LIGHTING EFFICIENCY FEASIBILITY STUDY OF
THREE OHIO UNIVERSITY BUILDINGS

A thesis presented to
the faculty of
the College of Arts and Sciences of Ohio University

In partial fulfillment
of the requirements for the degree
Master of Science

Jahan Kariyeva
June 2006
This thesis entitled
LIGHTING EFFICIENCY FEASIBILITY STUDY OF
THREE OHIO UNIVERSITY BUILDINGS

by

JAHAN KARIYEVA

has been approved for
the Program of Environmental Studies
and the College of Arts and Sciences by

Dorothy Sack
Professor of Geography

Benjamin M. Ogles
Dean, College of Arts and Sciences
Abstract

KARIYEVA, JAHAN, M.S., June 2006, Environmental Studies

LIGHTING EFFICIENCY FEASIBILITY STUDY OF THREE OHIO UNIVERSITY BUILDINGS (72 pp.)

Director of Thesis: Dorothy Sack

This thesis aims to evaluate the lighting efficiency of three Ohio University campus buildings. The primary research question is: What are the short- versus long-term costs and benefits to Ohio University of renovating the lighting systems of these older buildings? The research was conducted as a case study with examination of two subquestions: What types of lighting fixtures are currently being used and how efficient are they? How efficient can proposed lighting fixtures be? Results indicate that the cost of installing more energy-efficient lighting fixtures can be quickly recaptured in older buildings. With replacing the present lighting fixtures Ohio University would pay approximately 2.5 times less than it pays currently for the lighting utilities cost of the case study buildings. With these energy savings it would take 3 to 4 years to reclaim the money spent for reinstallation of the energy-efficient lighting fixtures.

Approved:

Dorothy Sack

Professor of Geography
Acknowledgments

I am deeply grateful to Andy Sinozich, Cinergy Solutions Project Manager, for his continuous support and willingness to share his invaluable experience and environmental audit techniques and skills. Some of this support appeared in the help that was provided by Terry Conry, Ph.D., Associate Vice President for Finance and Administration, Facilities and Auxiliaries, Facilities Management; Joe Fabiny, Director, Standards and Support Services, University Planning and Implementation; and Ron Chapman, Director, Energy Management, Maintenance and Operations.

I am very thankful to Associate Professor Michele Morrone for her bright suggestions and thoughts. Associate Professor Geoffrey Buckley deserves exceptional thanks for all his insights and ideas that he shared with me during the research. I am extremely grateful to Professor Dorothy Sack for her support with her incomparable considerate and tactful guidance through the compiling and writing processes.

I owe thanks to my dearest friend Tehsin Aurangabadwala, Ohio University MSES student, as the person who gave me tremendous moral support during the entire period of graduate study and particularly the thesis project time. Murad, my beloved husband, earns an exceptional word of thanks for just being always here for me and providing me all the strength and support that I needed. I also would like to acknowledge my parents who provided me an educational and intellectual background without which I would not be able to accomplish my present achievements.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>3</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>4</td>
</tr>
<tr>
<td>List of Tables</td>
<td>7</td>
</tr>
<tr>
<td>List of Figures</td>
<td>8</td>
</tr>
<tr>
<td>Chapter 1: Introduction</td>
<td>9</td>
</tr>
<tr>
<td>Purpose</td>
<td>9</td>
</tr>
<tr>
<td>Rationale</td>
<td>13</td>
</tr>
<tr>
<td>Chapter 2: Study Area</td>
<td>16</td>
</tr>
<tr>
<td>Chapter 3: Literature Review</td>
<td>20</td>
</tr>
<tr>
<td>Principles of Sustainability</td>
<td>20</td>
</tr>
<tr>
<td>Sustainable Architecture</td>
<td>22</td>
</tr>
<tr>
<td>Environmental Auditing Tool</td>
<td>25</td>
</tr>
<tr>
<td>Universities and Sustainability</td>
<td>28</td>
</tr>
<tr>
<td>Chapter 4: Methods</td>
<td>34</td>
</tr>
<tr>
<td>Data Collection</td>
<td>35</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>37</td>
</tr>
<tr>
<td>Lighting Analysis</td>
<td>38</td>
</tr>
<tr>
<td>Current energy consumption from lighting</td>
<td>38</td>
</tr>
<tr>
<td>Energy consumption of the proposed lighting fixtures</td>
<td>39</td>
</tr>
<tr>
<td>Environmental Health and Safety</td>
<td>42</td>
</tr>
<tr>
<td>Chapter 5: Results</td>
<td>43</td>
</tr>
<tr>
<td>Existing Historical Information</td>
<td>43</td>
</tr>
<tr>
<td>Results from Field Observations</td>
<td>45</td>
</tr>
<tr>
<td>Lighting</td>
<td>45</td>
</tr>
<tr>
<td>President Street Academic Center lighting analysis</td>
<td>48</td>
</tr>
<tr>
<td>Research and Technology lighting analysis</td>
<td>50</td>
</tr>
<tr>
<td>Bentley Hall lighting analysis</td>
<td>51</td>
</tr>
<tr>
<td>Environmental Health and Safety Analysis</td>
<td>52</td>
</tr>
<tr>
<td>Environmental health and safety analysis of the President Street Academic Center building</td>
<td>52</td>
</tr>
<tr>
<td>Environmental health and safety analysis of the Research and Technology building</td>
<td>58</td>
</tr>
</tbody>
</table>
### List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2.1</td>
<td>Ohio University total utility data for fiscal year 2004-2005</td>
<td>16</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Lighting-related variables collected from each room in the three buildings</td>
<td>36</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Environmental health and safety variables</td>
<td>36</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Lighting variables calculated</td>
<td>41</td>
</tr>
<tr>
<td>Table 5.1</td>
<td>Summary of the current and proposed luminaire numbers</td>
<td>51</td>
</tr>
<tr>
<td>Table 5.2</td>
<td>President Street Academic Center environmental health and safety summary</td>
<td>57</td>
</tr>
<tr>
<td>Table 5.3</td>
<td>Research and Technology environmental health and safety summary</td>
<td>59</td>
</tr>
</tbody>
</table>
List of Figures

Figure 1.1: Thesis research case study buildings............................................................. 10
Figure 1.2: President Street Academic Center building (built in 1910) ......................... 12
Figure 1.3: Research and Technology building (built in 1948)....................................... 12
Figure 1.4: Bentley Hall (built in 1923)........................................................................... 13
Figure 5.1: T12 fluorescent lamp..................................................................................... 45
Figure 5.2: T8 trichromatic phosphor lamp...................................................................... 46
Figure 5.3: 75-watt incandescent bulb lamp................................................................. 47
Figure 5.4: Light-emitting diode one compact fluorescent lamp..................................... 47
Figure 5.5: T8 trichromatic phosphor U-shaped bulb lamp............................................. 49
Figure 5.6: Shape alteration and destruction of hygiene gloves...................................... 53
Figure 5.7: Shape alteration of plastic soda bottles......................................................... 53
Figure 5.8: Dripping water from ceiling.......................................................................... 54
Figure 5.9: Standing water and mold on the floor with fallen ceiling pieces............... 54
Figure 5.10: Mold on the room walls............................................................................. 55
Figure 5.11: Falling ceiling presents a health threat......................................................... 56
Figure 5.12: Falling ceiling presents a health threat......................................................... 56
Figure 5.13: Continually turned on computers in Bentley Hall classrooms ................. 62
Chapter 1: Introduction

Purpose

Each campus of an institution of higher education is like a city in miniature, an isolated and autonomous bionetwork with its own energy, food, transportation, and water systems. The unique role of university campuses is that while offering educational resources to the public they concurrently have unnecessary effects on the same society. The educational resources that campuses offer include future scholars and specialists. Through their extensive footprint on the natural environment, such as waste generation, exploitation of natural resources, and emission of thousands of tons of pollution due to massive use of transportation and to energy-consumptive buildings, the campuses make a significant impact on the environment and therefore on society. Ohio University is an excellent example of a campus ecosystem that provides a strong sense of community and influences societal change through its academic mission. At the same time, it has a tremendous effect on its surrounding physical environment.

Ohio University’s main campus comprises 1,700 acres encompassing about 160 old and new structures, including dormitories, laboratories, lecture halls, office space, and support buildings. The university provides an exceptionally dynamic, lively, and challenging place to study, work, and live for its students, faculty, and staff. The university is constantly in the process of planning, constructing, and renovating campus buildings. New buildings are typically constructed when the university needs additional space. In most cases, the energy efficiency of the new buildings is not completely
known. Although it has almost continuous new building construction projects, Ohio University currently has several buildings that are not in use. The major reason for not using a building is that it is too inefficient and expensive to maintain. It is cheaper to keep these buildings closed and unused than to maintain them and pay tremendous utility bills.

Figure 1.1: Thesis research case study buildings

The purpose of this thesis is to assess the sustainability of three buildings on the Ohio University campus as one of the key components of campus sustainability (Figure 1.1). Since building sustainability addresses a very broad range of issues, I narrowed the focus to efficiency of current lighting fixtures and to environmental health and safety in
buildings. The core question of the project is: What are the short- versus long-term costs and benefits Ohio University can realize by renovating the lighting systems of two old buildings? To answer this question, the two following subquestions were examined: What types of luminaires (lighting units) are currently being used and how efficient are they? How efficient can proposed lighting measures be?

This thesis project is aimed at finding ways for making Ohio University buildings of different ages energy efficient through environmentally friendly approaches while cutting costs in energy utilities, raising environmental awareness among the faculty and students, and reducing the environmental impact of the university. This research is conducted as a case study of three Ohio University buildings. President Street Academic Center (Figure 1.2), Research and Technology (Figure 1.3), and Bentley Hall (Figure 1.4) have been selected for this purpose. In order to provide Ohio University with a realistic assessment of its sustainability problems and potential, a thorough analysis of the available lighting fixtures and systems and environmental health and safety efforts was implemented for each of these three buildings using environmental audit techniques. A major hypothesis of the research project is that the investment from installing more energy-efficient and ergonomic lighting fixtures can be recaptured quickly in older buildings, such as President Street Academic Center and Research and Technology. Bentley Hall’s luminaires are already as efficient and safe as they can be because of replacement of all old lighting fixtures with new more energy-efficient and safe fixtures as the part of its complete renovation in 2002-2003. Existing lighting fixtures in Bentley Hall, therefore, are not modeled to change.
Figure 1.2: President Street Academic Center building (built in 1910)

Figure 1.3: Research and Technology building (built in 1948)
Figure 1.4: Bentley Hall (built in 1923)

**Rationale**

Educational communities are among those which do not always wisely consume fuel, water, chemicals, ozone-depleting substances, and electricity; which over-generate solid, hazardous, radioactive, and biomedical types of wastes; which release pollutants; and which very often have building projects. According to the U.S. Department of Energy's Center of Excellence for Sustainable Development (2005), buildings consume 40% of the world's total energy, 25% of its wood harvest, and 16% of its water. The building industry is the nation's largest manufacturing activity, representing more than 50% of the nation's wealth and 13% of its gross domestic product (U.S. Department of Energy, 2005). Energy and material consumption in buildings can contribute
significantly to global climate change (U.S. Department of Energy, 2005).

Lessons learned from the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program and other regional, national, and global sustainable-design initiatives can be applied to the operation and planning of almost every U.S. college and university campus. College communities should be urged to embrace sustainability concepts in their day-to-day operations and long-term planning. Because of their unique role in delivering constructive messages to the public, through the full process of establishing the academic mission to implementing it, university campuses can be one of the best examples of sustainable development. Educational institutions can have a variety of diverse sustainability goals and can focus on any of the sustainability targets, such as environmental stewardship, green initiatives, and sustainability in general, which is sustainable consumption of resources and funds.

Pursuing environmental sustainability can offer significant benefits to colleges and universities. The campus that can carry out a successful and effective sustainability program will have fulfilled federal and state laws and regulations, saved money, and improved competitive advantages in recruiting faculty and students (Kenney et al., 2005). Faculty and students have to be made aware of the negative effects that significant energy usage produces in order to make environmental sustainability projects on campuses a success.

Considering its educational significance and large number of students, Ohio University can be an excellent model of environmental leadership. This research demonstrates how Ohio University can be more sustainable, and it discusses a number of
advantages of being a sustainable campus. These advantages can include saving money with cheaper operations, serving as a successful green role model for other institutions and other sectors of local and world communities, conserving resources, and protecting the environment.
Chapter 2: Study Area

Ohio University is located in the heart of Athens, Ohio. Athens lies in southeastern Ohio in the foothills of the Appalachian Mountains at the intersection of U.S. Highways 32 and 33. These highways lead toward the major cities of Cincinnati and Columbus, respectively. Established in 1804, Ohio University is the oldest public institution of higher learning in the state of Ohio and the first in the Northwest Territory. The total enrollment on the Athens campus is approximately 19,300, while the regional campuses enroll more than 8,100 additional students.

Ohio University’s electrical service is supplied by American Electric Power. Ohio University’s heating plant burns coal and natural gas to produce steam and domestic hot water for the entire campus. Utility details supplied by Ron Chapman (personal communication, 2006), who is Ohio University Renovation Project manager for Residence Auxiliary Services, are provided in Table 2.1.

<table>
<thead>
<tr>
<th>Utility</th>
<th>Consumption</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>119,571,639 kwh</td>
<td>$4,683,658</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>2,216,118 ccf</td>
<td>$2,111,497</td>
</tr>
<tr>
<td>Coal</td>
<td>26,651 tons</td>
<td>$1,083,257</td>
</tr>
<tr>
<td>Water/Sewer</td>
<td>218,279,000 gal</td>
<td>$1,503,139</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$9,381,551</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1: Ohio University total utility data for fiscal year 2004-2005
Ohio University is currently developing plans to improve campus facilities and provide a better academic and physical environment for everyone in the community by promoting attention to its sustainability efforts. In May 2003, the Ohio University Ecology and Energy Conservation Committee, partnering with the Campus Renewal Project, Campus Recycling, Cinergy Solutions, and the Department of Environmental Health and Safety, developed the environmental audit team of students, staff, and faculty who work together to conduct environmental audits of buildings on campus. The team reports their findings and recommendations to representatives of the departments in the buildings, as well as to Environmental Health and Safety, Facilities Planning, and Facilities and Auxiliaries. Students gain hands-on experience with environmental audits and can earn internship credit from the Departments of Geography and Environmental Health Science. Audit teams perform building-wide audits of energy and water usage, recycling efforts, and health and safety measures, and the university benefits from an audit of its facilities to identify opportunities for improving efficiency and reducing negative environmental impacts. The audits can help make the buildings more environmentally sound and energy efficient.

Another Ohio University attempt to promote principles of sustainability for both campus “citizens” and the local community is the Ohio University Ecohouse. The idea of illustrating how sustainable living can be a bottom-up strategy for promoting sustainability originated during the 2004 summer meetings of concerned Ohio University faculty members, students, and citizens of Athens County. These meetings initiated the discussion of possibly transforming a university-owned house into a learning center about
ecologically sustainable lifestyles. Main support for the initiative was provided by the Ohio University Ecology and Energy Conservation Committee, and the university granted the request to establish this in January of 2005. A brick house on Dairy Lane, which is currently occupied by three Ohio University students, was bought by the university to meet the aim of the project. To support its mission and goals, the project was granted $43,000 from Cinergy Solutions and $20,000 from the Ohio Department of Energy Efficiency in the spring of 2005. The project, with its weekly discussion meetings, serves as an outreach platform for Ohio University in the local community.

There are three reasons why these particular buildings were selected for this study. The first reason is that, even though all three buildings are old, they still provide the opportunity to compare buildings with a different history while being representative of the different age classes of buildings on campus. The President Street Academic Center building is the oldest of the three, having been built in 1910. The next building by age, Bentley Hall, was constructed in 1923. Research and Technology, which was built in 1948, is the youngest building.

The second reason why these buildings have been chosen is their similar purpose. All three buildings were/are used for classrooms and faculty offices. Because of the similar purpose of the buildings the hours of energy use in each of the buildings is considered to be approximately the same, about eight hours per weekday and a couple of hours during the weekends. This is unlike dormitories where energy use is 24/7.

The last reason these buildings were selected is that all three are located close to each other (Figure 1.1). Their close proximity gives several advantages. They receive
energy from the same source so pay the same rate for their energy. All three buildings are located on one flat area and have similar access to natural sunlight. This means they need artificial lighting for the same amount of time. The additional advantage of their close proximity is the convenience for collecting environmental audit data.
Chapter 3: Literature Review

Principles of Sustainability

Attention to the concept of sustainable development started emerging about three decades ago. In the 1970s, the term basically referred to managing natural resources (Coomer, 1979; Howe, 1979). In the early 1980s sustainable development aimed to achieve lasting satisfaction of human needs and improvement of the quality of human life on the one hand (Allen, 1980) and maintenance of essential ecological processes and life support systems on the other (Creighton, 1998). In the late 1980s, the approaches to sustainability emphasized social and economic aspects, which require elimination of poverty and deprivation as well as the conservation and enhancement of the resources base. Interest in the term peaked after the 1987 publication of the World Commission on Environment and Development (WCED) report entitled “Our Common Future.” The report, which is known as the Brundtland Report defines sustainable development as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Barlett and Chase, 2004, p. 6). Following the Earth Summit of the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, sustainable development has become a worldwide accepted agenda for unbiased dialogue committed to sustainable existence, the conservation of natural resources, and a sense of obligation to future generations (Panjabi, 1997). According to Dresner (2002), sustainable development definitions have been broadened to include the ability of a society, ecosystem, or other ongoing system to
continue functioning into the indefinite future, without being forced into decline through exhaustion or overloading of the key resources on which that system depends.

Goodland and Ledec (1987) highlight the social system component by defining sustainable development, as cited in Loucks et al. (1999, p. 12), as “a pattern of social and structural economic transformations (i.e., development), which optimizes the economic and societal benefits available in the present, without jeopardizing the likely potential for similar benefits in the future.” In this definition Loucks et al. (1999) see that sustainable development can be both a scientific and a social concept.

Some recent researchers (Saunier, 1999; Newton and Freyfogle, 2005; Padoch and Sears, 2005) discuss the meaning of sustainability in conservation concepts. Saunier (1999) identifies four different movements of sustainable development: human development, nature conservation, natural resources management, and environmental protection. According to Newton and Freyfogle (2005), however, the term sustainability is not equal to the task of being the “guiding light” of environmental conservation. A fundamental problem according to them is the term's vagueness and utter malleability (Newton and Freyfogle, 2005). They argue that sustainability lacks clear meaning and clear goals, confusing sustaining natural systems with other human goals and values. Those authors question sustainability's usefulness in synthesizing "three strands – the human health/social justice strand, the biodiversity/ecological process strand, and the agrarian strand" (Newton and Freyfogle, 2005, p. 29).

Sustainability is often viewed as the interdependence of three components: economic, environmental, and social sustainability. The economic part refers to
production of goods and services to support the population’s sustenance, the environmental component refers to the maintenance of biodiversity and healthy ecosystems, and the social part of sustainability includes “social justice issues and broad political participation” (Holmberg and Sandbrook, 1992, p. 34). According to Padoch and Sears (2005), sustainability, as it refers to how humans are interacting with the natural environment, is, in fact, the goal, whereas conservation is but one of the means to achieve that goal. Environmental sustainability is fundamentally about the interaction between humans and the environment (Padoch and Sears, 2005). Loucks et al. (1999, p. 12) also state that it is “useful to indicate the three components of resilience” of the sustainable societal systems - environmental, economic, and social resilience. Sustainability is not a dilemma to resolve, but rather a process towards the mission of rational development.

**Sustainable Architecture**

The urban scene, with its complex matrix of buildings, activities, services, and transportation, consumes 75% of the world’s energy resources and produces the vast bulk of its pollution and climate-changing gases (Al-Hosany and Elkadi, 2002). Decisions made by architects are crucial to the achievement of a sustainable future (Edwards, 1999). Despite the importance of architecture to the overall success of sustainable development, there is still no agreement on a definition that is applicable to architecture (Al-Hosany and Elkadi, 2002). The term “sustainable architecture,” which once described the movement associated with environmentally conscious architectural design, has created ambivalence and confusion (Kremers, 1995). Emphasis, therefore, has been
on technical issues, such as reducing energy consumption in the construction and maintenance of buildings. Very little attention is paid to the social and economic aspects (Al-Hosany and Elkadi, 2002).

The confusion of sustainable development approaches in architecture is evident. Levine (1995) argues that attempts to include ethical dimensions as well as technical dimensions are seen as contradicting to the profession of architecture itself. Fournier (2002), a research specialist in sustainable planning and design at the University of Illinois Building Research Council, states that architects and builders have to adopt an integrated approach to building green in order to achieve results in sustainable development. According to Fournier (2002) architects, designers, and contractors remain understandably wary of changing the way they do business because going green usually translates into larger initial outlays of money. Herrmann (2005) argues that it is an equal responsibility of building owners, designers, and contractors to address today's energy and environmental concerns. The same author further argues that it is only through this team effort and a common vision for conscious and efficient living that sustainable building practices can be successful.

"The U.S. Green Building Council (USGBC) has developed a concise system in Leadership in Energy and Environmental Design (LEED) that allows the industry to be guided in the best practices in sustainable design and operation" (Herrmann, 2005, p. S10). This author provides background information on the LEED rating system explaining that it sets a series of goals that must be met to obtain certification points on the certified, silver, gold, and platinum levels (Herrmann, 2005). Implementation of a
building automation system is not required by LEED but can be an effective tool in obtaining LEED points and allowing the owner/operator to better maintain the facility. "LEED is intended to encourage sustainable development in the same way that other LEED programs have helped green buildings to flourish" (Stromberg, 2005, p.18).

Green, or sustainable, building design means design and construction practices that significantly reduce or eliminate the negative impact of buildings on the environment and occupants in the broad areas (Stromberg, 2005) of sustainable site planning, safeguarding water and water efficiency, energy efficiency and renewable energy, conservation of materials and resources, and indoor environmental quality. Green, or sustainable, design has optimal benefit only when addressed at the inception of a project and throughout the entire life cycle of a project, from concept to planning, to programming, design, construction, and ownership (Stromberg, 2005). It demands systematic considerations of environmental impact, energy use, natural resources, economy, and quality of life (Stromberg, 2005). Kim and Rigdon (1998, p. 8) argue that, "the goal of sustainable design is to find architectural solutions that guarantee the well-being and coexistence of these three constituent groups."

Kim and Rigdon (1998) state that it is necessary to develop a conceptual framework to educate architects to meet the goal of sustainable design. They argue that, "the three levels of the framework (principles, strategies, and methods) correspond to the three objectives of architectural environmental education: creating environmental awareness, explaining the building ecosystem, and teaching how to design sustainable buildings" (Kim and Rigdon, 1998, p. 8). The authors propose economy of resources, life
cycle design, and humane design as three principles of sustainability in architecture (Kim and Rigdon, 1998). These authors believe that the principles they propose are able to give an environmental awareness of architectural consumption on both local and global levels (Kim and Rigdon, 1998).

**Environmental Auditing Tool**

Today, almost all U.S. industrial businesses and federal agencies are affected by a bewildering array of regulatory requirements because there are numerous laws, regulations, and procedures addressing environmental protection and worker health and safety. Failure to meet legal standards can lead to costly fines, as well as bad publicity and low staff morale. Unfortunately, the risk of noncompliance with such regulations cannot generally be eliminated or covered in traditional ways, such as insurance. At the same time, meeting green standards not governed by law also provides commercial opportunities by improving a company's competitiveness, creating savings, and giving a company a good image. As a result, many businesses are discovering that there must be operational control to manage such risk. For today’s industrial business, regulations, financial reporting requirements, market competition, and community expectations require environmental performance to be assessed and reported. This has led both industry and government to adopt the environmental auditing process.

Environmental audit refers to a process of conducting regular internal examinations of the operation of a business and the condition of its assets to confirm that the business is in compliance with environmental laws and, when it is not, to institute corrective action and to verify that the required corrections take place (Burger and
Blackford, 1995). Most businesses already perform various internal auditing functions, for example, financial or inventory auditing. Environmental auditing merely extends this practice to a different aspect of management. Thus environmental audit is a tool that can, and in some cases must, be used by business to meet environmental and health and safety law regulations and manage risks related to them (Burger and Blackford, 1995).

The need to carry out an environmental audit will vary depending upon the type of organization and the objectives of the audit. The principal aims of an environmental audit are to identify and evaluate potential liabilities, risks, and hazards (Kim and Falkenbury, 1997). This, in turn, will assist in assessing the viability of operations after including the cost of reducing environmental risks and liability to acceptable levels.

There is no single environmental audit procedure applicable to all situations. The International Network for Environmental Management (INEM, 2005) provides the internal environmental audit procedure template that can be a very general basis for all situations. An audit can take different forms to achieve different objectives. The reason for undertaking an audit and the agreed outcomes are the deciding factors.

A number of bodies, such as the International Chamber of Commerce and the International Organization for Standardization, have developed detailed definitions for environmental audit. For its purposes, the International Chamber of Commerce defines an environmental audit as “a management tool comprising a systematic, documented, periodic and objective evaluation of how well environmental organization, management and equipment are performing with the aim of helping to safeguard the environment by facilitating management control of environmental practices and assessing compliance
with company policies, which includes meeting regulatory requirements” (Kim and Falkenbury, 1997, p. 3).

The International Organization for Standardization defines environmental audit as “a systematic, documented verification process of objectively obtaining and evaluating audit evidence to determine whether specified environmental activities… conform with audit criteria (policies, practices, procedures or requirements…), and communicating the results of this process to the client (organization commissioning the audit)” (Kim and Falkenbury, 1997, p. 15). The British Standard Institution (BSI) draft on environmental management systems defines environmental audit as “a systematic evaluation to determine whether or not environmental performance complies with planned arrangements, and whether or not these arrangements are implemented effectively, and are suitable to fulfill the organization’s environmental policy” (BSI, 1991, p. 9).

The environmental audit is an attempt to provide information on the environmental performance of a company, and thus to include environmental issues in the decision-making process. Environmental audit at present is usually informal and voluntary (Kim and Falkenbury, 1997, p. 16). Consequently, the findings are not usually available for public scrutiny (except in rare cases involving statutory or mandatory audits or audits of government agencies) and the results are not reviewed by any government authority (Kim and Falkenbury, 1997, p. 20). The environmental audit has no force in law, and is admissible in court only as evidence of “all due diligence” (Kim and Falkenbury, 1997, p. 27) or for other reasons, on the basis of voluntary disclosure by the defendant. Environmental audit is carried out on existing facilities and operations to
assess the environmental impact of current activities by looking at current operations and their immediate past history. Environmental audits can be conducted internally by staff of the business concerned, or independently by experts. Unlike financial audits, there is currently no legal requirement for an external audit.

Voluntary environmental audit reports in the past have been regarded as highly confidential documents and have not usually been made available for public scrutiny (Kim and Falkenbury, 1997). While this attitude is changing, it is sometimes difficult to choose among external environmental auditors because examples of their work are unavailable owing to confidentiality provisions. Environmental audits can occur at many different levels, for example in commerce, industry, municipalities, and governments, and on a less formal level, in households and schools. Within a school, for example, an audit can focus on the classroom, the school grounds, or the entire school. Whether an audit leads to simple changes, such as a school adopting a recycling program, or more complex changes, such as a supermarket chain introducing energy saving practices, the cumulative effect will benefit everyone.

**Universities and Sustainability**

Environmental awareness in the U.S. began to enter the public consciousness in the late 1960s due to growing perception of the catastrophic and overt evidence of pollution and nature degradation following publication of Rachel Carson's *Silent Spring*, which in 1962 exposed the hazards of the pesticide DDT, and when the highly polluted Cuyahoga River near Cleveland burst into flames in the summer of 1969. Following these disillusioning awakenings, environmental awareness formally appeared on
university campuses in 1970 with the first Earth Day celebration (Barlett and Chase, 2004). The succeeding energy crisis of the 1970s and the development of scientific interest in stratospheric ozone depletion in the late 1970s and early 1980s focused so much attention on environmental issues that U.S. national legislation emerged in the Clean Air, Clean Water, and Endangered Species Acts (Benedick, 1991; Barlett and Chase, 2004). This change in public perception created grounds for the various campus efforts to raise environmental awareness in society. The efforts consisted of such things as establishing and institutionalizing environmental studies departments, promoting health, safety, and productivity through developing of outdoor activities as a part of physical education, and preserving green space through the long-term use planning of campus ecosystems.

Today, sustainability has a special significance for institutions of higher education, whose key role is to prepare students to take an essential part in ameliorative development of society. In 1990, a group of more than 320 university presidents and leaders from over 40 countries signed the Talloires Declaration at an international conference in Talloires, France (Creighton, 1998; Edelstein, 2004). The Talloires Declaration (Creighton, 1998, p. 291-292) acknowledges that “universities have a major role in the education, research, policy formation, and information exchange…” because they “…educate most of the people who develop and manage society’s institutions.” Thus, according to the Talloires Declaration, “universities bear profound responsibilities to increase the awareness, knowledge, technologies, and tools to create an environmentally sustainable future” (Creighton, 1998, p. 292).
Many activists, organizations, scholars, and individuals have worked in the past fifteen years to motivate the key role of higher education in furthering sustainability efforts. Established through the National Wildlife Federation in 1989, the Campus Ecology Program works on more than 140 U.S. campuses to “transform the nation's college and university campuses into living models of an ecologically sustainable society, and training a new generation of environmental leaders” (Calder, et al., 1999; ULSF, 2006). Founded in 1992, University Leaders for a Sustainable Future is “a leading international non-profit organization working to strengthen the capacity of colleges and universities to make sustainability and environmental literacy a major focus of teaching, research, service, and operations” (ULSF, 2006).

The Sustainable Buildings Industry Council has published a second edition of its High-performance School Buildings Resource and Strategy Guide (American School and University, 2005). The guide describes the features and benefits of high-performance educational facilities and is targeted for those who make decisions about the design and construction of K-12 schools. As cited by American School and University (2005, p. 10) "anyone else advocating for school buildings that are cost-effective, sustainable, and healthy and productive for students, teachers, and staff” works towards the sustainable development of the worldwide public society.

In 2005, Washington State Governor Christine Gregoire signed legislation that requires new public buildings to meet green building standards for energy efficiency, water conservation, and other environmental initiatives (American School and University, 2005). The law states that all public agency facilities of more than 5,000 ft²,
including school buildings that receive state funding, are required to meet the U.S. Green
Building Council's Leadership in Energy and Environmental Design (LEED) standards
(American School and University, 2005). "Washington State is taking the lead to build
schools and other state buildings that do a much better job of protecting Washington's air,
land and water," says Gregoire (American School and University, 2005, p. 10). The
potential savings by using high-performance design solutions are $50 per student per year
(American School and University, 2005).

The University of British Columbia’s campus sustainability office, through the
Social, Ecological, and Economic Development Studies program, gave a team of students
in a bio-environmental engineering design course an environmental problem to resolve
for their term project (Brunetti et al., 2003). The students did not resolve the problem,
but the project-based learning approach was effective in teaching them about social,
economic, and environmental sustainability issues. It also provided the campus with a
new sense of direction concerning the solution to the particular problem. The teaching
process required that the instructors change their teaching approaches as well as subject
matter. Changes in individual engineering-related skill levels were difficult to assess and,
due to this, corrective actions were undertaken to address team project-based assessment
in the future. This adaptable teaching approach can be applied to other educational
settings.

Today, there is a constantly increasing number of university campuses that have
achieved tremendous success and are continuing to work on sustainability efforts. Many
work on bringing something new and innovative into the current sustainability practices.
Christopher Uhl (2004), a biology professor at Pennsylvania State University, describes how the initiative to develop environmental audit strategies led to the broader sustainable practices. He describes how environmental audit strategies attracted faculty members and students, resulted in the “formation of a research team,” and further incorporated the sustainability vision of Pennsylvania State University into its “ecological mission” (Uhl, 2004, p. 30). Uhl concludes that the environmental audit experience at Pennsylvania State University clearly demonstrates the three-step process of “developing sustainability indicators, then an ecological mission, and finally policies to institutionalize sustainable practices” (Uhl, 2004, p. 30).

The idea of the urgency of institutionalizing further campus sustainability efforts is revealed by Geoffrey Chase and Paul Rowland in “The Ponderosa Project: Infusing Sustainability in the Curriculum” (2004). These authors illustrate how Northern Arizona University faculty through the development of Ponderosa Project in 1995 led to establishment of the Center for Sustainable Environments in 2000, the institutional framework for sustainability at Northern Arizona University. To accomplish the key element of the project – emphases on the environment within the undergraduate curricula – the faculty members revised more that 120 courses over the five-year period to include environmental sustainability issues (Chase and Rowland, 2004).

In 2001 Perrin, writing in “The greenest campuses: an idiosyncratic guide” rated University of Michigan as one of the top green campuses in the U.S. In 2003 the University of Michigan health system received an Environmental Leadership Award for its recycling and steam-sterilization (as opposed to incineration) efforts (Shriberg, 2003).
All the examples reviewed above give a clear picture that development of a centralized coordinated institutional agenda for sustainability efforts will bring better results, over the long run, than implementing isolated sustainability projects. In order to succeed, the centralized framework needs to bring together top-down and bottom-up strategies.
Chapter 4: Methods

Most of the expense and most of the environmental impact of Ohio University buildings derives from energy consumption. For the purpose of this study, which focuses on building sustainability, lighting is the principal variable tracked. In essence, electricity use by lighting systems can be an indicator of a building’s efficiency. It is important to note, however, that lighting is not the only indicator of efficiency. Assessing overall energy use, including energy for lighting, heating, and cooling, would be the best indicators of the environmental efficiency of a building. Due to the lack expertise and time, the emphasis in the collection of quantitative measured electricity data was given to the lighting data. Lighting is often the most obvious energy-consuming system in a facility, and it has a considerable effect on perceived occupational quality, appearance, operating performance, and operating and maintenance costs. In addition to being one of the most expensive utilities, because of its contribution to the well being of building occupants, lighting also plays a significant role in the quality of the interior environment.

To gain a better understanding of the overall efficiency and safety of the buildings, in addition to lighting data, observations on environmental health and safety data were made for the three buildings. These data include such things as air, water quality, temperature, humidity, and safety concerns. Meeting the objectives of this research was fulfilled in two steps, data collecting and data analyzing.
Data Collection

Two types of data were collected. First, existing information was gathered from publications, archives, and experts on each building regarding its age, design, energy history, building materials and resources, and electricity data. Second, lighting and environmental health and safety field data were measured in each of the three buildings.

To collect these quantitative data I applied the environmental audit skills that I learned from my internship with the Ohio University environmental audit team. From November of 2005 to April 2006 I went through each building in a systematic order conducting environmental audits.

The lighting and environmental health and safety data were collected by a survey method. For these field measured data specific forms were prepared on which to record the environmental audit observations. Every room of each building was checked for lighting and environmental health and safety data. The variables that I observed related to lighting are listed in Table 4.1. The environmental health and safety variables that I recorded appear in Table 4.2. Besides my personal observations, I asked any room occupants of Bentley Hall and the Research and Technology building about their related experiences.
<table>
<thead>
<tr>
<th>Current room information</th>
<th>Current luminaire information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room number</td>
<td>Luminaire type</td>
</tr>
<tr>
<td>Room type or purpose</td>
<td>Luminaire condition</td>
</tr>
<tr>
<td>Room description</td>
<td>Luminaire quantity</td>
</tr>
<tr>
<td>Room length dimensions</td>
<td>Luminaire configuration</td>
</tr>
<tr>
<td>Room height dimensions</td>
<td>Hours of lighting use</td>
</tr>
<tr>
<td>Room width dimensions</td>
<td>Quantity of bulbs in lamp</td>
</tr>
<tr>
<td>System voltage</td>
<td>Lamp type</td>
</tr>
<tr>
<td>Light control method</td>
<td>Lamp wattage</td>
</tr>
<tr>
<td>Ceiling type</td>
<td>Lamp mounting type</td>
</tr>
<tr>
<td>Ceiling condition</td>
<td>Luminaire mounting height</td>
</tr>
<tr>
<td>Room temperature</td>
<td>Low illumination level</td>
</tr>
<tr>
<td>Room relative humidity</td>
<td>High illumination level</td>
</tr>
</tbody>
</table>

Table 4.1: Lighting-related variables collected from each room in the three buildings

<table>
<thead>
<tr>
<th>Floor number / room number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air quality: e.g., stuffy, fresh, dusty</td>
</tr>
<tr>
<td>Air inlet diffusers</td>
</tr>
<tr>
<td>Cold air return</td>
</tr>
<tr>
<td>Type of heat</td>
</tr>
<tr>
<td>Number of windows / # of windows open</td>
</tr>
<tr>
<td>Temperature / relative humidity</td>
</tr>
<tr>
<td>Swings in temperature / thermostat</td>
</tr>
<tr>
<td>How reg. room cleaned / chemicals in room</td>
</tr>
<tr>
<td>Trash bins / recycling bins</td>
</tr>
<tr>
<td>Odor pollution: smells</td>
</tr>
<tr>
<td>Molds: wall, ceiling</td>
</tr>
<tr>
<td>Water damage</td>
</tr>
<tr>
<td>Green plants</td>
</tr>
<tr>
<td>Water quality</td>
</tr>
<tr>
<td>Insects / animals</td>
</tr>
<tr>
<td>Noise pollution</td>
</tr>
<tr>
<td>Environmental and safety concerns</td>
</tr>
<tr>
<td>Emergency preparedness</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>

Table 4.2: Environmental health and safety variables
Data Analysis

Once collected, the data were analyzed. Most of the existing part of the data, such as historical facts and details, did not require analytical processing and are included in the description section of the Results chapter. The existing electricity consumption data that came from the facilities experts were used in combination with the lighting field measured data to assess the total electrical cost from lighting of each of the buildings.

All quantitative data and observations required analysis. Data analysis was implemented mathematically; special formulas were applied to calculate savings as the difference between existing and proposed numbers. In order to simplify the calculations, the collected data were entered into Excel spreadsheets. The formulas to determine the cost and/or savings for different fixtures were provided by Andy Sinozich (personal communication, 2006), who is the Project Manager of Cinergy Solutions, an energy efficiency consulting company contracted by Ohio University.

Since July of 2002 the President Street Academic Center building has not been used because it is considered to be inefficient in terms of utility consumption (A. Sinozich, personal communication, 2006). However, even though the building has been shut down since 2002 its utilities are still on. For analyses in this thesis it was assumed that the President Street Academic Center building is currently being used the same number of hours as Bentley Hall and the Research and Technology building, from 8:00 a.m. to 11:00 p.m. Monday through Friday and ten hours during the weekend. Both lighting and environmental health and safety data of President Street Academic Center were calculated and analyzed as if the building was operated and maintained.
During its 2002-2003 renovation the lighting fixtures of Bentley Hall were replaced with newer, more energy efficient and safe fixtures. These fixtures, therefore, are considered as efficient and safe as they can be and in this thesis are not proposed to be changed.

**Lighting Analysis**

**Current energy consumption from lighting**

From the field observations of the existing lighting variables, I calculated the total energy consumption contributed by lighting and its cost for each building. The first step of the computation was determining the system wattage (SW) in each room, which depends on the type and number of ballasts and usually is provided by the ballast manufacturer. The next step was the estimation of the total energy demand (TD) in kW for each room. TD is the amount of electricity that customers are pulling out of the power grid supplied by generators at any given moment. TD is calculated as follows,

\[ TD = \frac{SW}{1000} \times n \times F_d \]

where \( n \) is number of lamps used in this particular room and \( F_d \) is the demand factor. \( F_d \) is the assumed average percentage of available lighting used at a building’s peak time, from 2.00 p.m. to 4.00 p.m. For buildings of this type of use the demand factor equals 85% (A. Sinozich, personal communication, 2006). The second figure needed to be calculated is total energy consumption from lighting (TC) in kWh which is determined as follows,

\[ TC = \frac{SW}{1000} \times n \times h \]
where \( h \) is total amount of hours lighting is used in this particular room during the year.
The last number to be computed is the total consumption cost (TCC), which is calculated as the following,

\[
TCC = TC \times 0.0376
\]

where $0.0376$ is the current electric utility cost Ohio University pays for one KWh. The sum of the total consumption cost of all the rooms in a building is the lighting consumption cost of the entire building for one year. All of these calculations were performed for each of the three buildings.

**Energy consumption of the proposed lighting fixtures**

After totaling the existing lighting data the same formulas were applied to the proposed luminaire fixtures. Proposed lighting fixtures were found by searching for the most energy efficient available designs and retrofits for lamps, ballasts, and luminaires for President Street Academic Center and Research and Technology buildings. The combination of all proposed fixture characteristics, such as installation (material and labor) costs, life expectancy, wattage consumption, and ergonomic safety, was considered for determining the most long-term, energy efficient, and cost efficient measures. A list of available fixture attributes was provided by Andy Sinozich (personal communication, 2006). Selection of the proposed systems considered the most energy-efficient models listed that were appropriate to the existing purposes of room, hours of use, and its area. All proposed lighting measures for President Street Academic Center and Research and Technology buildings are the same generation of lighting systems that was used in the renovation of Bentley Hall. The lighting fixtures of Bentley Hall were not modeled to
change because it is assumed that they are already as efficient and safe as they can be.

The estimation of cost and consumption of the proposed fixtures was done using the same formulas as the calculations for the existing luminaire fixtures, as explained above. After the estimation of the lighting energy consumption and cost of all the existing and proposed lighting systems the proposed savings were calculated. Total savings (TS) in dollars was computed as the difference between the total consumption cost of the existing (TCC_E) and total consumption cost of the proposed measures (TCC_P). The TS equation looks as follows,

$$TS = TCC_E - TCC_P$$

To get the whole picture of the efficiency of proposed measures the installation cost (IC) of the proposed measures had to be evaluated. The installation cost in dollars was estimated as,

$$IC = LC + MC$$

where the LC is the labor cost demanded for the installation of the proposed fixtures and MC is the material cost of the proposed measures. LC and MC were provided along with the listing of proposed fixtures by Andy Sinozich (personal communication, 2006). After the calculation of the total savings and installation cost of the proposed measures the payback (P) in years was calculated for each room. The total annual payback (P_T) of the building represents how long in years it will take for the cost of the new fixtures to be recovered by lighting savings. It is determined as the ratio of the total installation costs for the building to the value of total savings per year, and was computed as follows,

$$P_T = IC/TS$$
The \( P_T \) differs from the simple payback per year (\( SP_T \)) because it includes costs of the outside contractor markup (17% of total installation cost) and an energy efficiency consulting company markup (15% of total installation cost) in addition to the installation cost. Simple payback per year was determined as,

\[
SP_T = \frac{(IC+IC*0.32)}{TS}
\]

It was proposed that all fluorescent ballasts be replaced with high frequency electronic types that are healthier for human eyesight and more energy efficient than existing fixtures. All proposed luminaires are high efficiency designs using high reflectivity material as part of the optical assembly. All variables calculated are listed in Table 4.3.

<table>
<thead>
<tr>
<th>Existing lighting</th>
<th>Proposed lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand factor – DF</td>
<td>Demand factor – DF</td>
</tr>
<tr>
<td>System wattage – SW</td>
<td>System wattage – SW</td>
</tr>
<tr>
<td>Total demand – TD (kW)</td>
<td>Total demand – TD (kW)</td>
</tr>
<tr>
<td>Total consumption – TC (kWh)</td>
<td>Total consumption – TC (kWh)</td>
</tr>
<tr>
<td>Total consumption cost – TCC ($)</td>
<td>Total consumption cost – TCC ($)</td>
</tr>
<tr>
<td>Total savings – TS ($)</td>
<td></td>
</tr>
<tr>
<td>Labor cost – LC ($)</td>
<td>Material cost – MC ($)</td>
</tr>
<tr>
<td>Installed cost – IC ($)</td>
<td>Payback per measure – P (years)</td>
</tr>
<tr>
<td></td>
<td>Simple payback per year – SP (years)</td>
</tr>
</tbody>
</table>

Table 4.3: Lighting variables calculated
Environmental Health and Safety

Unlike lighting data, which were analyzed mathematically using special formulas to calculate savings between existing and proposed numbers, the environmental health and safety data were analyzed by making decisions by general (visual) observations and comparing these with presently available amenities. The description of the building health and safety conditions is from the perspective of its occupants. If the condition of an environmental health and safety variable was found to be unfavorable and/or unsatisfactory then the analysis summary includes the indication of the problem and ways for its solution.
Chapter 5: Results

Existing Historical Information

All three buildings studied were built in the 20th century. The oldest building is the President Street Academic Center, which contains 38,002 $\text{ft}^2$. This building was constructed in 1910, and was formerly known as “Old” Morton Hall (Hollow, 2004). In 1983, when the building was scheduled for destruction, it was decided to save it for use as the Ohio University Innovation Center. The Innovation Center was in use until July 2002 as southeastern Ohio’s only small business incubator (Hollow, 2004). It provided low-overhead space and basic business services to its clients, as well as access to technical and business consulting that could enhance the chances for success of new businesses (Athens Messenger, 1988). According to the Athens Messenger, (1988, p.A-5) the Ohio University Innovation Center was formed “to help direct the emerging business incubator industry, that currently has a membership of more that 450. The Innovation Center opened in 1983 and is one of the one of the nation’s oldest business incubators. It currently houses nine independent firms and about 70 employees (Athens Messenger, 1988, p.A-5).”

The next oldest building is Bentley Hall. Although Bentley Hall is now viewed as a newer building because of its complete renovation in 2002, it was originally constructed in 1923 as a men’s gymnasium (Athens Year Book, 1923). According to the Athens Yearbook, contract was awarded to the E.H. Latham Company with its bid of $219,358. The building was designed by architect Frank L. Packard from Columbus. The structure
was designed to be three storeys high, 106 feet wide, and 160 feet long. According to the plans, the ample floor space provided for all offices, rooms, and courts for indoor sports. The ground floor consisted of the playing arena, which was large enough for three small basketball courts to be used simultaneously during tournaments, and one large court for intercollegiate contests. The running track occupied most of the second floor. The track was 8.5 ft wide, with about twelve laps to the mile. There was also an observation gallery on the second floor. The third floor was a large varsity club room. Team rooms and offices occupied all three floors (Athens Year Book, 1923). In 1960 the Men’s Gym was converted into approximately 16 classrooms varying in student capacities from 20 to 200. It was used largely by the Departments of History and Government, however the basement was reserved to be the future home of several advanced physics or chemistry laboratories and a large library or reading room. In 1960, the building was outfitted with new plumbing, heating, and electrical facilities. At that time only one-fourth of the basement had been renovated. The building was renamed Bentley Hall in 1961 (Keller, 1960). Today, the building is 70,408 ft$^2$, although the initial size in 1923 was 56,772 ft$^2$.

Construction of the Engineering building, currently known as the Research and Technology building, began in 1948. By the time it was completed in 1950 the building was already so crowded that it required the construction of a second section (Hollow, 2004). The second section was added in 1958 (Hollow, 2004). Currently the building contains 45,814 ft$^2$ of space.
Results from Field Observations

Lighting

Once the existing luminaire data were collected, it was determined that T8 trichromatic phosphor would be proposed as a more energy and ergonomically efficient replacement for the existing primary fluorescent T12 lamps (Figure 5.1). These ergonomically safe T8 lamps are high-color rendering lamps with a 4,100 Kelvin color temperature (Figure 5.2).

Figure 5.1: T12 fluorescent lamp
Most existing exit lamps were found to be illuminated by one 75-watt incandescent bulb (Figure 5.3). All existing exit signs were proposed to be replaced or re-lamped with light-emitting diode technology. The light-emitting diode technology is far superior to both long-life incandescent and compact fluorescent lamps. The use of the light-emitting diode fixture requires far less energy and the rated life of the product, which is approximately 25 years, all but eliminates future maintenance costs. Each exit 75-watt incandescent bulb luminaire was proposed to be retrofitted with one compact fluorescent 23 watt lamp (Figure 5.4) (A. Sinozich, personal communication, 2006). The following results of the lighting analyses are presented in order from the least energy efficient of the three buildings to the most energy efficient.
Figure 5.3: 75-watt incandescent bulb lamp

Figure 5.4: Light-emitting diode one compact fluorescent lamp
President Street Academic Center lighting analysis

The first part of the calculation included a consumption evaluation of the current luminaire fixtures. The system wattage was determined first. Since President Street Academic Center is an old building and has not been renovated recently the system wattage is mostly 144 W, ranging from 60 to 144 W. The next step was the calculation of the total demand (TD) figure. TD for President Street Academic Center building’s existing luminaire fixtures is 44.1 kW for a year of use. The total consumption (TC) value of the existing luminaire system for President Street Academic Center is estimated as 233,235 kWh, thus the total lighting consumption cost (TCC) for the building equals $8,770.

After totaling the data for existing luminaires, values for the proposed fixtures were estimated. For President Street Academic Center, three types of replacements were chosen: 87 pieces of 4B-6 retrofit systems with 2-F32T8 bulbs that come with SA 2LP electronic ballasts (Figure 5.2); 21 pieces of 3A-3 retrofit systems with 2-F32T8U bulbs and SA 2LP LW electronic ballasts (Figure 5.5); and eight 2B-1 relamp with compact fluorescent bulbs (Figure 5.4). The estimation of system wattage, total demand, cost, and consumption of the proposed fixtures was made using the same formulas as for the calculation of the existing lighting fixtures. Each of the 4B-6 retrofit systems requires 52 W, a 3A-3 retrofit system requires 51 W, and a 2B-1 relamp needs 23 W. The value of the total demand (TD) of the proposed lighting for the building for one year equals 16.2 kW, which is 2.7 times less than the TD of the existing fixtures (44.1 kW). The total
lighting consumption (TC) of the proposed lighting systems equals 85,286 kWh, with the total consumption cost (TCC) of $3,244 at $0.0376 per kWh.

After the cost and energy consumption estimation of all existing and proposed lighting systems the total lighting savings are $5,545 per year. To get the whole picture of the efficiency of proposed measures the installation cost (IC) of the proposed measures had to be evaluated, which depends on the type of lamp and ballast proposed. The value of installation cost includes the labor cost (LC) and material cost (MC). LC and MC, respectively, for 4B-6 retrofit is $17 and $15.9, for the 3A-3 retrofit is $14.5 and $41, and for the 2B-1 relamp is $10 and $17. For the entire building labor would cost $6,116 and material $7,015 with the total installation cost of $13,130. The payback (P), therefore, equals 2.4 years and the simple payback per year (SPY) equals 3.1 years. This means
that in 3.1 years after installation of the proposed fixtures Ohio University would pay 2.7 times less than it currently pays for the lighting utilities, assuming energy costs remain the same.

**Research and Technology lighting analysis**

Because the Research and Technology building is also old and not recently renovated, its system wattage ranges from 60 to 144 W and mostly equals 144 W. The annual total demand for the building’s existing luminaire fixtures equals 44.3 kW. The Research and Technology building total annual consumption of the existing luminaire systems is 215,620 kWh, which makes the total annual lighting consumption cost $8,107.

For the Research and Technology building two types of replacements were chosen: 135 pieces of 4B-6 retrofit systems with 2-F32T8 bulbs that come with SA 2LP electronic ballasts, and 23 pieces of 2B-1 relamps with compact fluorescent bulbs. The annual total demand of proposed lighting for Research and Technology is 18.8 kW. The total annual lighting consumption of the building’s proposed fixtures equals 88,205 kWh, with the total consumption cost of $3,317 at $0.0376 per kWh.

The annual total lighting savings are $4,791 for the Research and Technology building. The installation cost of the proposed measures is $14,113, which includes the labor cost ($6,917) and material cost ($7,196). The payback equals 2.9 years and the simple payback equals 3.9 years. This number means that after 3.9 years Ohio University would pay 2.4 times less money for the lighting cost of this building.
Bentley Hall lighting analysis

Since lighting fixtures of Bentley Hall were not modeled to change, the lighting analysis of the building includes only the analysis of the existing lighting fixtures. The system wattage of Bentley Hall ranges from 23 to 72 W and mostly equals 58 W. The annual total demand for the building’s lighting fixtures equals 53.4 kW. Total annual consumption of the luminaire systems is 284,954 kWh with the total lighting consumption cost of $10,714 per year.

The results of the calculation on all three buildings are presented in Table 5.1.

<table>
<thead>
<tr>
<th>Building name</th>
<th>President Street Academic Center</th>
<th>Research and Technology</th>
<th>Bentley Hall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total building area (ft²)</td>
<td>38,002</td>
<td>45,814</td>
<td>70,408</td>
</tr>
<tr>
<td>Total electric consumption (kWh)</td>
<td>1,370,900</td>
<td>390,754</td>
<td>585,586</td>
</tr>
<tr>
<td>Total annual electric cost ($)</td>
<td>50,723</td>
<td>14,458</td>
<td>21,667</td>
</tr>
<tr>
<td>Total lighting consumption (kWh/year)</td>
<td>233,235</td>
<td>215,621</td>
<td>284,954</td>
</tr>
<tr>
<td>Total lighting consumption cost ($)</td>
<td>8,770</td>
<td>8,107</td>
<td>10,714</td>
</tr>
<tr>
<td>Current annual lighting cost per ft² ($)</td>
<td>0.23</td>
<td>0.17</td>
<td>0.15</td>
</tr>
<tr>
<td>Total lighting consumption savings (kWh/year)</td>
<td>147,488</td>
<td>127,416</td>
<td>0.0</td>
</tr>
<tr>
<td>Total lighting savings ($)/year</td>
<td>5,545</td>
<td>4,791</td>
<td>0.0</td>
</tr>
<tr>
<td>Total proposed measures costs ($)/year</td>
<td>13,134</td>
<td>14,113</td>
<td>0.0</td>
</tr>
<tr>
<td>Payback (year)</td>
<td>2.4</td>
<td>2.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Simple payback (year)</td>
<td>3.1</td>
<td>3.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Times less cost after simple payback</td>
<td>2.7</td>
<td>2.4</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*President Street Academic Center is shut down and remains unoccupied since 2002

Table 5.1: Summary of the current and proposed luminaire numbers
Environmental Health and Safety Analysis

The descriptions of the environmental health and safety observations for the three buildings appear in order from the least safe to the safest building.

Environmental health and safety analysis of the President Street Academic Center building

Air quality in most rooms of the building is unsatisfactory. Stuffiness, dampness, and putrefaction odors were experienced in almost all rooms of the building. Food odors were observed in the rooms on the first and second floors. Windows require insulation. Air handler and vent configurations for these rooms should be reviewed for efficiency and consistency. Most of the rooms in President Street Academic Center have windows that do not open, either due to paint or age of the window. Windows that do not open and close properly should be replaced.

The comfort conditions of rooms are also found to be unacceptable. Extremely high temperature and stuffy air in the rooms of the building were observed. Temperatures recorded in rooms ranged from 86°F to 105°F because the heater was left on. Damage and alteration of plastic and rubber articles were observed (Figures 5.6, 5.7). Evidence of standing water and/or mold in most of the rooms (Figures 5.8, 5.9, 5.10) in President Street Academic Center (particularly in the corner rooms and rooms on the upper floor) indicates that drains should be checked and the condition of the walls and ceiling should be monitored. Presence of seasonal mold demonstrates a need for better ventilation and insulation.
Figure 5.6: Shape alteration and destruction of hygiene gloves

Figure 5.7: Shape alteration of plastic soda bottles
Figure 5.8: Dripping water from ceiling

Figure 5.9: Standing water and mold on the floor with fallen ceiling pieces
Due to the poor acoustic insulation of the windows and lack of sound protection in the walls noise pollution was observed in every room of the building. Besides the street noise, the heating system was very loud. In some of the rooms the ceilings are falling due to water damage and present a health threat (Figures 5.11, 5.12).

Damaged electrical lines and cables were visible. Water dripping from walls and ceilings onto damaged electrical cables and lines produce an electroshock hazard. Lack of ground fault circuit interrupters in the areas where water is supposed to be used (water tubs and wash-basins) was observed.
Figure 5.11: Falling ceiling presents a health threat

Figure 5.12: Falling ceiling presents a health threat
Water quality, ergonomic conditions, emergency preparedness, and chemical use observations were not recorded because the building is not occupied. The environmental health and safety audit observations for the President Street Academic Center building are included in Table 5.2.

<table>
<thead>
<tr>
<th>Environmental health and safety summary</th>
<th>Problem</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air quality</td>
<td>Windows that do not open</td>
<td>Repair or replace</td>
</tr>
<tr>
<td>Comfort</td>
<td>Swings in temperature</td>
<td>Check vents for consistency and efficiency</td>
</tr>
<tr>
<td>Objectionable odors</td>
<td>Food (from the street) and dampness odors</td>
<td>Check ventilation to and from these areas and windows insulation</td>
</tr>
<tr>
<td>Water damage/persistent moisture</td>
<td>Standing water and mold on walls and ceilings</td>
<td>Check drains, ventilation, and isolation in affected area</td>
</tr>
<tr>
<td>Chemical use</td>
<td>No info</td>
<td></td>
</tr>
<tr>
<td>Water quality</td>
<td>No info</td>
<td></td>
</tr>
<tr>
<td>Insects and animals</td>
<td>Not revealed</td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>Heating system noise, street noise</td>
<td>Better acoustic protection of the windows and walls</td>
</tr>
<tr>
<td>Work sanitation/ergonomics</td>
<td>No info</td>
<td></td>
</tr>
<tr>
<td>Environmental concerns</td>
<td>Rooms with very high temperature; lack of ground fault circuit interrupters</td>
<td>Check vents for consistency and efficiency, install devices as needed</td>
</tr>
<tr>
<td>Emergency preparedness</td>
<td>No info</td>
<td></td>
</tr>
<tr>
<td>Electrical observations</td>
<td>Damage to the electrical cables and lines</td>
<td>Replacement and insulation</td>
</tr>
</tbody>
</table>

Table 5.2: President Street Academic Center environmental health and safety summary
Environmental health and safety analysis of the Research and Technology building

The Research and Technology building’s environmental health and safety review includes an examination of health and safety characteristics of every room. The assessment of the observations appears in Table 5.3.

Some occupants complained of swings in temperature in the rooms. Temperatures recorded in rooms ranged from 71°F to 86°F. Air handler and vent configurations for these rooms should be reviewed for efficiency and consistency. Food odors were observed in some of the rooms. Some rooms of the first floor have stuffy air. Insulation is required for windows, and the ventilation of these areas should be reviewed. Some of the rooms in the building have windows that do not open, either due to paint or age of the window. During quarterly reviews it should be verified by staff that all windows open and close properly. Windows that do not open and close properly should be replaced. Evidence of standing water and/or mold in some of the restrooms and rooms that have windows indicates that drains should be checked and the conditions of the rooms should be monitored. Presence of seasonal mold demonstrates a need for better ventilation.

The use of chemicals for sanitation in some rooms and bathrooms necessitates yearly training in the proper use and storage of these chemicals. This is particularly important considering the high number of occupants in the building. The occupants of rooms on the second floor complained of cockroaches. They should be made aware of measures that can be taken to avoid exacerbating this problem (including sanitation
training). If the problem is not controlled by proper sanitation, occupants should report the problem to maintenance staff.

Some of the rooms have improper work stations and poor ergonomic conditions for occupants. Lighting also should be replaced in order to provide proper ergonomic support for the occupants’ health and safety. The use of new, high efficiency fixtures will allow dramatically improved lighting performance in this building. Most of the occupants are aware of the emergency exit locations. Some of occupants indicate that training in the proper use of fire extinguishers may be necessary on a rotating basis.

<table>
<thead>
<tr>
<th>Environmental health and safety summary</th>
<th>Problem</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air quality</td>
<td>Windows that do not open</td>
<td>Repair or replace</td>
</tr>
<tr>
<td>Water quality</td>
<td>No info</td>
<td></td>
</tr>
<tr>
<td>Comfort</td>
<td>Swings in temperature</td>
<td>Check vents for consistency and efficiency</td>
</tr>
<tr>
<td>Objectionable odors</td>
<td>Food odors</td>
<td>Check ventilation to and from these areas and windows insulation</td>
</tr>
<tr>
<td>Water damage/persistent moisture</td>
<td>Mold on walls and ceilings</td>
<td>Check drains, ventilation, and isolation in affected area</td>
</tr>
<tr>
<td>Chemical use</td>
<td>Training is essential for proper handling</td>
<td>Verify training conducted regularly</td>
</tr>
<tr>
<td>Insects and animals</td>
<td>Cockroaches reported on second floor</td>
<td>Make occupants aware of the importance of proper hygiene. Report for facilities intervention</td>
</tr>
<tr>
<td>Work station/ergonomics</td>
<td>Improper lighting fixtures and work stations in some rooms</td>
<td>Replacement of the lighting and work stations</td>
</tr>
<tr>
<td>Emergency preparedness</td>
<td>Training in use of fire extinguishers</td>
<td>Provide regular training</td>
</tr>
</tbody>
</table>

Table 5.3: Research and Technology environmental health and safety summary
Environmental health and safety analysis of Bentley Hall

Environmental health and safety conditions of Bentley Hall were found to be appropriate, satisfactory, and safe.
Chapter 6: Conclusion

Findings and Recommendations

It was hypothesized that the investment from installing the proposed more energy-efficient and ergonomic lighting fixtures would be recovered quickly in the older buildings, President Street Academic Center and Research and Technology. The results of existing and proposed lighting systems analysis and assessment of the buildings’ existing environmental health and safety conditions confirmed the hypothesis. Even though for Bentley Hall analysis of only existing luminaires was performed and nothing was proposed to be reinstalled, the research results prove that its current lighting fixtures are more efficient than the existing luminaires of the two other buildings (Table 5.1).

The least lighting efficient and least safe building is the President Street Academic Center building (Table 5.1). Out of the three buildings, Research and Technology is considered an average building which consumes fairly large amounts of energy resources and money (Table 5.1). Ohio University includes numerous buildings on its campus. Most of these buildings are older and therefore likely more wasteful of energy and money compared to Bentley Hall and other buildings that are new or completely renovated with consideration to and installation of lighting and other energy resource efficient fixtures.

Three very important findings were revealed during the environmental audit conducted for this thesis. These are the needless, extreme heating of the unoccupied President Street Academic Center, almost continuous use of lighting fixtures of Bentley Hall classrooms, and constantly switched on computers in Bentley Hall (Figure 5.13).
Figure 5.13: Continually turned on computers in Bentley Hall classrooms

According to Ohio University facilities and maintenance representatives the President Street Academic Center building has been shut down since 2002. During data collection for this thesis the average temperature recorded in the building was 98°F, with a maximum of 107°F. The heating in the building remained on until January 10, 2006, after I mentioned this situation to the person who had access to such kind of information. The reason why the heat was on could be that someone just forgot to turn it off.

Lights in the 31 Bentley Hall classrooms were observed to be turned on almost continually, contributing to enormous loss of energy and, therefore, money for Ohio University. These rooms are usually occupied for a few hours on week days and their lighting fixtures are turned off only after a custodial person cleans the rooms, usually not earlier than 11:00 p.m. This problem can be solved with the installation of occupancy
sensors. It is proposed that occupancy control mechanisms be used wherever additional savings can be achieved by limiting lighting use to occupied periods. Occupancy sensors, carefully located, will reduce the amount of electrical energy wasted due to lights being left on even when spaces are not in use. These occupancy sensors are provided with a manual override switch that can be used to lock out the control when the room needs to be dark (e.g., for presentations). Even though Bentley Hall was totally renovated in 2002-2003, the installation of occupancy sensors was not part of its renovation. This discovery raises the question as to whether this happened because of neglect or omission.

Another solution for the problem of lights left on is increasing awareness through repeated messages from the administration to save energy by turning off the lights. This solution implies an alteration of the disconnected interaction practices between the administration and individuals. Those who teach in the classrooms should comply with Ohio University’s goal to save energy and set an example by turning off the lights after dismissing the class. Leadership and personal involvement are critical factors for transforming action of existing, and developing new, sustainability efforts.

Each of the 31 Bentley Hall classrooms has a computer, which is turned on 24 hours a day seven days per week. The suggestion to improve this situation is the same that was recommended above. The key is in repeating the message from the administration so that it is perceived by individuals. Professors and others who teach should strive to save energy by providing a personal example through turning off at least the computer monitor after the class is over.
Many university rooms have thermostats that are set by the occupants, rather than being centrally controlled. To reduce energy usage, the thermostats of most rooms should be controlled by a central system. It would also be advantageous to determine the amount of power consumed by the computers in labs and offices of the buildings and the effects of upgrading the energy saving modes on the computers or turning off some of the computers overnight. The same can be done for the water consumed, electricity used by the air handling systems, steam used by the building, and natural gas consumed by the building.

**Conclusions**

The objective of this thesis is to evaluate the sustainability of three buildings on the Ohio University campus as one of the principal characteristics of campus sustainability. This research was driven by two secondary questions: What types of lighting fixtures are currently being used and how efficient are they? How much more efficient can lighting fixtures be? Specifically, the research emphasized the lighting fixtures in Bentley Hall, Research and Technology, and President Street Academic Center to determine the short- versus long-term costs and benefits due to renovating the lighting systems. This study confirmed that renovated buildings, like Bentley Hall, are more energy efficient and safer than the old and unrenovated President Street Academic Center and Research, and Technology type of buildings (Table 5.1). It was determined that Ohio University could pay 2.7 and 2.4 times less, respectively, for President Street Academic Center and the Research and Technology buildings if they were set up to Bentley Hall standards for lighting fixtures. These savings could be applied in 3.1 and
3.9 years, respectively, after the installation of the energy efficient and safe lighting fixtures in President Street Academic Center and the Research and Technology buildings.

The mission and principles of institutions of higher education connect them to society. Even though institutions of higher education exercise considerable influence in society through young scholars and specialists, their slowness to change can represent an obstacle to achieving sustainability. Fundamental goals of a university mission are to prepare new specialists with necessary skills in their fields, new leaders, and valuable local and global society members.

The physical campuses of these institutions of higher education play a substantial role in conveying and achieving their missions. Campuses offer an exceptional opportunity to support the mission and objectives of the institutions, providing the classrooms and laboratories for formal academic learning while also serving as areas for obtaining less formal but equally critical messages. These messages include increasing student awareness about campus sustainability efforts and enhancing better student engagement in optimizing “green” performance on campus.

Ohio University has an opportunity to create a more sustainable campus and to promote environmental sustainability through the alteration of the campus design and consumption policy. This universal campus modification can be initiated and maintained by bottom-up communication strategies with examples of personal leadership through constructive messages that they deliver. If everyone who teaches would repeat the message to save energy and become personally involved through their example, by turning off lights and computer monitors after the class is over, changes in students’
perspectives and attitudes will soon follow. For the university administration, on the other hand, through the top-down approach, this green attitude can start through a number of activities, such as institutionalizing campus sustainability behavior, minimizing campus environmental impact by reusing existing sites and buildings in all possible ways before building new ones, considering building location and design for the long term, maximizing building flexibility for reuse if necessary, and many other initiatives. Achievement can be guaranteed when both bottom-up and top-down strategies are brought together to accomplish the green goals of the university.

Ohio University can benefit greatly by bringing sustainability into the curriculum. It can be incorporated in a variety of forms and ways. According to Creighton (1998, p. 226) “to promote environmental commitment universities” put more focus on developing and strengthening environmental specialties for academic programs, rather than on “their efforts to install energy efficient heating systems or state-of-art composting.” This author argues that “focusing environmental education in a single department” or several specifically related academic specialties “will not provide complete knowledge or understanding of environmental problems and their solutions” (Creighton, 1998, p. 226).

Another example is provided by the Mission and Place authors who state that “establishing an institutional framework for sustainability practices will have greater effects, over the long run, than conducting individual sustainable building projects” (Kenney et al., 2005, p. 166). As cited in Creighton (1998, pp. 226-227), Antony Cortese, a principal author of the Talloires Declaration, proposes introduction of
environmental concepts in all disciplines of the institution of higher education. Thus, for the university as a whole, it is best to have an integrated sustainability agenda.

To bring the environmental appreciation into all of its disciplines, Ohio University, for instance, could develop a curriculum of “Ohio University, pathway to sustainability” as a requirement for graduation from the university. This course could be on two levels, one for undergraduates and one for graduate students. This class can be constructed as either a seminar or regular class. If developed in seminar form, it could be a 2-3 credit seminar on a weekly meeting basis, conducted by professors from mostly science departments. Creighton (1998) proposes to link student learning and academic projects with campus-based action. The environmental audit team efforts of Ohio University is a good example of this kind of initiative. These efforts could be developed to work in coordination with the proposed class/seminar. The leader of this team can be a professor who facilitates the “Ohio University pathway to sustainability” class/seminar conduction, who can be represented as the university manager of environmental affairs. Additionally, through this class/seminar Ohio University could develop the practices to conduct an obligatory environmental audit procedure on all campus buildings at regular intervals.

Results of this thesis demonstrate that environmental audit is a very useful tool for realistically assessing the current status of a building to identify opportunities for improving efficiency and reducing negative environmental impacts of the facilities. Other advantages of bringing sustainability into the curriculum include the chance that new faculty, employers, and students will perceive it as an institutional norm and it is a
fast way to infuse sustainability throughout multiple courses of the university (Chase and Rowland, 2004).

Another example of a top-down communication strategy that Ohio University could follow is the reusing of old building space as much as possible instead of new construction. According to Kenney et al. (2005, p. 158), “re-using existing buildings is preferable to new construction” from “an environmental perspective as well as a cost perspective.” This research project has demonstrated that using older, but renovated buildings reduced utility costs and improved environmental health and safety for occupants. Another benefit of renovating is reducing the need for new building construction. These construction projects alone produce all types of negative environmental impacts, such as waste generation from the construction of new buildings and demolishing of old buildings, both of which require disposal costs and landfill space; utilization of natural resources through the production and consumption of new building materials; and emission of tons of pollution related to construction of the new and demolishing of the old building. The last advantage of renovating and revising old buildings is that it highlights the unique history and architecture of the campus.

Ohio University can be an excellent model of a green university, and a leader in the green university movement. The university is capable of implementing institutional initiatives to promote environmental sustainability on campus. This thesis has demonstrated that Ohio University would be able to save energy and other natural resources by renovating and reusing old buildings on campus. Now it is time to make the Ohio University community more aware of and more involved in all day-to-day
environmental actions. In order to fit with global green education, Ohio University should consider the Talloires Declaration principles to move toward a sustainable future and yet develop a university-specific strategy of environmental sustainability efforts.
References


University of Michigan: Ann Arbor, Michigan.


