior. Where 12 footcandles might suffice in a nave of a Gothic Revival Church, 30 footcandles would be required to suitably light a Colonial interior. Conversely, if 30 footcandles were pumped into a handsome old Gothic interior, its materials might become "unbeautiful" – the slate floor, limestone columns, oak wainscoting, etc., suddenly would be thrown out of context. These materials would seem to lose their luster and solemness and instead would appear dirty, since they were not meant to be brightly lighted.[30]

Another advantage to preservation projects is that historic fabric can be light sensitive. Bright light can fade fabrics, paint and other pigments, and contribute to the drying out of

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[29] Cook, 37. Cook and Ferro go on to warn about a possible result of under-illumination, and suggest task lighting as a solution, demonstrating a potential synergistic relationship between multiple strategies, such as Multi-Level Lighting covered below.

[30] Viggo Bech Ramsbusch. "Interior Lighting Systems for Historic Churches: Planning to Meet Restoration Goals & Current Needs" Technology and Conservation 2.4 (1977): 29.

materials—especially if the light source produces heat in addition to light, such as is the case with all modern electric sources such as incandescent and halogen lamps as well as historic combustion sources.[31] Light levels of 8 footcandles may be required to ensure the protection of historic fabrics and paintings,[32] and some situations may call for even lower light levels. Therefore the reduction of light levels can also be a means of preservation of historic fabric.

There are also other, less preservation-centric advantages. In the case of overlit spaces, such as illustrated above, decreasing light levels can actually improve the lighting quality in some spaces:

> The quantity of footcandles, while important, is only one component of the lighting design process and should never be relied on to the exclusion of all other components. In most situations, in fact, increasing the number of footcandles for a particular task will improve visual performance only up to a point. Providing additional illumination past this point may actually be counterproductive.[33]

In essence, overlighting a space may actually be decreasing light quality and the reduction of light levels could improve light quality.

Primary Concerns

Lumen/Lux Reduction is only a viable strategy if the space if currently overlit. While the discussion of the vast variation in historic recommended light levels discussed above may make it very possible that a historic space may be over-illuminated, it does not guarantee it. If a space is not over-illuminated, then reducing the levels of lighting could actually have serious negative impacts on the space. Foremost are concerns over

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[31] Helms, 81.

[32] Ramsbusch, 30.

[33] New York State Energy Office. Energy Efficient Lighting Design and Maintenance Manual (Albany, NY: Bureau of Codes & Standards, New York State Energy Office, 1988) 15-16.

life safety. Under-illuminated spaces can present dangers for users navigating the space and for wayfinding, especially in the case of an emergency. Additionally, while over-illuminating a space can have a negative impact on lighting quality, so can under-illuminating. Underlit spaces can make it difficult to work or live in the space, and can cause maladies such as eye-strain.

Just as the Lumen/Lux Reduction is only a viable strategy if the space is currently overlit, the opportunity for savings is limited to the amount that a space is over-illuminated. Therefore, as is the case with Conservation, potential savings are limited to current wastefulness. Although the strategy requires little investment in terms of materials, it does require an investment in time and labor. And although the interventions associated with the strategy are easily reversed, their reversal can also require an investment in time and labor. Therefore, it is important to assess the savings that can actually be garnered before embarking on a campaign of Lumen/Lux Reduction in order to ensure that the investment is worth the time and intervention. Prominent in this pre-planning should be an assessment of the opportunity for the light-levels in the space to be reduced. If luminaires or light sources in luminaires are to be deactivated, the remaining light sources need to be able to still adequately illuminate the space. For example, if a space is over-illuminated by 30%, but the only way to reduce light levels is to extinguish one of two light sources, then the light levels will be reduced by 50% and the space will be left under-illuminated. A sophisticated plan would include mock-ups—scaled models that are smaller in size and/or scope—in order to ensure that the space will still have sufficient illumination after Lux/Footcandle Reduction has been pursued.[34]

For the preservationist, there is an inverse to the problem of historic spaces and over-illumination. Many buildings, such as the example from *Mechanical and Electrical Equipment for Buildings* above, were constructed in an "energy glut" era and were designed to have illumination levels considered to be too high by today's standards. Yet as these buildings make their way into the sphere of concern of the field of preservation, the reality of the high illumination levels in the original design must be considered. Just as many buildings could be inappropriately lit—from a historical accuracy standpoint—through over-illumination, other buildings could be inappropriately lit through under-illumination. In situations like this, the desire for historic authenticity could come at odds with a lux/footcandle reduction scheme.

As a final note, there is a concern over the use of some controls—especially some existing controls—to reduce light levels. Although even historic lighting systems are sometimes equipped with dimming capabilities, these are not always actually capable of reducing energy consumption.

> The original dimmers were resistance types that diverted some of the current through a variable resistor. Although the resistance dimmers have their advantages and disadvantages, the only characteristic of importance here is that they do not save energy. The total power used is the same whatever the light level, because the dimmer itself draws power.[35]

Since some dimmers decrease the amount of power that reaches the light sources by consuming the extra power themselves, they do not save energy and therefore should not

[34] McKay, 113.

[35] Helms, 285.

be used as part of an energy-saving plan. There may be other reasons to use such dimmers to reduce light levels, but energy savings is not one of them.

Summary

Lux/Footcandle Reduction							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	N	A	N	N	N
Fabric	N	N	N	A	N	N	N
Function	N	N	N	N	N	N	N

Pros:

- Intervention is one-time and does not require on-going attention.
- Lower light levels may be more appropriate for some historic spaces or present the spaces in a more historically accurate manner.
- Lower light levels can reduce contrast when directly viewing historic light fixtures, making their details more visible.
- Many spaces are overlit, and lowering the lighting levels will actually improve the lighting in the space.
- Lower light levels may reduce glare and thereby improve visibility on tasks such as computer work.
- Lower light levels will, in most situations, reduce the fading of historic fabric such as curtains and upholstery.

Cons:

- Savings are limited to the amount that a space is currently over-illuminated.
- The fact that a space is over-illuminated does not mean that the space provides the opportunity to reduce the light levels.
- If the space is not overlit, then light level reduction will make the lighting worse.
- Some spaces were originally designed to be overlit, and therefore reducing the light levels could be less historically accurate.

AUTOMATIC CONTROLS[36]

Automatic controls are installed to turn the lights on and/or off under certain circumstances. They achieve automatically what is achieved manually through user intervention in conservation. It is therefore logical that Larry Spielvogel's enthusiasm for Conservation extends next to such controls: "And the second most cost-effective technique, with paybacks measured in terms of months, is improved controls."[37]

A very basic example of an automatic control is a time-clock, which can turn the lights on or off based on the time of the day, thereby ensuring that lights are not left on during scheduled periods of non-use. A more sophisticated example is the use of photocontrols, light-sensor equipped controls that can turn lights on when light levels decrease past a certain level and off when they increase past a certain level, thereby ensuring that the lights are only on when natural lighting is not sufficient for the space's lighting needs. Another common example is occupancy controls, which can turn the lights on when a person enters a space and off after the person has left, thereby ensuring that the electric lights are only on when a person is in the space.

Primary Advantages

The strategy of Automatic Controls is really just Conservation where the vigilant control of the users has been replaced by well-planned automatic controls, and that is its foremost advantage. It removes the largest concern over the pursuit of the strategy of Conservation: the breakdown of that vigilance.

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[36] While it is certainly possible to control historic lighting technologies with automatic controls, this strategy will really only find reasonable use with electric lighting.

[37] Wagner, 11.

> The designer who plans to save energy while leaving control of the lights in the hands of the occupants risks disappointment. If everyone were energy minded, one might argue, there would be no need for devices that work independently of human interaction. The problem with this reasoning is that even the most conscientious person forgets, or has overriding motivation for leaving lights on when not in use. Case studies have repeatedly shown that occupants cannot be relied up on to turn off the lights.[38]

This caution by Helms and Belcher highlights the concern about Conservation described in the above section, and sums up the rationale for relying instead on Automatic Controls. Automatic Controls do not forget; they do not have other concerns; they are not rebellious. Whether time-clocks, occupancy controls or photocontrols, the primary advantage of pursuing the strategy of Automatic Controls is eliminating the lost savings that result from the forgetfulness, negligence or simple lack of user understanding.

Of especial concern to preservationists is that pursuing a strategy of Automatic Controls has the potential to have a very limited impact on form, fabric and function.[39] Many automatic controls can be installed in the place of existing manual controls. However, they can also be introduced elsewhere along electrical wires—or the distribution lines of the lighting technology of another past or future lighting technology. However, the location of automatic controls is not limited to the distribution lines, providing far more flexibility and less severe interventions for preservation projects. Sensors—such as occupancy controls and photocontrols—and other control devices—such as time-clocks—can be located remotely from the physical switches and connected

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[38] Helms, 284.

[39] The degree of impact on function may be debatable. If a preservationist considers the manner in which lighting is controlled to be a part of function, then the introduction of an automatic control would have considerable impact on that aspect of the function.

by thin, low voltage wires or even by radio waves. Additionally, remote sensors can frequently be small and provide the opportunity for discreet placement, even when the optimal location for them is a prominent one.

Finally, the users of buildings have reasons for being in the building other than controlling the lighting; however, the only reason that automatic controls have for being in a building is to do just that. This regularity means that automatic controls also present the opportunity for finer-grained control, and therefore greater energy savings. This is especially the case with dimming:

> Automatic dimmers can provide slow, smooth light level adjustments and are particularly appropriate for regulating levels between electric and natural light. Dimming is also generally acceptable and more energy-conserving than on-off switching.[40]

The specific mention of daylighting touches on the reality that many of these strategies can work synergistically.

Primary Concerns

One of the primary advantages of making use of automatic controls is also the greatest concern. Putting control of the lights in the hands of a programmable device makes the programming of utmost importance. Poorly programmed controls will be a detriment to both users and energy savings. Automatic controls are great when they operate as intended, but when their actual operation begins to deviate from their intended operation, users can find themselves with a lighting system that turns on or off at the wrong time. Time clocks can be programmed with the wrong schedule of use, leaving users literally in the dark. Photocontrols can be poorly adjusted and turn lights off when

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[40] Energy Efficient Lighting Design and Maintenance Manual, 44.

there is not enough daylight, leaving users straining to see. Occupancy controls can also be poorly adjusted, with preprogrammed shut-off times that are too short or sensitivity levels that are set too low, leaving users periodically waving their arms or yelling to trigger the occupancy controls and get the lights on again. Any of these can decrease the quality of lighting in the space and will therefore likely increase the frustration of the users in the space. Even if the malfunction of the automatic controls leaves the lights on, users can become frustrated by the fact that the controls aren't doing the thing for which they were installed, saving energy. The lighting industry is filled with anecdotes of users disabling controls, taping over photosensors and otherwise overriding controls that are not operating properly.

Therefore, commissioning—the programming and fine-tuning of automated systems such as automatic lighting controls in buildings—is of vital importance. It is not enough to just choose the correct automatic controls for the situation and have them correctly installed, those controls must be carefully adjusted before they can be depended upon to control the lighting satisfactorily. But beyond this, users need to have at least some understanding of how the controls work. Conditions in the space and uses can all change and even careful commissioning can still fall short of satisfaction. Users need to be able to adjust the system if savings and lighting quality are to be optimized:

> The design of sophisticated lighting systems and controls for energy conservation will be wasteful if the building user does not know how to properly use and maintain the system. The designer should provide instructions on how to use the system.[41]

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[41] Helms, 274.

Automatic controls that have been bypassed or disabled not only run the danger of losing energy savings, but can even lead to increased energy consumption if the end result is an "automatic control" that just always leaves the lights on.

Automatic controls can also have an impact lighting quality in ways other than just the timing of controls. Dimming can cause color shifting in many kinds of light sources. For example, incandescent lamps shift toward the red end of the color spectrum as they are dimmed.[42] This color shift can affect the way that colors in the space are rendered—a consideration of special concern in preservation projects where the accurate reproduction of interior finishes has been an important goal, but also in any project where colors have been carefully chosen—and the mood of the space. (The impact of light source color is covered more fully in the section on High-Efficiency Light Source.)

User satisfaction can suffer in other ways as well. A lighting system that has been completely automated can leave users feeling disempowered and out of control. This can even happen when the system is working perfectly. Many users, especially those who use a building daily, simply like to have control over their environments. Therefore, "users should be given override capabilities and control of turning lights back on when required. This will generally be more user-acceptable than a totally automated switching system."[43] Dissatisfaction over loss of control can motivate users to disable systems just as dissatisfaction over poor lighting quality can.

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[42] Jankowski, Wanda. "Guidelines for Specifying Controls," Architectural Lighting July-Aug. 1994: 52.
[43] Energy Efficient Lighting Design and Maintenance Manual, 43.

Just as the strategy of Automatic Controls shares some of the advantages of Conservation, so too it shares some of the concerns. Among these is the reality that the potential for savings are completely dependent on the wastefulness of current lighting practices. If no lighting energy is being wasted, then pursuing a strategy of Automatic Controls will not save any energy.

Lastly, but certainly not the least important concern in a preservation project, automatic controls can be a rather expensive solution.[44] Simple conservation can often achieve similar savings, and the fallibility of the users can be tempered with good education, encouragement and incentives.[45]

Summary

Automatic Controls							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	A	N	N	N	N
Fabric	N	N	R	N	N	N	N
Function	N	N	R	N	N	N	N

Pros:

- Savings can be achieved with only limited user interaction.
- Controls can be introduced in inconspicuous locations so as to minimize visual impact.

Cons:

- Savings potential is dependent on properly commissioning (programming) the controls, which could be beyond typical users.
- Many automatic controls introduce a level of complexity to lighting control; in the face of that complexity, users may decide to just override

44 McKay, 113.

45 *Ibid.*

the system to on, thereby negating all saving potential and potentially even increasing energy consumption from manual control levels.

MULTI-LEVEL LIGHTING

Different tasks require different levels of light. Reading in a room requires more light than navigating through a room but less light than fine, detail-focused work. It might be desirable to leave some lights on during off hours to aid in security or safety, but that level of light may very well be much less than is required for the space's normal use. Multi-level lighting saves lighting energy by providing different levels of lighting for different lighting needs—whether different parts of the space or different times in the space—and allowing the users to select the level appropriate for that sub-space or time.[46] These differences in lighting needs present the opportunity to reduce the level of illumination for tasks that need less light while retaining higher levels of illumination for the tasks that need more light.

> The most often criticized lighting design practices of the 1960s and early 1970s were overlighting ("more light, better sight") and general lighting. Overlighting was caused principally by the availability of cheap energy. It encouraged architects and engineers to design lighting for the most difficult expected task rather than tailoring the light levels to the actual tasks. High light levels, typically 100 footcandles or more, became standard to the building industry.[47]

This phenomenon has consequences beyond just the period described as many existing buildings were retrofitted in this push for "more light, better sight." This, in turn, is one of the sources for potential savings through pursuing a strategy of Lux/Footcandle Reduction.[48] It is,

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[46] This selection can either be made manually or by combining multi-level lighting with automatic controls.

[47] James Benya. "Light Loads: Interior Techniques: Energy-Conserving Lighting," Progressive Architecture Apr. 1983: 128.

[48] "Any opportunities for reducing uniform space lighting (and the energy if consumes) should therefore be explored by the design team. It may, for example, be possible to reduce ambient illumination levels while providing localized lighting specifically directed at the work being performed. This approach will put light where it is needed and save energy in the process." Energy Efficient Lighting Design and Maintenance Manual, 20.

> …very simply, putting enough light (but no more than that) on each of the tasks in any building. To be obvious about it, this concept would put less lighting in the hallways than in a drafting room or shop where detailed work was done—or the kitchen. This task lighting—as opposed to the uniform lighting levels (even luminous ceilings) so common just a few years ago—has proven appealing to architects not just because of the energy conservation, but because it tends to create a successful architectural environment.[49]

When pursuing a strategy of Multi-Level Lighting, it is easy to focus just on the spatial dimension. However, the temporal dimension can provide great opportunities for savings as well. For example, Viggo Rambusch recommends as many as five different light levels for church interiors: security or night light, maintenance and cleaning lights, tourist or visiting devotional light, regular service lighting, and full system to satisfy requirements such as television broadcast lighting.[50] Even putting aside the less common need for television broadcasting levels, lighting levels for regular services could be far greater than the minimal lighting needed for tourist/devotionals or security. Although Rambusch is advocating Multi-Level Lighting in order to achieve appropriate light levels from a design standpoint, not an energy savings standpoint, it is clear that pursuing Multi-Level Lighting could provide considerable energy savings for most of the hours of use in such a situation.

Primary Advantages

Multi-level Lighting is, in many ways, a more sophisticated version of Lux/Footcandle Reduction—light levels for each task are reduced to the minimum appropriate level rather than illuminating the entire space for the task with the greatest light demands—and therefore shares some of its advantages. Among those, the potential

[49] Wagner, 10.

[50] Ramsbusch, 31.

for more historically accurate lighting levels are of especial concern for many preservation projects, as well as the protection of historic materials that lower light levels can provide.

For preservation projects, a strategy of Multi-Level Lighting provides additional advantages. Foremost among these is the opportunity to tailor lighting to specific needs. Rather than illuminating an entire space so that certain architectural details can be clearly seen, separate lights can be used to provide higher levels of illumination for just those details. The use of task lighting at work surfaces is frequently a more historically accurate configuration. Different light levels can be used for different uses, thereby increasing the usefulness of a historic space. Different light levels can be used to interpretive effect, emphasizing certain details or aspects of a space. Multi-Level Lighting can be accomplished with portable luminaires such as table lamps, which can prevent the loss of existing and/or historic fabric that results from the replacement of existing lighting systems. Portable lighting also has the advantage of complete reversibility and a high level of flexibility—something that can be especially valuable in historic spaces in which the demands of protection of the form and fabric can lead to a certain inflexibility in the space.

Multi-Level Lighting also offers many opportunities for synergistic use with other energy efficient lighting strategies. It can be combined with automatic controls to allow for greater control of the different light levels; this is especially valuable when Multi-

Level Lighting is pursued for different times in the same space.[51] It can also be combined with Daylighting—described below—to use daylight to provide the ambient light while uses with higher illumination needs get additional artificial lighting.[52] It can be combined with Lux/Footcandle Reduction to provide transition zones between spaces with lower illumination levels and those with higher illumination levels—especially outside—so that users' eyes have a chance to adapt and those spaces do not seem dim or dark in comparison.[53]

Primary Concerns

The largest concern in pursuing a strategy of Multi-Level Lighting is that the impact on form, fabric and function is completely situation specific and can be significant. Realistically, if a space is already configured with different luminaires with individual controls serving different lighting needs, then Multi-Level Lighting is already part of the lighting system and can't really be pursued as an energy saving strategy. In such a situation, savings would really be achieved through Lux/Footcandle Reduction or Conservation. Pursuing Multi-Level Lighting in a space with only a single level of lighting or increasing the number of levels of lighting in a space that already has multiple levels of lighting requires the creation of those additional levels of lighting. In many situations, this can mean the replacement or alteration of the entire lighting system.

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[51] "To allow for local control while avoiding excessive illumination, lighting circuits should be wired so that activation of one system locks-out or prevents activation of other systems. In this way lighting will be specific to the use involved and energy waste will be avoided." Energy Efficient Lighting Design and Maintenance Manual, 47.

[52] Derek Poole. "Low Energy Factories 4: Daylighting," Architect's Journal 191.22 (1990): 63.

[53] McKay, 112. Energy Efficient Lighting Design and Maintenance Manual, 21.

The impact, however, can be limited with some creative thinking. For example, luminaires with multiple light sources can be reconfigured so that they can be illuminated either by all of their light sources or only by a limited set, providing multiple levels of illumination for different uses. Multi-Level Lighting can also be easily pursued in a space that has multiple luminaires but no individual control for those luminaires or the light sources within them. New controls can be introduced for each individual luminaire or logical group of luminaires, or new controls can even be introduced for separate light sources within the same luminaire. (This might involve the addition of new controls at the luminaires themselves or the addition of new, separate distribution lines—such as electrical circuits—each with their own controls.) Another example of limiting the impact through good design would be reducing the light output of a lone or primary luminaire, relegating it to ambient lighting, and adding additional luminaires to provide the multiple levels of lighting throughout the space.

There is also reason for concern about the savings potential and lighting quality of Multi-Level Lighting. "Task/ambient lighting has great potential in this respect. But … it may or may not use less energy than a well-designed ceiling lighting system. Without careful design, it can be troublesome from the standpoint of reflected glare."[54] Multiple levels of lighting do not automatically ensure energy savings over a configuration with only one level of lighting, nor do they automatically ensure superior lighting quality. A good lighting system can be made worse from the standpoint of energy performance or lighting quality. Pursuing Multi-Level Lighting requires more design talent and

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[54] Wagner, 165.

understanding of lighting than many of the other strategies.[55] It is one of the situations where it may be wisest to take the advice of Gary Behm and hire a lighting professional.[56]

Summary

Multi-Level Lighting							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	A	A	A	A	A
Fabric	N	N	A	A	A	A	N
Function	N	N	A	N	N	N	A

Pros:

- Many approaches to multi-level lighting, such as the use of task lighting, present more historically accurate lighting in many circumstances.
- Provides the potential for greater savings than simple on/off switching.
- Has auxiliary uses such as architectural or interpretive lighting.
- Is essentially a one-time intervention.

Cons:

- Will only be successful if the use of the building or space includes the potential use of different lighting levels.
- Requires a greater level of lighting design ability than many other strategies.
- Even though it is possible to mitigate through creative design, it can have significant impact on form, fabric and function.

[55] Wagner, 144.

[56] Behm, 158.

HIGH-EFFICIENCY LIGHT SOURCES

The concept of using a higher efficiency light source is a straightforward energy efficient lighting strategy. Remaining within the same era of lighting technology and retaining all of the other parts of the lighting system, the light source itself is replaced with one that consumes less energy/fuel in order to fulfill the same lighting task. This can save energy in two ways, either through simply cutting the fuel consumption of the light source, or through producing more light with the same amount of fuel, thereby allowing for a reduction in the number of light sources.

Although progress has been made in the efficiency of the incandescent lamp since Edison perfected the technology in 1880, the prolific incandescent lamp is still an inefficient light source. Figure 7 shows the distribution of the power consumption of a standard incandescent lamp. Only ten percent of the power consumed by the lamp is actually converted into light. The lamp actually converts over seven times as much energy into heat as light. Despite the number of more efficient light sources available, incandescent lamps are still prolific and provide many opportunities for energy savings. And while incandescent lamps may stand out in terms of wasting energy, they do not stand alone. For example, fluorescent lamps—a lighting technology that has displaced incandescent lamps in many situations due in part to its greater efficiency—can present an opportunity for greater efficiency. Advancements in the technology have led to vast improvements in ballast efficiency, and modern electronic ballasts can save ten to 15 percent over the older magnetic ballasts.[57]

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[57] Benya, 131.

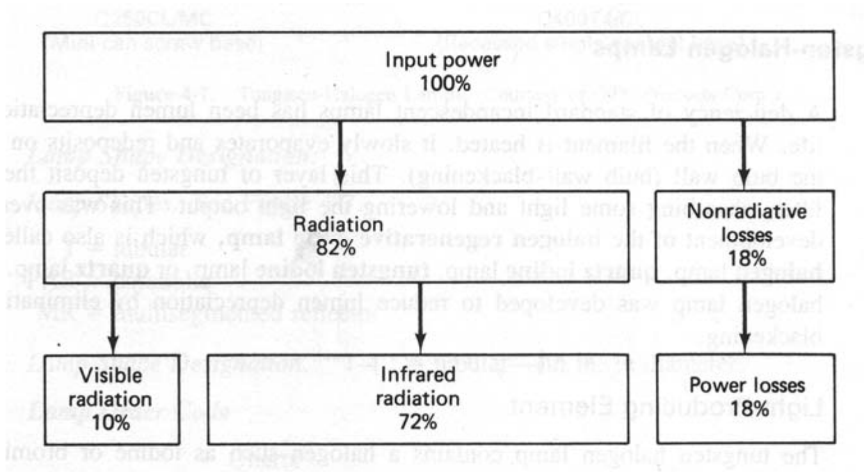

Figure 7: The distribution of the power consumption of a typical incandescent lamp. (source: *Lighting for Energy Efficiency Luminous Environments*, 81).

For most people, the most recognizable example of pursuing high-efficiency light sources as an energy saving strategy is the compact fluorescent lamp (CFL). One only has to go to a home-improvement store to see the proliferation of this technology. More efficient fluorescent lighting technology has been reduced in scale and adapted for the standard A-lamp socket, allowing it to replace a standard, less efficient incandescent lamp. High-pressure sodium lamps (a type of high induction discharge [HID] lamp) are another example frequently found in exterior lighting retrofits. These two technologies, like most high-efficiency light sources, save energy through having higher luminous efficacies.

> Luminous efficacy is a ratio of the total luminous flux emitted by a source to the total power input to the source. (units are lumens/Watt) … Efficacy is similar in concept to miles per gallon. The larger the efficacy, the higher the light output with less power consumption. … A 100 W incandescent lamp produces 1750 lumens while a 40 W fluorescent produces 3150 lumens.[58]

[58] Helms, 13. The same concept can, of course, be applied to any fuel source: lumens per cubic foot of natural gas or per volume of oil or per volume of wax or per the fuel of the future.

However, greater luminous efficacy is only one metric of light source efficacy. Even if a one light source may produce fewer lumens than another for the same amount of fuel, it can still be more efficient if it can meet a lighting need while consuming less fuel. For example, low-voltage incandescent lamps can

> produce a narrower cone of light than a standard voltage lamp. When used for accent or display lighting, this concentrated spot of brightness gives more emphasis than a wider beam of equivalent wattage and is especially energy effective in combination with low-level ambient lighting (e.g. in museums or retail establishments).[59]

Although other light sources may have a higher luminous efficacy, less efficient light sources can be ultimately more efficient if they can meet a lighting need while producing fewer lumens, and therefore consuming less fuel than some of their counterparts with greater luminous efficacy. This situation is frequently due to scale. For example, LEDs (light emitting diodes) do not have an especially high luminous efficacy, but they are capable of emitting very low levels of light. Most light sources with higher luminous efficacies are not available in such small configurations and therefore would consume more fuel/energy to meet the same lighting need, even though they would consume it more efficiently.

High-Efficiency Light Sources was the only energy efficient lighting strategy for use in historic preservation found in literature review, so this, combined with the proliferation of CFL and high-pressure sodium lamp retrofits mentioned above, makes it safe to assume that it is the most widely used energy efficient lighting strategy in preservation.

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[59] Energy Efficient Lighting Design and Maintenance Manual, 32. See also Benya, 129.

Primary Advantages

The greatest advantage of making use of High Efficiency Light Sources is that it is both a straightforward and effective energy efficient lighting strategy. It does not require a redesign of the lighting in the space—or the space itself—as many other strategies do. It saves energy when the lights are on, and not just by finding ways to turn them off. Its savings do not depend on the ongoing or vigilant interaction of users. It does not require oftentimes-complex commissioning. Additionally, the fact that this is perhaps the most prominent energy efficient lighting strategy offers several additional advantages for preservation projects. Many efficient light sources—notably the CFL—have been specifically developed or adapted for easy retrofit applications,[60] so retrofits can frequently be done with "out of the box" products rather than requiring specialized design and implementation, or at least not as much. The prominence of the strategy also results in a higher availability of information and technical assistance for preservation projects. And lastly, the prominence of the strategy means that there may be cash incentives, rebates or free or reduced cost technical assistance or even equipment available to preservation projects from energy efficiency programs.[61]

Primary Concerns

The first consideration before pursuing a strategy of using high-efficiency light sources is the issue of color. A brief summary diversion into color theory would be

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[60] This same trend can be seen in historic lighting technology: kerosene burners for oil lamps, Welsbach burners for gas lamps, etc.

[61] These programs can be provided by a diversity of sources, from local to federal governmental agencies, to public good not-for-profits, to local utilities.

useful in order to establish the basis for this concern.[62] The perceived color of an object is determined by two factors: the reflective characteristics of the pigments in the object and the color characteristics of the illuminating light. An object appears a certain color to the viewer because it reflects the wavelengths of the spectrum of visible light that compose that color and absorbs the other wavelengths. Therefore, the color of the illuminating light is important to color rendition because it provides color components of light that the object reflects and provides them in certain proportions. Light sources with different proportions of wavelengths can render the color of the same object quite differently. Under a light source that is weighted toward the blue end of the visible spectrum, a blue object will appear vivid while orange and red objects will appear more dull and grayish. Conversely, the blue object will appear more dull and grayish while the orange and red objects will appear more vivid under a light source that is weighted toward the red end of the visible spectrum. The pattern follows for all light sources, the colors of whichever wavelengths are more pronounced in the illuminating light will be highlighted in the rendition of objects, while the colors of whichever wavelengths are less pronounced in the illuminating light will be duller, more suppressed and de-emphasized in the color rendition of those objects. This is, of course, a concern for all interiors, but is especially important in preservation projects where the colors of finishes and fabrics have been carefully chosen for historical accuracy. A change in light source can result in a change in the color rendition in the space, which can be a detriment to that historical accuracy. This is of special concern when using high-efficiency light sources:

[62] For an accessible, yet reasonably technical and comprehensive treatment of color and illumination, see Stein and Reynolds' *Mechanical and Electrical Equipment for Buildings, Eighth Edition*, especially sections 18.31-18.33 – Color Temperature, Object Color, and Reactions to Color and 19.25 – Spectral Distribution of Light Sources.

> Some high efficacy sources, while saving energy, may have inadequate color characteristics for certain environments and will ultimately waste energy if additional fixtures must be installed to compensate for color problems.[63]

However, historical accuracy in the color rendition of surfaces is not the only concern. Color contributes to the mood and "feel" of a space, and that in turn can have an impact on the mood and even behavior of people.[64]

For professionals working on preservation projects, there are ways to deal with the issue of color. Several designation systems have been developed to characterize the appearance of the light emitted by different sources and can be used to deal with the problem of the color rendering of light. Prominent among these are the (Correlated) Color Temperature[65] and Color Rendering Index (CRI).[66] Figure 9 summarizes the color characteristics of various light sources and their subsequent impact on color rendering. Color Temperature can be especially useful. Figure 8 shows the relative Color Temperatures of several light sources. Since higher Color Temperatures generally correspond to "bluer" light and lower Color Temperatures to "redder" light, it is a good place to start in order to compare the color rendition of different light sources. However, while Color Temperature and CRI can be very useful, they do not provide an absolute

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[63] Energy Efficient Lighting Design and Maintenance, 10.

[64] Helms, 273.

[65] "A light source is often designated with a color temperature, such as 3400 K for quartz iodine lamps, 4200 K for cool white fluorescent tubes, and so on. This nomenclature derives from the fact that when a light-absorbing body (called a black body) is heated, it will first glow deep red, then cherry red, then orange until it finally become blue-white hot. The color of the light radiated is thus related to its temperature. Therefore, by developing a black-body color temperature scale, we can compare the color of a light source to this scale and assign to it an approximate "color temperature," that is, the temperature to which a black body must be heated to radiate a light approximating the color of the source in question. Temperature is measure in Kelvin." Stein, 961.

[66] Stein, 1056. CRI builds upon the concept of Color Temperature. It is the degree to which a light source renders color the same as a reference light source at the same color temperature, the reference light source is almost always daylight.

metric for light source selection. And, especially in the case of CRI,[67] they can even be misleading. So, when color is a concern, professionals should look beyond the numbers for Color Temperature and CRI listed for a light source.

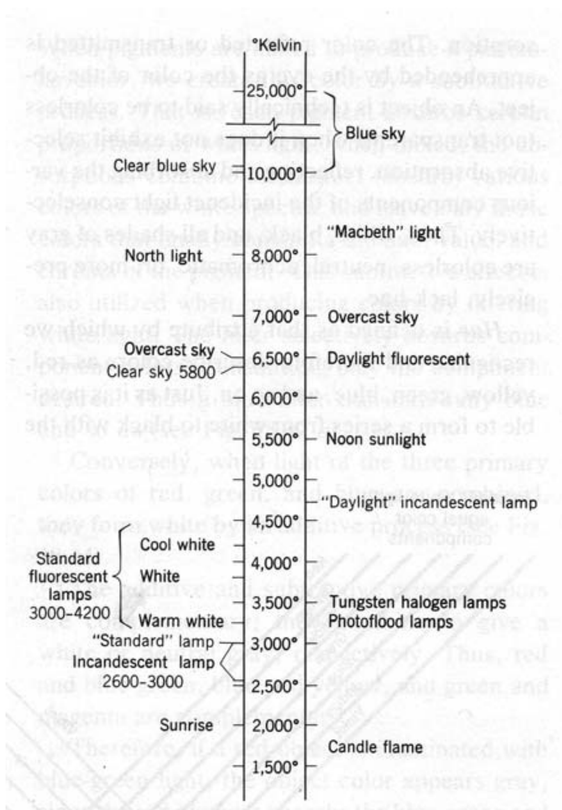

Figure 8: The Color Temperature of various common light sources. (Source: *Mechanical and Electrical Equipment for Buildings*)

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[67] "Many misconceptions and misapplications of CRI have arisen. For example, since the operating characteristics of incandescent lamps approximate a blackbody, the CRI of these lamps is very high, typically approaching 100. There is a tendency to interpret this as meaning that the color rendering of incandescent is somehow "best." What the actual interpretation should be is that incandescent lamps have very similar color rendering characteristics as their reference source.

Another potential problem with CRI concerns the fact that only sources having the same correlated color temperature can be compared. It is often tempting to think of a 5000K lamp with CRI of 80 as having color rendering that is superior to that of a 3000K lamp with CRI of 60. As the CRI system is defined, however, the only comparative statement we can make about the color rendering of these two lamps is that this 5000K lamp is more similar to its reference source than is the 3000K lamps to its reference source." Helms, 65.

The best tool for evaluating the impact of a light source on color is a mock-up. Side-by-side samples of colors from the project illuminated by different light sources and divided by opaque barriers can be used to evaluate the impact of those different light sources on colors specific to the space. In the case of lighting retrofits for preservation projects, professionals can evaluate the impact of various energy efficient light sources on the colors of a space and determine if those impacts are acceptable. When the impact is unacceptable, mock-ups can be used to demonstrate that to outside parties and to justify not using high-efficiency light. Alternately, in the case of preservation projects where both the lighting and the surface pigments will be new, mock-ups can allow professionals to select colors that will match historic precedents specifically when illuminated by a new, energy efficient light source. The color of the finish itself can be used to offset the color-shift that can result from some high-efficiency light sources.

Despite all the concern over color rendition by high-efficiency light sources, it is important to keep in mind that these lamp technologies are advancing quickly and have made significant improvements in color rendering over the years. The days of fluorescent lamps making everything look sickly and green are a thing of the past;[68] the same is also the case with HID lamps, even the notorious, pale pinkish-orange High Pressure Sodium lamps.[69] Therefore, professionals should not let old prejudices about high-efficiency light sources make decisions for them.

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[68] Benya, 129.

[69] *Ibid.*

TABLE 19.22 **Effect of Illuminant on Object Colors**

Lamp	*CRI (Approx.)*	*CCT (K)*	*Whiteness*	*Colors Enhanced*	*Colors Grayed*	*Notes*
Fluorescent						
Warm white	52	3000	Yellowish	Orange, yellow	Red, blue Green	
White	60	3450	Pale yellowish	Orange, yellow	Red, blue Green	
Cool white	62	4150	White White	Yellow Orange Blue	Red	
Warm white deluxe	77	3025	Yellowish	Red, green Orange Yellow	Blue	Simulates incandescent
Daylight	75	6250	Bluish	Green Blue	Red Orange	
	75	3000	Yellowish	Red Orange	Deep red Blue	T8 bulb
Tri-phosphor	75	3500	Pale yellowish	Red Orange Green	Deep red	T8 bulb
	75	4100	Pale greenish	Red, blue Orange Green	Deep red	T8 bulb
Mercury						
Clear	15	5710	Blue Green	Blue Green	Red Orange	Poor overall color rendering
Deluxe	50	3900	Pale purplish	Blue Red	Green	Shift over life to greenish
Warm deluxe	50	3300	Pinkish	Blue Red	Green	Shift over life to greenish
Metal halide clear	65	4100	White	Blue Green Yellow	Red	Shifts to pinkish over life
Phosphor coated	70	3900	White	Blue Green Yellow	Red	Shifts to pinkish over life
HPS standard	21	2100	Yellowish	Yellow	Red, blue	
HPS color corrected	65	2200	Yellowish white	Red, blue Green Yellow	Deep red Deep blue	CRI decreases slightly over life
Incandescent	99+	2900	Yellowish	Red, orange, yellow	Blue, green	

Source: Courtesy of General Electric Co., Lighting Business Group.

Figure 9: The effect of different light sources on the color rendition of objects. (Source: *Mechanical and Electrical Equipment for Buildings,* 1055).

While probably the largest, color is not the only concern when using high-efficiency light sources. Many high-efficiency light sources may have very different size, positioning and wiring requirements than existing light sources. For example, many light sources, such as fluorescent and HID lamps, require a ballast that will have to be incorporated into the existing luminaire, which can have an impact on the form and fabric of the luminaire. Additionally, these light sources may look very different. Often, particularly in preservation, the light source itself is a part of the aesthetic of a light fixture. Replacing an incandescent lamp with a CFL is a simple, low-impact intervention, but that incandescent may have contributed to the form of the luminaire, and its replacement may have a detrimental impact (Figure 10). However, even this impact can be mitigated as many high-efficiency light sources have been altered to better imitate the shape of other light sources; CFLs have received much attention in this regard, receiving alterations such as translucent globes in various shapes and increasingly small integrated ballasts. Finally, many high-efficiency light sources are only available, or easily available, in higher-output configurations. Using such light sources could then introduce inappropriate levels of illumination into a space.

A final concern for using high-efficiency light sources in preservation projects is that historic wiring may provide electrical current that is too variable for modern, high-tech light sources.[70] This could lead to decreased performance, decreased energy efficiency and even frequent equipment failure. However, some high-efficiency light sources—such as fluorescent lamps with electronic ballasts—have been designed to mitigate the effects of variances in line voltage.[71]

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[70] For a concise history of electrical wiring technology, see Electric Lighting and Wiring in Historic Buildings: Guidelines for Restoration and Rehabilitation Projects.

[71] Stein, 1044.

Figure 10: The addition of CFLs to this candelabra contrast starkly with the imitation candles and candelabra lamps. (Photograph by Ellen Buckley)

Summary

High-Efficiency Light Source							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	N	R	A	N	A
Fabric	N	N	N	R	A	N	N
Function	N	N	N	A	N	N	N

Pros:

- Creates savings even when the lighting is on, unlike most conservation-based strategies.
- Can frequently be introduced into existing fixtures.
- High efficiency light sources frequently also have longer useful lives, thereby decreasing relamping costs (including new lamps, labor and equipment such as lifts).

Cons:

- Higher efficiency light sources frequently look different physically—lamp shape, lamp size, etc—or have different light characteristics—especially light color—than older light sources.

- Higher efficiency light sources frequently use ballasts that would need to be incorporated into the lighting fixture itself or located very close to the light source.

- Although they usually have a longer lamp life and subsequently lower total cost of use, modern high efficiency light sources frequently have a higher up-front capital cost, which can be a barrier to installation.

HIGH EFFICIENCY LUMINAIRE

Increasing the efficiency of the luminaire itself is an approach that has frequently been utilized in the history of lighting. While the historic goal was to utilize the light more efficiently in order to provide more lighting to the space, the effect was also to increase the efficiency of the lighting system. Examples of these are the placing mirrors behind candles and lamps in order to reflect light into the room from walls and the sinumbra variation of the Argand burner lamp. And this has especially been the case with electric lighting. "Luminaire design has come a long way since the novelty of electric lighting made a bare bulb in a socket an acceptable approach."[72]

> Design approaches have changed significantly in response to the demand for energy conservation. This has in turn cause the development of more efficient reflectors, louvers, lenses, and other components of the optic system. The net result is lighting equipment that is exceptionally efficient without sacrificing quality.[73]

Through more efficiently utilizing the light that is being produced, smaller or fewer light sources are necessary to light a space to the same levels.

Photometrics is a method of quantifying these lighting characteristics.[74] It tracks three-dimensionally the level of light that is delivered by the lighting fixture. Currently, many manufacturers of luminaires provide photometric data for their luminaires. Through examining the photometric characteristics of different fixtures, a lighting fixture that disperses light in the way that most efficiently makes use of the light being produced in that particular space can be chosen.

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[72] Cook, 30.

[73] Benya, 130.

[74] Helms, 162-176.

Primary Advantages

One of the primary advantages of High Efficiency Luminaires is that the strategy is completely passive. It shares many of the advantages of High-Efficiency Light Sources while also avoiding many of the concerns. Installation of the luminaire is a one-time intervention and does not require ongoing user interaction like Conservation and Maintenance. Once the appropriate luminaire has been selected, there is no need for the oftentimes-complex and sometimes-ongoing task of commissioning, as is the case with Automatic Controls; the luminaire simply needs to be installed in the location indicated by the photometric profile. Finally, there is not the same concern over color rendition as there is with High-Efficacy Light Sources.

High-Efficiency Luminaires also offer many opportunities for synergistic use with other energy-efficient lighting strategies. Foremost among these is the simultaneous use with High-Efficiency Light Sources. However, Lux/Footcandle Reduction and Multi-Level Lighting also provide a significant opportunity for synergistic use. High-Efficiency Light Sources can allow the level of illumination in a space to be more effectively reduced. Lux/Footcandle Reduction is frequently limited by the reality that the part of the space least illuminated by the luminaire is the part that is reduced to the target level of illumination. Other parts of the space may still be overlit, but the light output of the luminaire cannot be further reduced because the dimmer parts of the room will consequently become underlit. However, through the more effective distribution of light, High Efficiency Luminaires can help overcome this limitation. In spaces making use of Multi-Level Lighting, High-Efficiency Luminaires can be used to produce lighting that is specific to the task, making it possible to further reduce energy consumption. And, High-Efficiency Luminaires can be used in conjunction with Parallel, High-Efficiency Lighting Systems—discussed later this chapter—thereby increasing the efficiency of the system or allowing more discrete placement through the use of luminaires designed to distribute light in a specific way.

Figure 11: The basement level of the Second Bank of the United States in Philadelphia. The indirect and floor-mounted luminaires are unlikely to be mistaken for “historic” lighting.

Finally, the strategy can have an advantage specifically for use in some preservation projects. Most High-Efficiency Luminaires are notably of contemporary design. This can be used to advantage, as they would be clearly discernable as a contemporary addition. Preservationists could use these luminaires to illuminate spaces in ways completely different from their historic lighting, or to illuminate spaces that may never have had a lighting system, or to light spaces for which the historic lighting design is unknown or insufficiently known. The contrast created by the clearly contemporary luminaires can be used to reduce the chances of creating a lighting design that users and/or visitors might mistake for being historic or original. This can be seen in the basement level—and now ADA accessible entrance—of the Second Bank in Philadelphia (Figure 11).

Primary Concerns

The largest concern when using High-Efficiency Luminaires is that the strategy will likely have considerable impact on the form, fabric and function of the lighting system as the strategy inherently includes deviating from historic and/or existing luminaires. At the very least, existing and/or historic luminaires will have to be replaced with luminaires of a different design, sacrificing form and fabric. Consequently, these luminaires will likely be completely incapable of being used as reproductions. In addition to this, many High-Efficiency Luminaires make use of indirect lighting, an innovation that came to luminaires with electric lighting,[75] and even then not until the development of bright, ductile, tungsten-filament incandescent lamps in 1911 made it practical.[76] This leaves a large swath of buildings and building types that were not designed to be indirectly illuminated by the luminaires. For these buildings, indirect lighting can represent a considerable deviation in the function of the space and/or lighting system and can have a significant effect on the appearance of the space.

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[75] Lynne Elliott and Gordon Bock. "Lights for a New Century" Old-House Journal 21.6 (1993): 28.

[76] Cook, 30.

Summary

High-Efficiency Luminaire							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	N	N	R	A	A
Fabric	N	N	N	N	R	N	N
Function	N	N	N	N	R	A	N

Pros:

- High efficiency lighting fixtures are usually also designed with lighting quality in mind.
- Most high efficiency fixtures are of modern design; therefore, the principle of juxtaposition can be used to clearly set these fixtures apart from the historic components of the building.

Cons:

- The form, fabric and perhaps function of existing/historic luminaires will be considerably compromised.
- Many historic spaces were not designed to be indirectly illuminated and therefore the indirect lighting utilized by many High-Efficiency Luminaires will likely impact the appearance and character of the space.
- The reality that most high efficiency fixtures are of modern design means that they will almost certainly not be able to be used as historically accurate reproductions.
- A sophisticated analysis of existing fixtures in order to make comparisons is cost prohibitive.

PARALLEL, HIGH-EFFICIENCY LIGHTING SYSTEM

Adding another lighting system may seem like a contradictory means of achieving greater efficiency, but it is at the heart of this strategy. Through adding a parallel lighting system that has a higher efficiency, the original lighting system can be relegated only to those lighting tasks that justify its retention. All other lighting tasks are then served by the more efficient lighting system. The Parallel, High-Efficiency Lighting System allows for the use of the less efficient existing/historic system to be minimized. This reduction can be preventative, using the Parallel, High-Efficiency Lighting System to avoid the need to expand an existing/historic, inefficient system in order to meet new lighting needs, especially higher illumination levels that may be needed for life-safety. The reduction can come from allowing for the reduction of the frequency and/or duration of use of the less efficient, existing/historic lighting. For example, the inefficient, but historically accurate lighting in a house museum could be used only when visitors are space, or even only for a period long enough for visitors to see the historically accurate lighting, while the remainder of the usage could be served by the Parallel, High-Efficiency Lighting System. Or, the savings can come from using a Parallel, High-Efficiency Lighting System in conjunction with Lux/Footcandle Reduction.

Primary Advantages

For preservation projects, the biggest advantage of this strategy is that it allows for flexibility in the lighting design of a space that does not affect the current lighting system. This approach can be especially useful in situations where the existing/historic lighting system is insufficient for current lighting needs. The use of a high-efficiency parallel system can eliminate the need to replace the original system with one that can serve the needs of the current use or the current lighting requirements of the space. It can also eliminate or the need to increase the size of the current lighting system, which could in turn compound the high energy consumption and perhaps even destroy the historic character that justifies the retention of the original lighting in the first place.[77]

This was the approach used in the restoration of the Wang Center—originally the Metropolitan Theater—in Boston in the late 1980s. It was important to illuminate the space in a way that was appropriate for the rich Art Deco interior. This meant retention of the incandescent lighting system. However, this lighting system consumed 155 kilowatts, an amount that could be justified for the brief periods of patron seating and intermissions, but not for cleaning, maintenance and rehearsals. Therefore, the lighting design by Fisher Marantz Renfro Stone, Inc. included a parallel metal halide system that could be used during non-performance times. The metal halide fixtures were discretely placed so that they were almost invisible to the audience during and consumed only 10% of the energy consumed by the incandescent lighting system.

A Parallel, High-Efficiency Lighting System provides opportunities to work synergistically with other energy efficient lighting strategies. Foremost among these is Lux/Footcandle Reduction and Multi-Level Lighting. The parallel system can allow the light output to be reduced even further than they might otherwise be capable. It can relieve historic/existing lighting systems of the need to be bright enough for life-safety or

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[77] This is one of the strategies proposed by energy-efficient lighting expert Lisa Heschong. An additional advantage for the energy efficient professional who is not well-versed in historic preservation is the ability to avoid interfering with the historic lighting system entirely and thereby avoid the possibility of unintentionally altering it in an unacceptable way.

contemporary use, or allow them to be relegated to use as accent or "mood" lighting, and therefore allow their light outputs to be reduced even further.

Primary Concerns

The primary concerns over the use of a Parallel, High-Efficiency Lighting system have to do with its potential impact on the appearance of a room. First among these concerns is the intrusion of the lighting system itself, especially considering the temptation to install a system that is meant to appear "historic:"

> …while mixtures of historic fixtures with indirect supplements or with modern task lights can be successful, mixtures of periods seldom are: Victorian gasoliers will not look well with Georgian sconces. One light source should be allowed to dominate. A lovely art glass luminous bowl fixture can be easily supplemented by a pattern of fully-recessed ceiling spotlights, but visible track lights on either side would be far more disruptive and visually competitive. With all the more satisfactory options available, such hasty compromises should be avoidable, and harmonious solutions should be possible to overcome any combination of functional and esthetic problems.[78]

The solution is fairly simple, but requires attention to detail. The new system needs to be introduced discretely so that it has minimal visual impact. Advancements in lighting technology, especially the miniaturization of light sources and the use of modern optics make it easier to install an "invisible" lighting system.[79] When it is visible, it may also need to be designed in such a way that it is unmistakably a later addition.

However, the intrusion of the system itself is not the only concern about the effect that the addition of a Parallel, High-Efficiency Lighting System may have on the appearance, and thus the form, of a space. The efficiency of the new system will most likely come from either the light sources or the luminaires. Therefore, most of the

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[78] Helms, 37.

[79] Ramsbusch, 28.

concerns about the impact of High-Efficiency Light Sources and High-Efficiency Luminaires can potentially apply. The added lighting system could potentially introduce light sources with different color rendering characteristics or, very likely, luminaires that will illuminate the space in a way different from the historic/existing lighting design. The appropriateness of these potential impacts would have to be evaluated for each individual preservation project.

A more practical concern is the effect of the installation of a Parallel, High-Efficiency Lighting System itself. The system will likely require the addition of new wiring and the mounting of new luminaires. These intrusions can damage the fabric of the building. And, although the intrusion can be minimized through good design, and may be reversible, the desire to minimize the impact on the fabric of the building may have to be balanced against the desires to minimize the appearance of the system and to maximize the effectiveness of the lighting design of the new system.

Summary

Parallel, High-Efficiency Lighting System							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	N	N	N	N	A
Fabric	N	N	N	N	N	N	A
Function	N	N	N	N	N	N	N

Pros:

- Existing/historic lighting systems are completely unaffected.
- The parallel lighting system can be used to serve modern lighting needs, such as accent lighting of architectural details or objects, life-safety, etc., and thereby avoid using historic lighting in manners that may not be historically accurate or appropriate.

Cons:

- Impacts on the rendering of colors and the historic/existing lighting design of the space may be introduced by the new system.

- Optimal positions for lighting can likely already be taken up by the existing/historic lighting system, so the parallel system may be relegated to less than optimal places.

- The parallel system will likely require the introduction of new electrical wiring and luminaire mountings into the existing/historic fabric.

Replace the Lighting Technology with a More Efficient Technology

This is one of the more drastic approaches to increasing lighting energy efficiency. However, when energy efficiency improvements are considered within the larger context of making lighting "better," this strategy has seen great historic use. It involves more than just the alteration of an existing lighting system—such as the replacement of an Argand burner in an oil lamp with a kerosene burner, the addition of a Welsbach burner to an existing gas lighting fixture, the replacement of an incandescent lamp with a compact fluorescent lamp, even the replacement of an entire lighting fixture—it involves replacing the lighting system of one lighting era with that of another. The shift from gas lighting to electric lighting is the most recent example of this strategy.

With the current landscape of lighting technology usage, few preservationists are likely to encounter a lighting system from a previous lighting era still in use. However, many restoration projects are going to confront this question: does the restoration include reintroducing a lighting system that belongs to a past era, or will a lighting system from a later era be utilized? When the approach to lighting in historic spaces is considered in this way, this strategy gets far more usage than it might seem. It is a simple reality that most projects will, almost by default, include replacing historic lighting technologies. Additionally, this strategy may again become very pertinent for preservationists. The description of the methodology in Chapter 3 introduced the concept of different eras of lighting technology. Currently, we are in an era where electric lighting is the dominant lighting technology for buildings, but that is not likely to always be the case. Even if fiber-optic lighting is not the lighting technology of the next lighting era, some other technology may be. When and if this happens, future preservationists will be faced with the question of whether to retain "historic" wire and lamp based systems or whether they will replace that technology with whatever technology has succeeded it in a new era.

There are two primary methods that one might pursue in utilizing this strategy in a preservation project—although, if form, fabric and function are not a priority, then there are far more methods. The first is the method that has dominated most transitions in eras in lighting technology: imitation. The historic/existing lighting system can be imitated with the new lighting system. Candle-shaped gas jets, candle-shaped electric lamp sockets with flame-shaped lamps, oil-lamp-shaped electric luminaires, etc. are all historic examples of imitation. The other method can be termed juxtaposition. This is the same approach that was suggested above in the discussion of High-Efficiency Luminaires. The new lighting technology can be introduced in a way that makes it clearly discernable from the historic/existing lighting technology.

Primary Advantages

The advantages of this strategy are mostly of a pragmatic nature. New lighting technologies replace old lighting technologies because they are superior in some way. Oil Lamps produced more light than candles with less fuss. Gas luminaires produced more light more conveniently than either, and gas ultimately became cheaper than the oil for lamps. Electric lamps ultimately were able to continue that trend and represented an improvement on lighting quantity and convenience over previous technologies. This trend may continue with future lighting technologies, or perhaps the emphasis that energy efficiency has had over the last several decades will mean that the next lighting technology's superiority will be based on energy efficiency. Regardless of its basis, that superiority is one of the primary advantages of replacing the lighting technology of past eras with the lighting technology of the current era.

Another pragmatic advantage of utilizing the lighting technology of the current era is the ease use that comes from prominence. The production and labor capacity, and the regulation, of the lighting market caters to the current lighting technology. It is no small matter to go to a hardware store and buy a new lamp, lamp socket, wiring, switch or receptacle or to open the phone book and find a large selection of electricians who can install or repair that lighting system. However, one would have to do considerable research in order to find replacement parts for a gasolier, or a person with the expertise to install or repair it. Beyond these technical concerns is the concern over regulation. Safety is frequently one of the reasons for a new lighting technology overtaking an older one, and the older technology is frequently consequently prohibited by contemporary regulations.[80]

Primary Concerns

The primary concern is clearly the significant impact on form, fabric and function that is involved. New lighting technologies frequently have different lighting characteristics, which can affect the appearance of spaces. They frequently have different distribution systems or control mechanisms that will need to be incorporated into existing buildings, which can have a serious impact on the fabric. Sometimes luminaires can be converted to accommodate new lighting technologies—as was the case with the electrification of candle luminaires and gasoliers—but that is not a universal truth and the

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[80] Moss, 11-12.

adaptation will still almost certainly have an impact on the fabric of the existing luminaries and will likely have at least some impact on the form.

Previous transitions between eras of lighting technology have demonstrated both how significant these impacts can be and how they can be mitigated. Anyone pursuing this strategy would do well to consider these past examples.

> There is a tendency to forget that these same issues came up when electricity was first introduced, and that a vast number of buildings with no provisions for this new system had to be retrofitted in some practical manner. […]
>
> Early electric lighting fixtures, thus, deserve more recognition as appropriate lighting in reuse and restoration of historic buildings. They offer a fascinating study of how new technology and old esthetic sensibility react and interact to produce a succession of styles, until a general consensus is reached as to the "right" form for the function.[81]

Summary

Replace the Lighting Technology with a More Efficient Technology							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	R	R	R	R	R	R	A
Fabric	R	R	R	R	R	N	A
Function	R	R	R	R	R	N	A

Pros:

- Great capacity for savings since the lighting needs can be completely served by the latest, most efficient lighting technology.
- Completely new lighting systems can be introduced so as to clearly read as being new and not historic/original, thereby avoiding confusion about what is and is not historic/original.

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[81] Cook, 29.

Cons:

- The existing/historic lighting system will be completely or nearly completely lost.

INCREASE THE REFLECTIVITY OF THE SURFACES IN THE SPACE

Basic color theory tells us that the color rendering of surfaces is dependent on how much of the spectrum of visible light the surface absorbs and how much it reflects. In general, lighter colors reflect more frequencies of light from the visible spectrum—therefore more light is reflected back into the space—and darker colors reflect fewer. This reality is the center of the strategy. It expands the concept of using more efficient luminaires to the entire space. Through increasing the reflectivity of the surfaces in the space, less of the light that is produced by the lighting system is absorbed by the surfaces and more is reflected back into the space in order to provide illumination.

Apparent color can be a poor indicator of how much light it will reflect: "What most designers would probably consider medium to light tones reflect less than 30 percent of the light."[82] In addition, color is not the only factor, and therefore other characteristics of the surface can affect how light is reflected. In fact, apparently different colors of materials can reflect the same amount of light.[83] Therefore, increasing the reflectivity of a space may not necessarily involve changing the color. The reflectivity of the surfaces in the space influences not only the actual amount of light in the space, but also the users' perception of the brightness of a space.

> The luminance of vertical surfaces is important for maintaining visual comfort and for generating a sensation of overall brightness in a specific space. Occupants perceive more light on task objects when the surrounding vertical surfaces are well lighted. Likewise, they can perceive insufficient light on task objects when vertical surfaces are dark, even when the horizontal footcandles on the task objects are identical.

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[82] McKay, 112.

[83] *Ibid.*

> Repainting interior walls a lighter color, for example, will add brightness to a space without any additional energy use."[84]

Primary Advantages

The foremost advantage of the strategy is that it has the potential to have absolutely no impact on the form, fabric and function of the historic/existing lighting system. Lightening the color of the surfaces, the most straightforward means of pursuing this strategy, may have an impact on the form of the space, but the reflectivity of surfaces can be increased without changing the color through the selection of especially reflective pigments. Other advantages include the potentially minimal and reversible impact on the form and fabric of the space. Paint does not have an infinite lifespan and therefore the time and expense involved in preparing and repainting the surfaces would occur periodically anyway. This strategy has long been used to increase the brightness of the space, and therefore for many preservation projects, light colors may be more historically appropriate for the spaces.

Primary Concerns

The primary concern is that a light-colored scheme for the surfaces in a space may not be historically accurate and special reflective pigments of the right color may not be available, cost effective or effective enough. Artistically, architecturally and historically significant color schemes could be lost to a sea of white. This may seem extreme, but high levels of reflectivity are required for the effectiveness of the strategy, as high as 70 to 80 percent reflectance values for ceilings and 50 percent and above for walls.[85] Even if these lighter colors are historically accurate or appropriate, the application of additional

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[84] Energy Efficient Lighting and Maintenance Manual, 13. See also McKay, 112-3.

[85] McKay, 113.

layers of paint can be a concern itself. Architectural details, moulding profiles, etc. can all be obscured by thick layers of paint.

Another primary concern is that, like Vigilant Maintenance, this is a preventative strategy for energy efficient lighting. It saves no energy in and of itself, but can only act to prevent the need to introduce compensatory lighting into an underlit space. It must be used in conjunction with Lux/Footcandle Reduction or to augment the usefulness of Daylighting if it is to reduce the energy consumption in an existing setting.

Summary

Increase the Reflectivity of the Surfaces in the Space							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	N	N	N	N	A
Fabric	N	N	N	N	N	N	A
Function	N	N	N	N	N	N	N

Pros:

- No impact on the lighting system itself.
- Lighter surfaces may be more historically accurate or appropriate.

Cons:

- Lighter or more reflective surfaces may not be historically accurate or appropriate.
- Savings are contingent on a corresponding reduction in the lighting in response to improved performance.

DAYLIGHTING

It is an obvious statement, but it bears making: the sun is the source of a tremendous amount of light. Therefore, the more that a space can utilize that light for its lighting needs, the less artificial light will be required. This should be even more obvious to preservationists, as many of the buildings with which they are concerned were built with daylight as the primary source of light and were therefore designed to maximize the utilization of daylight in the spaces. Light wells, clerestories, spatial arrangements where reading chairs and work surfaces are located near windows, large windows and high ceilings in industrial spaces, etc. are all examples of the historic utilization of daylight. These, and other methods of bringing daylight into a space, serve as the foundation for the strategy of daylighting. Artificial light sources are turned off when available daylight is sufficient for the use of the space.

For Daylighting to save energy, it must be coupled with some means of controlling the artificial light in the space.[86] Conservation and Automatic Controls are the obvious choices, both effectively turning artificial lighting off when the daylight is sufficient for lighting needs. Lux/Footcandle Reduction and Multi-Level Lighting are somewhat less obvious. Daylight can be used to reduce the amount of light that must be generated by artificial lighting or daylight can be used for ambient lighting while additional, artificial light is used for other tasks.

In existing buildings, Daylighting can be implemented primarily in two ways. The first is to make better use of the existing daylight in a space. This means removing

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[86] Poole, 63.

obstructions that block daylight, opening operable window coverings, and maybe even rearranging spaces so that the tasks are positioned in places that can make use of the existing daylight. The other, and more intrusive, implementation involves the introduction of more daylight into a space. This may be accomplished through the enlargement or addition of windows or skylights. It might involve the removal or fenestration of interior walls so as to give interior spaces access to "borrowed" light from spaces with access to daylight.

Primary Advantages

For many preservation projects, pursuing Daylighting is actually a more historically accurate and/or appropriate lighting design.

> Almost all buildings built before 1940 were designed to be illuminated primarily from the daylight...so they are a great opportunity to "restore" the daylighting, by removing the old "kludges" and improving the electric light distribution and controls to take advantage of the original design. In many historic buildings the skylights have been painted over, the ceilings lowered (cutting high old windows in half), partitions added.[87]

For a large portion of the buildings with which preservation is concerned, daylighting was the assumed norm, not an edgy, "green" approach to building design. Therefore, striving for historical accuracy in a preservation project may not just allow for the inclusion of Daylighting, but may actually demand it.

Another advantage of Daylighting is that it can supplant a large portion of the artificial lighting needed in a space. This is especially the case in those historic buildings that were specifically designed to utilize Daylighting. Because daylight is produced by the sun rather than artificial light sources, it is effectively infinitely efficient. Even when

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[87] Lisa Heschong, personal e-mail, 8 April 2006.

daylight can only supplant smaller portions of the artificial light in a space, every bit is pure energy savings, rather than the mitigation of energy usage that is provided by High-Efficiency Light Sources.

Finally, recent research strongly suggests that daylight has significant non-energy efficiency advantages. Studies conducted by the Heschong Mahone Group, Inc., suggest that the availability of daylight in a space can improve the productivity of workers in offices, the test scores of students in schools and the sales performance of retail spaces.

Primary Concerns

Several serious concerns face pursuing Daylighting in preservation projects. Many of these center around the complications involved in bringing daylight into a space. Perhaps foremost among these for preservation projects is the concern of the impact that daylight can have on historic fabrics, finishes and other materials. Daylight poses two dangers to historic fabric: the intensity of daylight and the full-spectrum nature of daylight. With illumination levels in the thousands of footcandles on even cloudy days, daylight can put a significant amount of light into a space. However, even at lower light levels, the penetration of the Ultra-Violet end of the light spectrum can also cause damage to historic fabric. Both intensity and UV exposure can be mitigated through the use physical controls of the light or special coatings on glass, but the former requires either user intervention or some sort of automatic control and the latter can affect view quality and involves a capital investment.

Color rendition can also be a concern:

> Although the color of an electric light source may be specified and relatively constant (ignoring gradual, predictable changes of the life of the lamp), the color of

> daylight is complex and dynamic. It changes at different times of the day and year, and fluctuates based on weather conditions, pollution levels and building orientation. […]
>
> Except during the sunrise and sunset hours, daylight falls toward the cool (blue) end of the color spectrum. Sunlight is about 5000K in color temperature; an overcast sky is 6500-7500k; and a clear blue northwestern skylight peaks above 20,000K. [88]

This reality can, of course, contribute to historical accuracy in buildings that were designed to be daylit, but can alter the impression of colors in buildings that were not designed to be daylit.

Finally, in buildings that were not designed to be daylit, the introduction of Daylighting could require significant alteration of the building's form and fabric. The introduction or enlargement of windows and/or skylights has serious consequences on the fabric of the building both in terms of opaque wall lost and in terms of casements and frames that will subsequently be the wrong size and therefore useless. Such alterations will also have a significant impact on the form of the building, especially considering that window size and placement is such a significant factor in many architectural styles. That impact can be mitigated through good design and advanced materials as is the case of the Thresher Building,[89] but it is an impact that must be considered nonetheless. The form of the space can be impacted in one additional way. Daylight can be brighter, have different color rendition and will be far more variable than artificial lighting, and any or all of these can lead to the character of the space itself can being seriously altered.

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[88] Barbara Erwine. "The Power of the Sun: Integrating Daylight and Electric Light," Architectural Lighting Apr.-May 1996: 56-7.

[89] "Harvesting Light: Thresher Building, Minneapolis, Minnesota." Progressive Architecture Apr. 1985: 83-85.

The designers of the Thresher Building rehabilitation avoided altering the historic façade of the structure by utilizing "passive solar optics," a combination of specially designed roof apertures, faceted reflective surfaces and optimized openings in the floors, to bring daylight into the deeper areas of the building.

There are additional concerns that are less specific to preservation projects. Among these is the reality that Daylighting is not, itself, an energy-saving strategy. As mentioned above, and like Vigilant Maintenance and Increase the Reflectivity of the Surfaces in the Space, it must work as a preventative measure or it must be coupled with another energy efficient lighting strategy that can reduce the energy consumption of the artificial lighting in response to the available daylight. Additionally, daylight presents design problems:

> To use daylight effectively in energy-conscious design, however, the designer faces a considerably more difficult problem. First, the light must be directed to the work area. Second, it must be of an appropriate level (illuminance) for the work tasks. And finally, there should be means to control and compensate for its many variations, and seasonal differences in solar angle."[90]

Like Multi-Level Lighting, Daylighting poses a significantly more difficult lighting design problem than simple, uniform lighting. Considering the variability of daylight, automatic controls may be necessary just to make Daylighting feasible for some preservation projects. As a last pragmatic lighting concern, Daylighting is (obviously) only feasible during the day and will not be of any benefit for night-time use.

Finally, daylighting can have an impact on the temperature/humidity conditioning of a space. Daylight constitutes a heat load in the space.[91] If a space is mechanically cooled, offsetting the potential heat-gains from the added daylight can actually result in a net gain in overall energy consumption. If a space is not mechanically cooled, this heat load can make the space excessively uncomfortable. Therefore, in order to make use of Daylighting, the problem of additional heat loads must be addressed.

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[90] Benya, 127.

[91] *ibid.*

Summary

Daylighting							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	N	N	N	N	A
Fabric	N	N	N	N	N	N	A
Function	N	N	N	N	N	N	A

Pros:

- Can be more historically accurate as many historic spaces were designed to be daylit.
- Can supplant a significant portion of the electric lighting use, depending on the configuration of the space.

Cons:

- Savings are contingent on the ability to reduce electric lighting in response to the available daylight.
- The retrofit of spaces that were not designed to be daylit can be a very intrusive and/or costly intervention.
- Unless controlled or filtered, daylight can be damaging to historic fabric such as fabrics and pigments.
- No savings for night use of spaces.

Efficiency Elsewhere / Average Efficiency

It is possible that the primacy of the desire for authenticity in the lighting of a space could make any and all interventions into the lighting system in a preservation project inappropriate, and the efficiency gains of active conservation and maintenance insufficient for goals of energy conservation. In this situation, preservationists can follow the example of the LEED and Energy Star rating systems and simply concentrate their energy efficiency efforts elsewhere. Most spaces are rarely isolated systems, most are part of a larger building, and sometimes these buildings are but one building in a larger complex of buildings. Therefore, even though a lighting system in a particular space may provide no appropriate opportunities for further improving the energy efficiency of the lighting, the larger collection of spaces and/or systems may provide the potential to increase the *average* efficiency. Even buildings seeking high levels of historic accuracy frequently have auxiliary spaces where the authenticity of the form, fabric or function of the lighting system is not a priority, or as high a priority. These spaces provide opportunities to improve the average efficiency of all the lighting systems in the building or complex. However, in order to raise that average efficiency, the lighting in those other spaces can be pushed to levels of energy efficiency well above average levels.

Primary Advantages

Quite simply, the greatest advantage to Efficiency Elsewhere / Average Efficiency is that it has absolutely no impact on form, fabric or function. There are no consequences to be weighed and no long-reaching implications to be found. If the effects of pursuing the other strategies outlined above have proven to be unacceptable in a particular preservation project, this strategy can allow that project to still realize savings beyond simple Conservation and Vigilant Maintenance. This can be used to diplomatic advantage for preservation projects under significant pressure from outside forces to improve the energy efficiency of the building. Combined with the clear reasoning provided by systematically evaluating the effects of the strategies described above, it demonstrates that resistance to these other strategies is not just a matter of preservationists being obstinate and hostile to energy efficiency.

Primary Concerns

The concerns about using Efficiency Elsewhere / Average Efficiency are of a practical nature. Associated spaces with little or no historical, architectural, artistic, culture, etc. significance must be available, and must be available with energy sufficient consumption from lighting that improving its energy efficiency will have a discernable impact on the average efficiency of the entire building or complex. Additionally, the lighting system used in these associated spaces will have to be significantly more efficient than the lighting systems in the rest of the building and/or complex or else it will also have little impact on the average efficiency of the building or complex. This can require an especially costly lighting system.

Summary

Efficiency Elsewhere / Increase Average Efficiency							
	Fuel Source	Fuel Distribution	Operation / Control	Light Source	Luminaire	Placement / Position	Characteristics of the Space
Form	N	N	N	N	N	N	N
Fabric	N	N	N	N	N	N	N
Function	N	N	N	N	N	N	N

Pros:

- No impact of any kind on the space or lighting system.
- Represents a more sophisticated and holistic approach to energy efficiency that can be used to justify not altering the lighting of a space.

Cons:

- Savings contingent on the availability of other energy uses that can be appropriately and significantly altered.
- Does not truly improve the lighting efficiency of the space.
- Can involve high cost as the efficiency of the other energy uses must be significantly above average in order to offset the higher usage of unaltered lighting.

THE STRATEGIES: PREVENTATIVE VS. REDUCTIONARY

Although this chapter has treated each of the energy efficient lighting strategies separately, the content of the separate sections reveals that the strategies should not really be considered in isolation. A preservationist seeking to improve the energy efficiency of the lighting system in a historic building should not look to just one strategy. One motivation for categorizing the myriad approaches to improving the energy efficiency of lighting is to make it possible to conceptualize the whole body of approaches in a systematic way, which in turn also makes it possible to see how the different strategies can and sometimes must work synergistically. In fact, the preceding twelve strategies might each be more basically characterized as preventative and reductionary strategies: strategies that make it possible to decrease the energy consumption of the lighting system and those that actually reduce the energy consumption of that lighting system. Vigilant Maintenance, Multi-Level Lighting, Parallel High-Efficiency Lighting Systems, Increasingly the Reflectivity of the Surfaces in the Space, and Daylighting do not actually reduce energy consumption, but rather make it possible to reduce energy consumption through one or more of the reductionary strategies: Conservation, Lux/Footcandle Reduction, Automatic Controls, High-Efficiency Light Sources, High-Efficiency Luminaires, Replacing the Lighting Technology with a More Efficient Technology and Efficiency Elsewhere / Average Efficiency. Thinking of the strategies in this way can help the preservationist make use of them to the greatest potential.

Historic buildings face many pressures for change. Like changing standards of style, life safety, convenience and building amenities, shifts in city use patterns and building uses and the simple entropy of all complex structures, the drive for energy efficiency and sustainability in architecture is one of those pressures. Preservation is a critical act. Ironically, a historic building must often be changed in order to be preserved, and this is the reality with energy efficiency. Whether by regulation, public pressure, or simple economics, many historic buildings will have to become more energy efficient if they are to continue to exist. Historic buildings cannot be just museum collections and preservationists their curators; preservationists must be able to manage change in such a way that historic buildings can change enough to find continued use while what is significant about them is retained.

The framework offered in the preceding chapters should bridge that information gap between historic preservation and energy efficient lighting and allow preservationists to successfully respond to those pressures. Preservationists already have the tools they need to assess the appropriateness of pursuing certain interventions and their accompanying impacts. However, for energy efficiency in general—and energy efficient lighting in particular—the information gap identified in this thesis can be a significant barrier to preservationists being able to mange the change that the pressure of energy efficiency often demands. Through taking a large and unwieldy body of energy efficient lighting approaches and offering a concise way to conceptualize them and identifying the potential impacts and synergies with preservation of these underlying strategies, this framework should be able to remove, or at least diminish, that barrier without necessitating that preservationists also be energy efficiency experts.

Lighting is just one of many systems in a building that consume energy, and the need for energy efficient lighting is just one area that puts pressures for change on historic buildings. Therefore, while the framework presented in this thesis may go some way toward bridging the gap between historic preservation and energy efficient lighting, there still exists an information gap between historic preservation and energy efficiency as a whole. Hopefully this model can be applied to those other arenas as well.

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