

Green Is the New Gothic: Wellesley's Greenhouses in the Twenty-First Century

**Environmental Studies 300
Professor DeSombre
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Photo courtesy of Anita Yip

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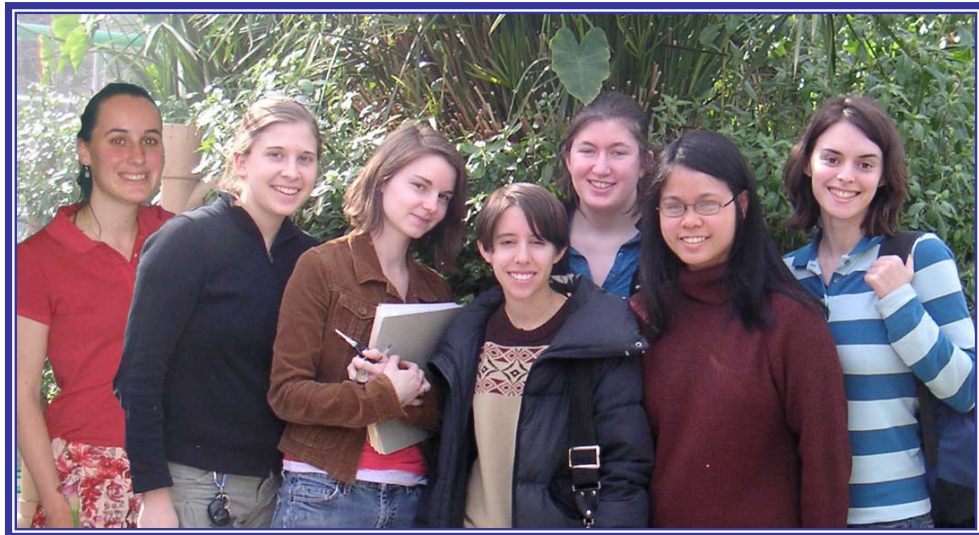
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“What nobler employment [. . .] than that of the person who instructs the rising generation.”
Marcus Tullius Cicero



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TABLE OF CONTENTS

HEADER	PAGE
Executive Summary	1
1. Introduction	2
1.1 Why build green?	2
1.2 Why build green at Wellesley?	2
1.3 History of the Margaret C. Ferguson Greenhouses	2
1.4 Environmental Studies Program Space	4
1.5 Project Overview	5
A. Greenhouses and Environmental Studies (GES) Design Proposal	5
B. The Layout	5
C. Life Cycle Analysis	6
D. Baseline Analysis	7
2. Background and Baseline Analyses	8
2.1 Sustainable Sites	8
A. Laws, Regulations and Incentives	8
B. Baseline Analysis	10
Current Site Conditions	10
2.2 Materials and Resources	11
A. Laws, Regulations and Incentives	12
B. Baseline Analysis	13
2.3 Indoor Environmental Quality	21
A. Laws, Regulations and Incentives	21
B. Baseline Analysis	21
Greenhouses	22
Pendleton East	23
2.4 Energy and Atmosphere	26
A. Laws, Regulations and Incentives	28
B. Baseline Analysis	28
Approaches	28
C. Methods for Calculation	29
Building Area	29
Top-down Energy Baseline Methods	30
Bottom-up Energy Baseline Methods	31
D. Results and Summary	33
E. Environmental impact of Wellesley College Energy-Use	34
2.5 Water Efficiency	36
A. Laws, Regulations and Incentives	38
B. Baseline Analysis	38
C. Methods for Calculation	38
Building Area	38
Top-down Energy Baseline Methods	38
Bottom-up Energy Baseline Methods	38
D. Results and Summary	40
E. Impact of Wellesley's Water Use	41

3. Options Analysis and Recommendations	43
3.1 The GES Building	43
Overview of the Options Analysis	47
3.2 Sustainable Sites	47
Paving Options	48
3.3 Materials and Resources	52
Glass	52
Insulation Materials	56
Foundation Materials	59
Wall Materials	63
Flooring Materials	66
3.4 Indoor Environmental Quality	69
Finishes (interior walls)	69
Furniture	72
Ventilation	75
Carpeting	75
3.5 Energy and Atmosphere	77
Electrical Lighting	77
Daylighting	79
Light Controls	82
Additional Sources of Energy	84
Heating Systems	87
Energy Saving Materials	90
Air Conditioning Systems	90
3.6 Water Efficiency	91
Collection Systems	91
Reduced-flow Faucets	94
Reduced-flow Showerheads	97
Reduced-flow Toilets	97
Water Reuse Systems	103
3.7 Crossover Among Sections	109
4. LEED Analysis	111
4.1 Introduction to LEED	111
4.2 Sustainable Sites	112
4.3 Materials and Resources	120
4.4 Indoor Environmental Quality	127
4.5 Energy and Atmosphere	136
4.6 Water Efficiency	145
4.7 Innovation and Design Process	149
4.8 LEED Conclusions	152
5. Conclusion	153
Appendix I: Energy Baseline Calculation Data	154
Appendix II: Water Baseline Calculations	157

LIST OF FIGURES

FIGURES	PAGE
Figure 1: Visitors' map of the Margaret C. Ferguson Greenhouses	4
Figure 2: Model of a life cycle analysis (LCA)	6
Figure 3: Cameron Garden at Wellesley's greenhouses	10
Figure 4: Comparison of top-down and bottom-up estimates of greenhouse energy consumption.	33
Figure 5: Bottom-up estimate of the relative contribution to total water consumption from each water source in the Wellesley College Greenhouses	39
Figure 6: Comparison of top-down and bottom-up estimates of greenhouse water consumption	40
Figure 7: Design of the proposed GES building	46
Figure 8: Example of block pavers	50
Figure 9: Example of mosaic (left) and rammed earth walls (right).	71
Figure 10: Louvered skylight.	80
Figure 11: Solar tube	80
Figure 12: Hands-free wall-mounted foot pedal controller	95
Figure 13: Hands-free faucet controller bar	95
Figure 14: Dual-flush toilet design	99
Figure 15: Sun-Mar Centrex 3000 separate composting unit and drum	101
Figure 16: An example of the various stages of a living machine system. Some systems have the anaerobic stage as the final step	105
Figure 17: Equaris Greywater Treatment System. Water enters from the right and is purified as it moves (left) through the system	106
Figure 18: From Google Maps, the Wellesley College greenhouses site (left arrow) and the Wellesley Square Commuter Rail stop (right Arrow).	114

LIST OF TABLES

TABLES	PAGE
Table 1: Fuel to energy conversion factors	30
Table 2: Energy use baseline analysis for Wellesley College academic and greenhouse buildings	34
Table 3: Fossil fuel emission levels in tons/million Btu of energy input	35
Table 4: Water use baseline analysis for Wellesley College academic and greenhouse buildings	41
Table 5a: Lifecycle costs and impacts compared to Asphalt	51
Table 5b: Feasibility of options compared to Asphalt	51
Table 6: Greenhouse Covering Insulation (R) Values	54
Table 7a: Lifecycle costs and impacts compared to Doubled Paned Glass	54
Table 7b: Feasibility of options compared to Double Paned Glass	55
Table 8a: Lifecycle costs and impacts compared to Fiberglass Insulation	58
Table 8b: Feasibility of options compared to Fiberglass Insulation	58
Table 9a: Lifecycle costs and impacts compared to Concrete	62
Table 9b: Feasibility of options compared to Concrete	62
Table 10a: Lifecycle costs and impacts compared to Drywall	65
Table 10b: Feasibility of options compared to Drywall	66
Table 11a: Lifecycle costs and impacts compared to Concrete Flooring	68
Table 11b: Feasibility of options compared to Concrete Flooring	69
Table 12a: Lifecycle costs and impacts compared to Synthetic Paint	71
Table 12b: Feasibility of options compared to Synthetic Paint	72
Table 13a: Lifecycle costs and impacts compared to Standard Furniture	74
Table 13b: Feasibility of options compared to Standard Furniture	74
Table 14a: Lifecycle costs and impacts compared to Incandescent light bulbs	78
Table 14b: Feasibility of options compared to Incandescent light bulbs	78
Table 15a: Lifecycle costs and impacts compared to the absence of daylighting	81
Table 15b: Feasibility of options compared to the absence of daylighting	81
Table 16a: Lifecycle costs and impacts compared to a manual light switch	83
Table 16b: Feasibility of options compared to a manual light switch	84
Table 17a: Lifecycle costs and impacts compared the Co-generation Facility	86
Table 17b: Feasibility of options compared to the Co-generation Facility	86
Table 18a: Lifecycle costs and impacts compared Radiators	89
Table 18b: Feasibility of options compared to Radiators	90
Table 19a: Lifecycle costs and impacts compared to exporting rainwater to Deer Island, MA	93

TABLES	PAGE
Table 19b: Feasibility of options compared to exporting rainwater to Deer Island, MA	93
Table 20a: Lifecycle costs and impacts compared to a 2.5 gpm faucet	96
Table 20b: Feasibility of options compared to a 2.5 gpm faucet	96
Table 21a: Lifecycle costs and impacts compared to a 1.6 gpf toilet	102
Table 21b: Feasibility of options compared to a 1.6 gpf toilet	102
Table 22a: Lifecycle costs and impacts compared to Wastewater Export	108
Table 22b: Feasibility of options compared to Wastewater Export	108
Table 23: LEED Sustainable Sites Credit Evaluation	116
Table 24: LEED Materials and Resources Credit Evaluation	124
Table 25: LEED Indoor Environmental Quality Credit Evaluation	132
Table 26: Points available for each increment of demonstrated energy-use reduction	139
Table 27: LEED Energy and Atmosphere Credit Evaluation	141
Table 28: LEED Water Efficiency Credit Evaluation	148
Table 29: LEED Innovation and Design Credit Evaluation	151
Table 30: LEED Credit Evaluation Summary	152
Table A.1: Total area for Wellesley College academic buildings	154
Table A.2: Fuel consumption in the Physical Plant for 2006 (January to December)	154
Table A.3: Constants used for bottom-up energy calculation	155
Table A.4: Average monthly temperature differences from winter greenhouses temperatures	155
Table A.5: Greenhouse data by room	156
Table A.6: Energy consumption per appliance	156
Table A.7: Greenhouses total water consumption per year	158

ACRONYMS AND ABBREVIATIONS

4-PC	4-Phenylcyclohexene
ADA	Americans with Disabilities Act
AIA	American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMPs	best management practices
BOD	Biological Oxygen Demand
BMP	Best Management Practice
Btu	British Thermal Units
CFC	Chlorofluorocarbon
CFL	Compact Fluorescent Light bulb
CITES	Convention on International Trade and Endangered Species
CO ₂	Carbon dioxide
CxA	Commissioning Authority
DCAM	Department of Capital Asset Management
DEG	distributed energy generation
DEP	Department of Environmental Protection (Massachusetts)
EA	Energy and Atmosphere
EAf	Electric Arc Furnace
EH&E	Environmental Health & Engineering
EOEA	Executive Office of Environmental Affairs
EPA	Environmental Protection Agency
EPS	Expanded polystyrene
EQ	Environmental Quality (indoor)
ES	Environmental Studies
FGD	Flue Gas Desulfurization
FOH	Friends of Horticulture
FPSF	Frost Protected Shallow Foundations
FSC	Forest Stewardship Council
GES	Greenhouses and Environmental Studies (building)
gpf	gallons per flush
gpm	gallons per minute
GSA	General Services Administration
HCFCs	Hydrochlorofluorocarbons
HID	High Intensity Discharge
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
ID	Innovation in Design
IEQ	Indoor Environmental Quality
ISO	International Organization for Standardization
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
LCA	Life Cycle Analysis
MADEP	Massachusetts Department of Environmental Protection
MAPC	Metropolitan Area Planning Council (Boston)

MERV	Minimum Efficiency Reporting Value
MR	Materials and Resources
MWRA	Massachusetts Water Resources Authority
NAIMA	North American Insulation Manufacturers Association
NFRC	National Fenestration Rating Council
NIOSH	National Institute for Occupational Safety and Health
NO _x	Nitrogen oxides
NWGR	New West Gypsum Recycling
OSHA	The Occupational Safety and Health Administration
PAN	peroxyacetyl nitrate
ppm	parts per million
PNE	Pendleton East
PVC	Polyvinyl Chloride
R-values	Insulation values
SCAQMD	South Coast Air Quality Management District
SMACNA	Sheet Metal and Air Conditioning National Contractors Association
SO ₂	Sulfur dioxide
SS	Sustainable Sites
USGS	U.S. Geological Survey
USGBC	U.S Green Building Council
UV	Ultraviolet
VOC	Volatile Organic Compounds
WE	Water Efficiency
WPA	Wetlands Protection Act
XPS	Extruded polystyrene

Executive Summary

Over the last decade, Wellesley College has undertaken several major environmental initiatives. The college began the twenty-first century with the remediation of Paint Shop Pond and Alumnae Valley. Scarcely a year later in 2001, the college established the Environmental Studies (ES) program. Since then, both environmental action on campus and interest in the ES major have continued to grow. To accommodate both current activities and further expansion, the ES program requires its own space. Similarly, the greenhouses are in need of updated facilities, as the current structures are in disrepair. The creation of a combined greenhouses and ES (GES) building would satisfy both of these needs.

During spring 2007, the ES 300 class studied ways that green design could fulfill the needs of both the greenhouses and the ES program if applied to a GES building. A *green* GES building would benefit Wellesley College in a variety of ways. Not only could such a building reduce the negative environmental impacts associated with traditional building practices, but it could lower operating costs and serve as an educational tool for students on campus. Given Wellesley's previous environmental actions, construction of a *green* GES building seems the next logical step in continuing Wellesley College's commitment to environmental issues.

In order to formulate a proposal for a *green* GES building, we completed two analyses. We first conducted a baseline analysis, in which we took both quantitative and qualitative approaches to characterize the current environmental impact of the greenhouses and a representative academic building. Using the college's present construction practices and resource use as a standard, we then completed an options analysis. We explored alternatives to current building practices that could decrease the environmental impact of our proposed GES building. Both of these analyses were divided between six different sectors: site, materials and resources, indoor environmental quality (IEQ), energy and atmosphere, water efficiency and innovation and design. The U.S. Green Building Council's (USGBC) Leadership in Energy and Efficiency Design (LEED) rating system, a nationally-recognized set of guidelines for green building, designates potential credits within these six sectors. LEED guidelines not only provided a framework for conceptualizing green design, but also allowed us to determine whether it would be worthwhile for our proposed GES building to pursue LEED certification.

Based on our analyses, we have made several recommendations that could help reduce Wellesley's current environmental footprint. Our goal is to integrate all aspects of construction and design in order to create a holistic building in which each component functions to educate and improve overall environmental quality. For example, we recommend a Living Machine, a system that would purify building wastewater through biological processes and make it available for reuse within the greenhouses. Additionally, a Living Machine would create educational opportunities to learn about ecological processes first hand. For the ES space in particular we recommend materials such as rammed earth and drywall made from recycled gypsum, linoleum flooring, and natural paints. These materials not only have low-impact production processes, but they improve IEQ. For the proposed GES site, our recommendations include permeable paving to reduce runoff and rainwater collection to reduce consumption of potable well-water.

Using our recommendations, we assessed the feasibility for Wellesley to obtain LEED certification for the proposed GES space. Based on our analyses, the GES building could receive silver certification with only slight adjustments to current design and construction practices, and gold certification with moderate effort. Since this goal is well within reach of Wellesley, we recommend that Wellesley pursue LEED certification to standardize and solidify the green design process.

1. Introduction

1.1 Why build green?

According to the U.S. Environmental Protection Agency, buildings account for over 39% of total energy use, 12% of total water consumption, a whopping 68% of total electricity consumption, and 38% of carbon dioxide emissions.¹ By building green, Wellesley could help reduce negative environmental impacts associated with intensive use of natural resources. Green construction practices minimize the amount of material that enters the waste stream by diverting used building materials from going to landfills and by using recyclable materials. Energy- and water-efficient fixtures, designs, and systems decrease operational costs. Better lighting, more sunlight and natural ventilation increases morale, productivity, and comfort and improves overall indoor environmental quality (IEQ). Green construction practices also reduce the amount of toxic materials used in a building, thereby improving occupant health. Green building has both immediate and long-term benefits, but the most opportune time to build green is now rather than later, when natural resources such as the oil and natural gas that supply Wellesley's power have become even scarcer.

1.2 Why build green at Wellesley?

As an institution of higher learning concerned with social responsibility, Wellesley should build green to publicly demonstrate its environmental commitment. Students are quick to point out that Wellesley lacks environmental stewardship because they don't know about Wellesley's environmental efforts. The major disconnect between what students think Wellesley does regarding environmental issues and what Wellesley actually does confirms the need for Wellesley to raise the visibility of its sustainability efforts on campus. Building green could increase awareness of Wellesley's environmental commitment both on and off campus.

An exceptionally innovative and green building could create a lasting legacy – something Wellesley has the potential to do. By constructing a green building that clearly illustrates the interconnection between our daily lives and the environmental resources on which we depend, Wellesley could raise environmental awareness. Greater environmental awareness, in turn, encourages students, faculty, and staff to reconsider their consumptive habits.

1.3 History of the Margaret C. Ferguson Greenhouses

Built in 1922, the Margaret C. Ferguson Greenhouses are an outstanding teaching facility and horticultural resource visited by thousands each year. The 15 greenhouses contain a remarkably diverse collection of over a thousand types of plants as well as botanical research facilities for faculty and students. The permanent collection contains desert, tropical, subtropical, and temperate plants. Two of the greenhouses are reserved for use by horticulture classes, while two others serve as research facilities for faculty and students.²

¹Why Build Green?, (Oct. 17, 2006) U.S. Environmental Protection Agency, accessed 05/11/2007, at <http://www.epa.gov/greenbuilding/pubs/whybuild.htm>.

² Wellesley College, *Margaret Ferguson Greenhouses*, (2006), accessed 04/23/2007, at <http://www.wellesley.edu/CampusMaps/Buildings/science.html>.

The greenhouses were named in honor of the designer, Miss Margaret C. Ferguson, a pre-eminent member of the Wellesley College faculty during the first half of the 20th century.³ A smaller greenhouse built in 1906 called the Annex remained from the collection of Henry Durant,⁴ and became part of the greenhouse complex constructed in 1922.

There are five greenhouses located along an East-West axis at the South of the complex (Figure 1). These greenhouses are of a higher elevation than the others, and the wet tropical house is the largest of all. Some plant specimens are planted in the ground and cannot be physically moved. Nine smaller houses link the Conservatory range to Sage (part of the Science center). Relocated to the North side of the tropical house, the Annex has wood glazing mullions set on a concrete block base. It still retains its wood entry canopy, although many of the wood framing members are in poor condition.⁵

The greenhouses are set on a top of a small knoll. There is a wooded slope to the South and East. The 1990s-era addition to the Science Center looms to the West and blocks some afternoon sun to the houses.⁶ Most equipment and fixtures are original to the building, including the steam heat and water distribution systems. Generally, environmental controls are not house specific, and there is inadequate ventilation as a result of a 1982 reglazing project. The renovation in 1982 converted the curved eave of single-glazed glass into a flat angled eave of double-glazed glass.⁷

The existing configuration of rooms causes public, faculty and student circulation paths to overlap and results in a lack of privacy for the faculty research houses. Because the public circulation paths have several dead ends in the collection houses, those houses are not fully toured.⁸

The greenhouses' infrastructure is failing, largely due to severe corrosion of structural members. The steam heating system operates irregularly at best, and there is no cooling system other than manual vents, many of which are inoperable. There is ongoing energy waste, and water use remains very inefficient. The environment cannot be controlled sufficiently to support most research, and the collections are in peril. The Physical plant frequently has to respond to minor emergencies that could quickly escalate. Resources are being used at an alarming rate: for example, between May and September of 2005 there were 13 work orders for Siltan Glass, at an average cost of \$1692 each. These are very expensive band-aids for a structure in serious disrepair.⁹

Since our ES 300 project commenced, more problems have arisen in the greenhouses' structural integrity. The glass of the warm temperate room started to bow and has since been replaced.

³ Wellesley College Botanic Garden, *History of the Greenhouses*, (2006), Wellesley: Wellesley College, accessed 04/21/2007, at <<http://www.wellesley.edu/WCBG/Welcome/history.html>>.

⁴ Kristina Jones, *Greenhouse Improvements at Wellesley*, November 2005.

⁵ Kristina Jones, November 2005.

⁶ Kristina Jones, November 2005.

⁷ Kristina Jones, November 2005.

⁸ Kristina Jones, November 2005.

⁹ Kristina Jones, November 2005.

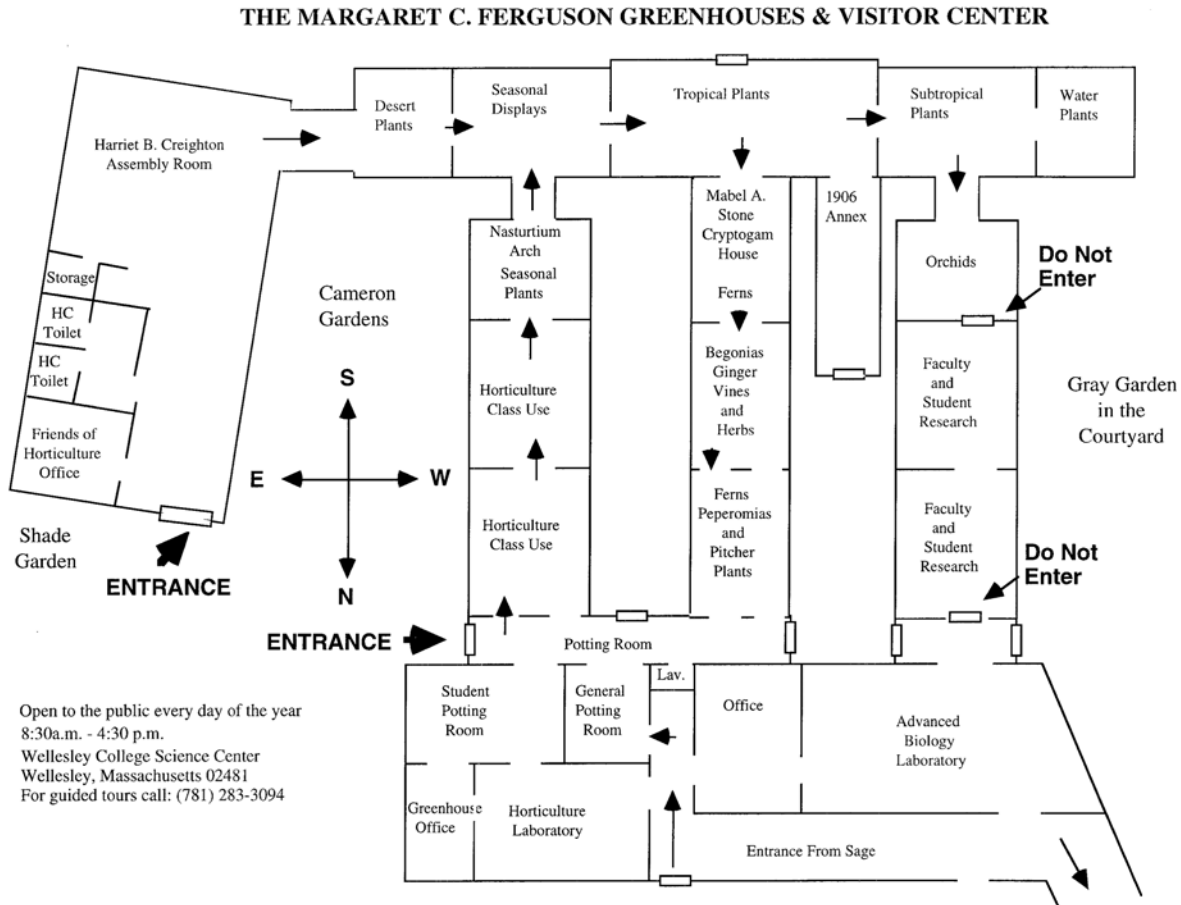


Figure 1: Visitors' map of the Margaret C. Ferguson Greenhouses.¹⁰

1.4 Environmental Studies Program Space

The Environmental Studies (ES) program at Wellesley College has only existed since 2001, yet students had been constructing individual majors in the field for many years before the program was office formed.¹¹ The ES program currently offers an interdepartmental major of the same name. A unique feature of this interdepartmental major is that it draws on three major disciplines, humanities, social science, and science.¹² Since its inception, the number of ES majors has grown and with the reorganization of the major requirements and the addition of a minor in the 2007-2008 school year, the number of students within the program should continue to increase.¹³ The ES program currently has no space on campus of its own, and faculty associated with the program have offices and teach classes all across campus.¹⁴ This lack of centralized space is particularly troublesome for a major with such a diverse area of study as ES. It is difficult to create a sense of community for those in the major, and lack of community is

¹⁰ Kristina Jones, *Map of the Margaret C. Ferguson Greenhouses* (2006), accessed 05/10/2007, at http://www.wellesley.edu/WCBG/Visit/WCBG_Greenhouses.pdf.

¹¹ Wellesley College Environmental Studies Program, *Self-Study*, (March 2005), 2.

¹² Wellesley College Environmental Studies Program, 6.

¹³ Beth DeSombre, personal communication, April 23, 2007.

¹⁴ Wellesley College Environmental Studies Program, 35.

certainly a source of dissatisfaction among those students choosing to major in ES.¹⁵ The ES program recognizes its need for program space,¹⁶ and an outside audit of the ES program came to the same conclusion.¹⁷ The program has proven its importance to the student body during its six years of existence. The logical and necessary step for the continued health of the program would be to provide space on campus for it to reside permanently.

1.5 Project Overview

A. Greenhouses and Environmental Studies (GES) Design Proposal

Wellesley College is not the only place where Environmental Studies (ES) is a burgeoning subject. Environmental awareness has become a global phenomenon. As industries, businesses, governments, and individuals begin to realize that resources are not as abundant as they once seemed, environmental problems and technologies have taken center stage in many social and political arenas. Wellesley has the opportunity to keep pace with the global interest by allowing the ES program to grow.

Our proposed design for the Greenhouses and Environmental Studies (GES) project is based on needs of the current greenhouses, the results of a survey distributed to ES faculty and to students majoring, minoring or interested in ES and limitations of the site.¹⁸ The overall floor coverage of the GES project would expand the existent greenhouses' footprint by approximately 5,500 square feet. Since the greenhouses are currently designed with undeveloped spaces between the three wings of the buildings, the increased ground coverage of the GES design is largely due to the enclosure of these empty areas (Figure 1, p 4).

The way the GES project design is arranged, there are three major components of the space: the permanent greenhouse collections, the research greenhouses, and the ES space (Figure 7, p 46). The location of the permanent collections in our design has not changed from where it is now, though the space has been rearranged to take advantage of shared walls to maximize energy and humidity control as well as to enable visitors to view the canopy of the Tropical and Warm Temperate Houses. The proposed ES space includes several offices and 3 classrooms, each of a different size and design to accommodate several different class styles. We have put the research houses on the second floor of the GES building so that they are separate from the visitor area. For a more detailed description, refer to Section 3.1.

B. The Layout

The paper you are reading is no modest proposal. Green buildings are not extraordinary in their own right. They are practical and, increasingly, a necessity, but they are not significantly more difficult to construct or maintain than any other type of building. Our Greenhouse and Environmental Studies (GES) project is a proposal of the grandest proportions, then, not in its scope or feasibility, but in the goal that it seeks to achieve. The educational merits and the integration of the greenhouses with work space as we've proposed are attempts to infuse Wellesley inhabitants with critical thoughts about the little choices we make on a daily basis, with appreciation of the interdependence between human and environment, and with novel ideas about how we can achieve our dreams and live our lives in a way that does not compromise the

¹⁵ Tom Tietenburg, *Report of the Wellesley College Environmental Studies Visiting Committee*, (2005), 4.

¹⁶ Wellesley College Environmental Studies Program, 34.

¹⁷ Tom Tietenburg, (2005), 4.

¹⁸ Space preferences for faculty included: office location, class rooms, shared spaces with students. Student preferences included common spaces and other features such as a kitchen.

world around us. Yes, the GES project as proposed is only a building, but it is a building unlike any other Wellesley has yet conceived; it is a building with a message.

As you read the following pages, whether you skim through briefly or read every word, we have organized these contents in a way to make the information as accessible as possible. This paper is divided into two sections. The first provides background information and a baseline assessment of environmental impacts and how they relate to Wellesley College. The second section consists of ways we can improve upon that baseline, including a description of building options, a list of recommendations specific to the GES project, a LEED¹⁹ analysis, and a discussion to tie everything together.

Both sections are organized according to LEED categories into the following sectors: Energy and Atmosphere, Water Efficiency, Materials and Resources, Indoor Environmental Quality, Site Sustainability, and Innovation and Design. While these categories overlap in many ways, we chose to organize the project in this fashion to facilitate data collection and provide some structure to the overwhelming amount of information and thought that has gone into this proposal. There are several sections throughout the paper that discuss overlap across sectors in recognition of the theme of integrated design.

Finally, as you read, please keep in mind that this proposal is just that: a proposal. We realize that whatever renovation the college plans for the greenhouses will require another evaluation and study. Our hope, however, is that this proposal will provide a solid and thorough starting place in addition to offering insight into the needs and desires of the Wellesley community.

Two integral components of our project are a life cycle analysis (LCA) approach and the completion of a baseline assessment, explained below.

C. *Life Cycle Analysis*

²⁰A life cycle analysis (LCA) is a tool that enables us to compare and evaluate the environmental impact of a material, resource, or process at every stage of its development. People tend to think of the world around them as they experience it, yet experience is limited. We don't experience the life cycle of the resources we use. To get into your car, gasoline first must be extracted, then refined, processed, and transported great distances. From your car, gasoline is combusted to form a gas that then circles the atmosphere until it eventually is transformed again by plants. As a car-owner, we don't see the energy and resources that were needed to get the gasoline into the car, and we (hopefully) don't see the exhaust going out. Although the production and disposal of gasoline have the

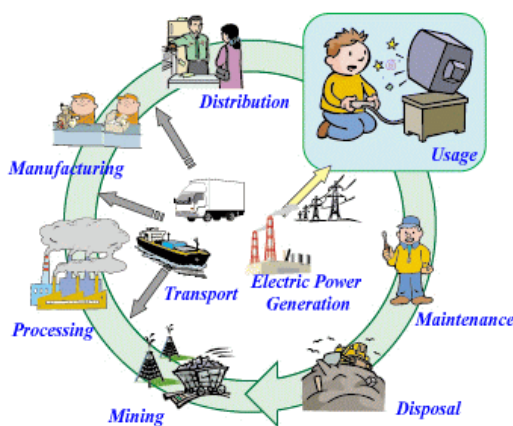


Figure 2: Model of a life cycle analysis (LCA)

¹⁹ LEED stands for Leadership in Energy and Environmental Design Green Building Rating System™. It is a nationally accepted benchmark for the design, construction, and operation of high performance green buildings.

²⁰ Advanced Industrial Science and Technology, *Research Center for Life Cycle Assessment*, accessed 04/28/07, at <http://unit.aist.go.jp/lca-center/cie/introduction/outline.html>.

greatest environmental impacts, we don't experience these stages. Since we are removed from the effects, consequences, and often awareness of production and disposal costs, it is difficult for us to consider them as anything more than abstract concepts.

The goal of a LCA is to counteract our present use-centered bias by describing the impact at each stage of development—from acquisition of raw materials to their ultimate disposal as used product. For this project, we have incorporated the concept of LCA into our baseline and options analyses. We did so with two goals in mind. First, by comparing the life cycle of resources that Wellesley currently uses, we were able to identify the environmental impact of the college both locally and to the world at large. Second, a life cycle approach to our options analysis enabled us to make more informed recommendations about the materials and systems that could reduce the environmental costs of our proposed GES building. Thus, as a tool, life cycle analyses enable us to quantify our environmental footprint in the present as well as to make more informed decisions about how to reduce that footprint in the future.

D. Baseline Analysis

Green buildings, by definition, consume fewer resources than do modern, standard-designed buildings. Without an idea of how much a standard building consumes, however, there is no quantitative way to compare the two. Establishing a baseline of resource consumption is useful, then, for several reasons. Perhaps the most significant is that baseline analyses provide definite means to evaluate to what extent technology and materials incorporated into a new design to reduce environmental impact are practical financially as well. In addition to cost considerations, baseline analyses enable you to set realistic goals for reducing environmental impact, or to evaluate how *green* a design actually is. Finally, baseline analyses are required for green building certification with LEED, as environmental impact must be reduced by a certain percentage from an established baseline.

For these reasons, we present baseline analyses to assess the environmental impact of the greenhouses and what the impact of the proposed GES space would be if it were an average building on campus. All baseline analyses evaluate energy consumption, water use, materials, site, and indoor environmental quality (IEQ). Since the GES space does not yet exist, we designated the current greenhouses plus the first floor of Pendleton East (PNE) as our representative space for the baseline analyses. Built in 1922, the greenhouses have undergone two major renovations. The first was during the 1950s and the second during the 1980s, which included the replacement of the superstructure—the exterior glass surface and associated framing—of the greenhouses. Pendleton Hall, a typical academic building, was completed in 1935 and renovated in 1977, when science laboratories were removed and offices added. In 2001, the college undertook another substantial renovation of Pendleton, during which additional classrooms, social sciences labs and public spaces were integrated into the design.²¹ Of all the buildings on campus, Pendleton most closely resembles the type of academic space that we propose for the Environmental Studies (ES) portion of the proposed GES.

While we employed a qualitative approach to assess site, materials and IEQ, we evaluated energy and water consumption through quantitative methods, which included both a top-down and bottom-up approach (Please see Energy & Atmosphere Section 2.4 (p 36) for more for further explanation). Because there are no meters installed on academic buildings to measure electricity and water use, it was not feasible for us to calculate the exact amount of energy or

²¹ Wellesley College, "Renovation", *Pendleton East*, accessed 04/01/07, at <http://www.wellesley.edu/PNE/Renovation/Renovation.html>.

water consumed in PNE. Furthermore, even if a meter did exist, it would be difficult to isolate energy and water use for particular sections of the building in relation to the whole. For these reasons, we used a bottom-up approach for the greenhouses, but not for PNE.

2. Background and Baseline Analyses

2.1 Sustainable Sites

Site sustainability refers to ways in which the space outside a building contributes to the sustainable impact of the building project on the environment. Site sustainability considerations include site selection and characteristics, construction impacts, landscaping, and hard top.

Wellesley College is renowned for its beautiful and historic campus. In order to maintain its campus, Wellesley has taken many steps over the years to restore neglected or disturbed areas. The \$30 million Brownfield rehabilitation of lead and arsenic from Paintshop Pond, completed in 2002, increased the cleanliness of Lake Waban while beautifying the surrounding wetlands. During the construction of the new campus center, Alumnae Valley was restored by converting a former service parking lot into a green and pedestrian-friendly space. Wellesley has a variety of green roofs located on a portion of the Wang Student Center, a portion of the parking garage, and on the new water treatment vault at the edge of the arboretum. A faculty-led initiative for regrowth of the Science Center meadow has brought local plants and wildlife back to a formerly barren site. The addition of permeable pavers to some Science Center walkways has reduced run-off and encouraged growth. Other green steps Wellesley has taken include providing Zip cars and public (bus) transportation to the college community, which reduces the high demand for parking on our campus. Additionally, the college has configured the lights in Clapp Library to reduce light pollution to surrounding areas.

Incorporation of site sustainability considerations into future construction projects would benefit Wellesley in several ways. First, the college takes great care to maintain beautiful grounds that distinguish Wellesley from other institutions,²² so it is important to protect these grounds during construction and after completion of the project. Second, the laws with which Wellesley must comply require a degree of site sustainability. In addition, providing alternative transportation accommodations would help alleviate parking pressures on campus. Finally, Wellesley should adopt sustainable site practices for this project because a number of the college's existing practices already fulfill the requirements of U.S. Green Building Council's LEED rating system, the leading rating system for green building in the United States. Compliance with only a few additional LEED specifications would be needed to make Sustainable Sites a strong sector for the proposed GES building's potential LEED certification.

A. Laws, Regulations and Incentives

The construction of a *green* greenhouses and Environmental Studies (GES) building at Wellesley will conform to the sustainable development initiatives currently in place in Massachusetts. In 2003, then-governor Mitt Romney created the Office for Commonwealth Development "to manage the built and natural environments by promoting sustainable development through the integration of energy, environmental, housing and transportation

²² The Princeton Review, *Best 361 College Rankings: Quality of Life: Beautiful Campus*, (2007), accessed 03/04/2007, at <http://www.princetonreview.com/college/research/profiles/rankings.asp?listing=1023842<id=1&intbucketid=>>.

policies, programs, and investments.”²³ The state’s recommended “smart growth” techniques include Low Impact Development (LID), a method of site planning that incorporates conservation of natural resources and hydrological patterns.²⁴ LID has evolved since its introduction in Prince George’s County, Maryland in the 1980s to include many landscaping approaches that “mimic a site’s predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source.”²⁵ These techniques include permeable pavers and disconnected downspouts. By integrating LID or similar techniques into our design, we would ensure that Wellesley’s planning decisions reflect those encouraged by the state.

Wetlands are one type of natural resource LID seeks to protect. The state of Massachusetts enacted the Wetlands Protection Act (WPA) in 1963 (Massachusetts General Law, Chapter 131, section 40) to protect wetlands, associated resource areas, and floodplains from construction and development.²⁶ Each town has specific bylaws for the WPA. The Wellesley Wetlands Protection Bylaw prohibits “altering land, water or vegetation in lakes, streams, wetlands, floodplains, or areas within 100 feet of wetlands (and 200 feet of perennial streams) without a permit from the Wellesley Wetlands Protection Committee.”²⁷ Before we develop a building proposal, we should ensure that our site does not fall within range of a wetland or stream requiring a permit, although the fact that we propose to build on an existing building site suggests we should not have a problem.

Wellesley town zoning bylaws would also affect our construction plans. Genesis Planners noted in their Renovation Plan Study of the Margaret C. Ferguson Greenhouses that the college is located within the town’s educational and water supply protection districts, neither of which limits “a small greenhouses addition.”²⁸ The study, however, evaluated only the possibility of reconstructing the greenhouses, a project of a smaller scale than the one we propose. According to Wellesley town bylaw,

Any construction project which involves a change in the outside appearance of a building or buildings or premises, and includes one or more of the following: 1. construction of twenty-five hundred (2,500) or more square feet gross floor area; 2. an increase in gross floor area by fifty (50) percent or more which results in a gross floor area of at least twenty-five hundred (2,500) square feet; 3. grading or regrading of land to planned elevations, and/or removal or disturbance of the existing vegetative cover, over an area of five thousand (5,000) or more square feet” and “Any construction project...which involves...the following: 1. a change in the outside appearance of a building or premises, visible from a public or private street or way, requiring a

²³ Commonwealth of Massachusetts, *State Policies and Initiatives, Smart Growth and State Government*, accessed 02/28/2007, at <http://www.mass.gov/envir/smart_growth_toolkit/pages/state-policy.html>.

²⁴ Commonwealth of Massachusetts, *Low Impact Development*, accessed 02/28/2007, at <http://www.mass.gov/envir/smart_growth_toolkit/pages/mod-lid.html>.

²⁵ Low Impact Development Center, Inc., *Introduction to Low Impact Development*, accessed 02/28/2007, at <<http://www.lid-stormwater.net/intro/background.htm>>.

²⁶ 2005 ES 300 Class, *Another Green Hall? The Ecological Footprint of Wellesley’s Next Residence Hall*, (May 2005), 15.

²⁷ Wetlands include Banks, Beaches, Dunes, Flats, Marshes, Wet Meadows, Swamps, Bordering Vegetated Wetlands, Land Under Water, Land Subject to Flooding, Streams, Ponds, Vernal Pools, and Riverfront Areas (Article 44 of Town Bylaws). See <http://wellesleyma.virtualltownhall.net/Pages/WellesleyMA_NRC/wetlands/BYLA-W-REGS_6-24-04.pdf>.

²⁸ Genesis Planners, *Wellesley College Margaret C. Ferguson Greenhouses Renovation Planning Study*, (2003), 2.3.

building permit” require a site plan review by the Special Permit Granting Authority of Wellesley (Section XVI of Wellesley Zoning Bylaws).²⁹

Since we propose to expand the building square footage at the current Greenhouses’ site from 7,235 ft² to 19,300 ft², the Wellesley town zoning bylaws would apply.

B. Baseline Analysis

Current Site Conditions:

The main wing of the greenhouses, located on the southern side of the site, houses the permanent collection. The permanent collection is the collection of plants that remains relatively consistent over time, and is open to the public for tours. This collection includes such specimens as the Durant Camellia, a gift from the college founders, which as a result has significance to the Wellesley College community and is also a very old and impressive plant specimen. The Camilla and certain other plants in the tropical greenhouse cannot be moved during the project because they are planted directly in the ground. Extending north from the main wing and connecting to the Science Center are three research and propagation houses that are shorter than the main houses. Between these research houses are cold houses, exposed ground, and storage area. Where the houses connect to the Science Center there is a slight addition between the main building and the greenhouses, which includes an entrance to the greenhouses, circulation space, and potting area. The additional space is incorporated in our proposed building site. Nestled between the Friends’ of Horticulture building (~1,200 ft²) and the first research wing is an outdoor garden that is maintained by the greenhouse staff. This garden also must be maintained throughout any construction on the site.



Figure 3: Cameron Garden at Wellesley’s greenhouses.
Photo courtesy of Margaret Rossano

To the northeast of the greenhouse there is an asphalt parking lot and drop-off area as well as sidewalks to the entrances of the greenhouse and the Friends’ building, to which the greenhouse room farthest to the east is attached. Beyond the parking lot the ground slopes up slightly but sharply and is held behind a retaining wall. Due to its location next to the Science

²⁹ Town of Wellesley, *Wellesley Zoning Bylaws, Section XVI*, accessed 02/28/2007, at http://wellesleyma.virtualltownhall.net/Pages/WellesleyMA_Clerk/zoningbylaws/sec16a.

Center, the northwestern room areas of the greenhouses are overshadowed during the late afternoon. To the south, the land slopes sharply away from the greenhouses. With our proposed GES building, we hope to minimize adverse impacts through careful construction planning and landscaping decisions. Any type of building renovation or new construction we propose, however, will result in increased resource use and negative environmental impacts on the Wellesley campus. This observation applies to the building site as well as the physical structure, building materials and energy and water systems. Still, our proposed project will have substantially fewer negative impacts on the building site than would entirely new construction, since it will occupy nearly the same site currently occupied by the greenhouses.

Construction:

Effects on stormwater flow patterns and hydrology form an integral part of any analysis of a building site and possible environmental impacts. The influence of the current greenhouses on runoff and hydrology is unclear. However, there is a steep slope within thirty feet of the southeastern side of the conservatory Greenhouses. While the slope is currently well-vegetated and shows no sign of erosion, potential for increased run-off and erosion due to construction exists.

Landscaping:

Besides the garden between the Friends of Horticulture building and the research houses, there is further landscaping on the proposed GES site. To the west of the Greenhouses, and surrounded on the north and west sides, there is another garden. This garden was originally planted with a mixture of native and non-native plants. The garden needs a lot of maintenance, however, especially to keep the non-native plants weed free. To the south of the Greenhouses is a grassy area above the steep wooded slope mentioned earlier.

Outdoor Paving:

Installing pavement for roads and parking lots often results in significant hydrological changes and deterioration of local water quality. There is already significant parking adjacent to, but not within, the site. Thus paving considerations for the site are limited to pedestrian paths. These paths are primarily asphalt.

2.2 Materials and Resources

Building materials contain the bulk of a building's overall environmental impact,³⁰ which is often less overt and more challenging to calculate than impacts caused by physical changes to a building site. While the steel, concrete, insulation or glass that form a building may not seem to pose an active environmental threat, each material possesses a different embodied energy (the amount of energy required to extract, manufacture and transport a product to its point of use) and has additional environmental effects. By taking a life cycle analysis (LCA) approach to evaluating building materials, we gain a more complete understanding of the environmental impact of a building.

³⁰ D.J. Harris, "A Quantitative Approach to the Assessment of the Environmental Impact of Building Materials," *Building and Environment* (34:6), 1999, 751-758.

The college has already made decisions regarding building projects that fit within a LCA approach. Much of the pre-cast concrete used to construct the Davis Parking Facility (completed in Spring 2004) was locally produced in Pittsfield, Massachusetts, which decreased the amount of fossil fuels required to transport the concrete to Wellesley. The interior of the Wang Campus Center contains bamboo and Brazilian Cherry finishes of Forest Stewardship Council (FSC) certified wood, which ensures that the wood was produced from a sustainably harvested forest. The college typically recycles 60 percent of unused materials from new building projects, and has also made an effort to reuse materials such as slate shingles when roofs require repair. If actions to promote sustainable building practices were expanded and combined in a single project, such as the proposed GES building, they would have an even greater positive environmental impact.

A. Laws, Regulations and Incentives

The design for any proposed building must comply with the Massachusetts Building Code (780 CMR), state Fire Prevention Code (527 CMR) and Architectural Access Board rules and regulations (521 CMR). There is no use group classification within the building code for “collections greenhouses.” The building code specifies requirements for all structural materials (concrete, steel, wood, plaster, glass, roofing, etc.), including fire prevention, load-bearing and weathering requirements. The closest category is business use (b3), the category usually used for college educational buildings (and the code that would also apply to a new ES building).³¹ Genesis Planners noted that if reconstructed, the greenhouses would have to be brought up to date with state accessibility requirements. We must take disability access requirements into account when planning the new building.

State codes aside, Massachusetts has recently taken steps towards becoming a leader in green building. In October 2006, the Massachusetts Sustainable Design Roundtable published an *Action Plan for Green Building in Massachusetts State Construction Projects*, a report produced through an 18-month public-private collaboration of 54 government agencies, private firms, and non-profit organizations involved in the funding, oversight, design, and construction of state building projects. The action plan provides recommendations for promoting green building in Massachusetts. The state has initiated a number of programs to encourage sustainable buildings, including \$500+ million awarded annually through the Executive Office of Environmental Affairs’ (EOEA) Commonwealth Capital Policy to support smart growth in communities; the Green Schools Initiative, launched in 2001, to test green buildings in public school construction projects; and the Department of Capital Asset Management’s (DCAM) adoption of sustainable design guidelines for their construction projects.

Many of the green building initiatives in the state that provide funding to projects are aimed at state or municipal construction, and not at projects undertaken by private institutions. For example, the Environmentally Preferable Products Purchasing Program (EPP Purchasing Program) establishes statewide contracts through which public entities may purchase green products.³² It is unclear whether Wellesley would be eligible for this program. The college may have to look for incentives and funding available through private foundations.

³¹ Genesis Planners, *Wellesley College Margaret C. Ferguson Greenhouses Renovation Planning Study*, (2003), 2.2.

³² Operational Services Division, Commonwealth of Massachusetts *Environmentally Preferable Products Purchasing Program*, accessed 02/28/2007, at <http://www.mass.gov/?pageID=osdterminal&L=4&L0=Home&L1=Buy+from+a+Contract&L2=Environmentally+>

B. Baseline Analysis

Before we could state that the building materials we recommend for our proposed GES building have fewer negative environmental impacts than those materials already in use, we had to first research the building materials that compose the greenhouses and the first floor of Pendleton East (PNE) (see Project Overview section for explanation of baseline analysis). We took a qualitative approach, and strove to identify the primary materials found in the greenhouses and PNE and to characterize the environmental impacts associated with them. Aluminum, glass, concrete, steel, and brick comprise the major building materials that make of the greenhouses. Minor materials include insulation, wood, metal screens (undefined metal), acrylic panels, field stone, some of which we did not analyze due to the small amount used relative to other materials or the difficulty in determining the exact composition of the material. Primary building materials in PNE include steel, drywall, wood, slate, insulation, glass, concrete, and brick.

Aluminum

We identified large quantities of aluminum in the current greenhouses. We have estimated 1,500 lbs of aluminum used in the structure. There are aluminum sashes and framing for the exterior glass panels, and aluminum-framed screens that protect the glass roof below from snow and ice sliding off adjoining roofs. Aluminum is extracted from bauxite, a naturally occurring mineral. Bauxite mining causes habitat destruction, while aluminum production requires a significant amount of energy. By the time aluminum may be employed in construction, it has an embodied energy of 103,500 Btus per ton.³³ The smelting process necessary for aluminum production releases greenhouse gases and a variety of toxic substances to the air and water.³⁴ Once in use, aluminum has little environmental impact and a long lifespan as long as it is not exposed to a corrosive environment. Aluminum is easily recycled, although there are significant transportation costs associated with recycling.³⁵ Aluminum's negative environmental impacts occur primarily during production rather than use.

Glass

The greenhouses consist mostly of double-paned glass. Four different types are used in the greenhouses: plain, clear, safety tempered glass composes the interior walls; clear glass that is not safety tempered makes up the roofing vents; 60%-tinted safety tempered glass sheathes the tropical and cryptogram houses; and frosted safety tempered glass accounts for the remainder of glass used. The greenhouses contain an estimated total of 17,250 ft², of which approximately 6,600 ft² is tinted.³⁶

Window glass (and other thin, flat sheets of glass)—the primary type of glass in the building we analyzed—is made from a combination of sodium carbonate, silica, and lime.³⁷ Extraction, transportation and processing of these minerals result in a variety of negative

[Preferable+Products+\(EPP\)+Procurement+Program&L3=Find+Green+Products+and+Services+on+Statewide+Contracts&sid=Aosd&b=terminalcontent&f=EPP_osd_es_epp_find_green_what_are_SWCs&csid=Aosd>.](#)

³³ N. Howard, Construction Industry Research and Information Association, *Environmental Impacts of Building and Construction Materials: Volume C Metals*, (June 1995).

³⁴ Bjorn Berge, *The Ecology of Building Materials*, (Architectural Press, 2000), 78.

³⁵ Berge, 78.

³⁶ Tony Antonucci, personal communication, March 27, 2007.

³⁷ J. E. Shelby, *Introduction to Glass Science & Technology*, (Cambridge, UK: Royal Society of Chemistry (RSC), 2nd Ed, 2005), 264.

environmental impacts. All three minerals must be mined from the ground,³⁸ which negatively affects surrounding habitats. During mining, silica and lime produce health hazards to those in the vicinity due to particulates created in the process.³⁹ When inhaled, the crystalline particles of silica can cause the development of silicosis, which can lead to death.⁴⁰ The transportation of these minerals from extraction to building site is a significant environmental impact as some of the minerals may be transported by truck through many states.⁴¹ Not only do the transportation and processing of minerals require significant amounts of energy, but a great deal of energy is necessary to produce the glass itself. Because fossil fuels provide the majority of energy used to create glass, air pollution and greenhouse gases that contribute to global warming result. The creation of tempered glass, used in the greenhouses for safety reasons, requires even more energy to quickly heat and cool the finished glass. This is so that when it breaks, the pieces will resemble pebbles and will not be sharp.

During installation and use, glass has few environmental impacts. There are several different uses for glass if and when it must be removed from a building. If the glass is tinted or has had chemical treatment applied to its surfaces, as most greenhouse glass has, it can not usually be recycled (melted down and formed into new glass). It may be used, however, for purposes such as flooring (glass pieces bound together with adhesive and then cut to form a smooth surface) or mulch.⁴²

Insulation

Any form of thermal insulation in a building provides environmental benefits, since it substantially reduces the amount of heat, and thus the amount of energy, lost from the building. Throughout the entire life cycle of the product, however, there are a number of negative environmental impacts. The nature and extent of these impacts vary depending on the type of insulation used. Several kinds of thermal insulation are currently available in different forms, including fiberglass, rock wool or slag wool blanket insulation (in batts or rolls); fiberglass, rock wool, cellulose, or polyurethane loose-fill or spray-applied insulation; polystyrene (XPS, EPS or bead board), polyurethane or polyisocyanurate foam rigid insulation; foil-faced paper, polyethylene bubbles, plastic film or cardboard reflective systems.⁴³ Currently cellulose insulation is used in the greenhouse and fiberglass insulation is used in Pendleton East.⁴⁴

Fiberglass insulation is produced from silica and recycled glass. While the North American Insulation Manufacturers Association (NAIMA) is keen to point out that fiberglass

³⁸ D. S. Kostick, *USGS Minerals Yearbook 2005 – Soda Ash*, (August 2006), at <http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/soda_myb05.pdf>, 70.1; T. P. Dolley, *USGS Minerals Yearbook 2005 – Silica*, (October 2006), at <<http://minerals.usgs.gov/minerals/pubs/commodity/silica/silcamyb05.pdf>>; M. M. Miller, *USGS Minerals Yearbook 2005 – Lime*, (June 2006), at <http://minerals.usgs.gov/minerals/pubs/commodity/lime/lime_myb05.pdf>, 44.7.

³⁹ Miller, 44.2

⁴⁰ Dolley, 66.1

⁴¹ Dolley, 66.3

⁴² Environmental Design & Construction (various issues), browsed on InfoTrac 03/09/07.

⁴³ Department of Energy, Assistant Secretary, Energy Efficiency and Renewable Energy, *Fact Sheet, Insulation*, (January 19, 2004), accessed 03/08/2007, at <http://www.ornl.gov/sci/roofs+walls/insulation/ins_08.html>.

⁴⁴ Kristina Jones, presentation to ES 300 class, February 21, 2007.

Michael Culcasi, personal communication, April 2, 2007.

insulation is made from sand, “a rapidly renewing resource,”⁴⁵ the organization does not mention some of the other negative impacts associated with the production of fiberglass. For example, the mining of sand and limestone used in fiberglass insulation results in air and water pollution and erosion, and also requires combustion of fossil fuels. Furthermore, fiberglass insulation contains approximately 6-8% boron oxide (B₂O₃) by weight.⁴⁶ Boron is a non-renewable resource. Fiberglass insulation also has a higher embodied energy than other types of insulation (particularly cellulose). It requires melting the input materials in a fossil fuel-burning furnace, which consumes substantial amounts of energy and generates air pollution.⁴⁷

Phenol formaldehyde (PF), a chemical precursor in fiberglass insulation production, poses potentially severe health effects. The Occupational Safety and Health Administration (OSHA) dictates that fiberglass insulation products must include cancer warning labels because of concern that the fibers may be carcinogenic, especially if inhaled. However the American Lung Association suggests, however, that glass fibers are not linked to increased cancer risk, even among glass fiber manufacturing workers.⁴⁸

Among building materials, insulation includes some of the highest levels of recycled content. Fiberglass insulation manufacturers are the second largest users of post-consumer recycled glass in the U.S.⁴⁹ EPA recycled content procurement guidelines require that insulation products contain 20% recycled content while some fiberglass insulation contains up to 40% recycled content. Fiberglass batt insulation itself may also be recycled, either through reuse in building renovations and construction, or by being chopped up to become loose-fill insulation. However, because of dirt and dust that becomes trapped in the insulation over its lifetime, it is unlikely that fiberglass batt could be used in a product other than insulation.

Insulation was not initially installed in the greenhouses. In an effort to improve thermal insulation between both the different greenhouses (temperate, tropical, etc.) and the greenhouses and the outdoors, panels of aluminum-coated cellulose insulation were attached to the surfaces of the brick walls on the interior sides. Cellulose loose-fill or spray applied insulation, an alternative to fiberglass batt, contains a much higher proportion of recycled content—typically around 75-80% post-consumer waste paper. Besides paper, cellulose insulation contains fire retardant chemicals (some of which may include boron). Because the production of cellulose insulation requires minimal extraction and processing of natural resources, as well as a less-intensive manufacturing process, it has a significantly lower embodied energy than fiberglass insulation. Other environmentally positive aspects of cellulose insulation include the lack of negative effects on indoor air quality and the fact that scrap cellulose may be reused during installation.

Conversely, NAIMA argues that the highly compact form of fiberglass batt insulation results in fewer packages of insulation material per home, and therefore lower transportation costs and less packaging material entering the waste stream. The organization claims that insulating a typical 2,500 square foot home requires 30 packages of fiberglass insulation versus a

⁴⁵ North America Insulation Manufacturers Association (NAIMA), accessed 03/08/2007, at <http://www.naima.org/pages/benefits/environ/impact.html>.

⁴⁶ Dr. Kelvin Shen of U.S. Borax, quoted in “Insulation Materials: Environmental Comparisons,” (1995), *Environmental Building News* 4:1, accessed 03/08/2007, at <http://www.buildinggreen.com/auth/article.cfm?fileName=040101a.xml&mid=11#comments>.

⁴⁷ GreenHomeGuide, *Choosing the Right Insulation Delivers Energy Savings*, (09/20/2005), accessed 03/08/2007, at <http://www.greenhomeguide.com/index.php/knowhow/entry/784/C236>.

⁴⁸ GreenHomeGuide, <http://www.greenhomeguide.com/index.php/knowhow/entry/784/C236>.

⁴⁹ NAIMA, accessed 03/08/2007, at <http://www.naima.org/pages/benefits/environ/environ.html>.

maximum of 109 packages of cellulose insulation.⁵⁰ One could argue, however, that this alleged reduction in packaging and transportation costs still does not make up for the substantially higher amount of natural resources and fossil fuel energy required to produce fiberglass insulation.

Concrete

Concrete makes up the foundation of the greenhouses and most of the paths through the houses. Since concrete was applied throughout the building multiple times, the exact composition of the concrete varies throughout the building ranging from concrete with a very fine aggregate to concrete with a coarse aggregate. The foundation in the permanent houses differs from a normal building foundation in that there is no floor slab, so the soil in the interior beds is not separated from the exterior soils under and outside the foundation walls. In PNE concrete was used in cast slabs. Portland cement, the binding agent that creates the hard stone-like mass that holds together the other components of concrete such as sand and crushed stone, was acquired from a local source in Milford, Massachusetts.⁵¹

The ingredients for concrete—cement, silica, crushed stone, and water—are abundant. Concrete production, however, is extremely energy-intensive, although opportunities exist to utilize many recycled materials during the process. On average, 817,600 Btus of energy are required to produce 1 ton of concrete, though the energy per ton of cement is more than seven times that amount.⁵² Cement⁵³ constitutes an average of 12% of concrete composition and 94% of the energy consumed during production (the actual percentage depends on the type, grade, and quality of the concrete).⁵⁴ The impact of cement production is primarily seen in energy consumption and greenhouse gas emissions. Including the direct fuel use for mining and transporting raw materials, cement production requires approximately 6 million Btus for every ton.

Another significant environmental concern associated with cement and concrete production is dust. The fine dust particulates ($1/25,000$ of an inch) are detrimental to workers' health and may lead to respiratory difficulties or eye and skin irritation. Dust particles also contribute to smog, and could negatively affect soil because of their extreme alkalinity. For every tone of cement produced, 360 pounds of dust are.⁵⁵

Sand and crushed stone are used as fine and course materials for concrete, comprising an average of 34% and 48% of concrete by weight, respectively.⁵⁶ Although together they make up 82% of concrete bulk, they account for only 8% of the energy needed to produce concrete. Their embodied energy values, including energy for hauling, are roughly 40,000 Btus per ton of sand

⁵⁰ NAIMA, accessed 03/08/2007, at <<http://www.naima.org/pages/benefits/envIRON/pkgtrans.html>>.

⁵¹ Tony Antonucci, personal conversation, March 27, 2007.

⁵² "Cement and Concrete: Environmental Considerations," *Environmental Building News* 2:2, (1993), at <<http://www.buildinggreen.com>>.

⁵³ For this paper, I am focusing on Portland cement, which constitutes 95% of cement in the U.S. ("Cement" 1993). There are 8 types of cement, all of which are essentially the same, though which vary slightly in the additives used to confer specific properties (e.g. heat conductance, sulfate-resistance, etc). Portland Cement Association, "Frequently asked Questions," *Cement and Concrete Basics* (Mar. 11, 2007), at <http://www.cement.org/basics/concretebasics_faqs.asp>.

⁵⁴ Portland Cement Association, <http://www.cement.org/basics/concretebasics_faqs.asp>, Table 2.

⁵⁵ Portland Cement Association, <http://www.cement.org/basics/concretebasics_faqs.asp>.

⁵⁶ Portland Cement Association, <http://www.cement.org/basics/concretebasics_faqs.asp>, Table 2. Table 2 assumes the following: Aggregate hauled 10 miles to plant; Concrete mix: 500 lbs. cement, 1,400 lbs. sand, 2,000 lb. crushed stone, 260 lbs water/yard.

and 100,000 Btus per ton for gravel.⁵⁷ As sand and gravel are abundant resources with many industrial uses, their primary environmental impacts derive from quarrying and transportation, which are reflected in their embodied energy.

In some instances, aggregates used for concrete have functioned as natural sources of radon gas. The worst problems with radon arose when uranium mine tailings were used as concrete aggregates, but some natural stones also emit radon. Small but constant quantities of radon gas in confined spaces (e.g. a basement), could lead to cancer.⁵⁸

Although some water is used in the production process for concrete (6%, by weight), the majority of it is associated with machinery for washing. Washwater is needed to clean kilns, trucks, and other machinery—each requiring hundreds of gallons per day. Due to the alkalinity of the cement products, washwater is also extremely alkaline—with pH as high as 12.5.⁵⁹ Washwater is often discharged into settling ponds where solids can precipitate and the water can be re-used in the production processes. Although this washwater must be kept separate from potential rain-water runoff sources, leachate from these ponds can occur. The extreme alkalinity of the leachate can have lethal effects on the surrounding biological community, including fish species.⁶⁰ Since 1995 new concrete manufacturers in the U.S. have been required by law to treat effluent so that it is within 3 degrees Fahrenheit of the surrounding waterbody and so that it falls within a pH range of 6.0 to 9.0. Preexisting entities remain unregulated.⁶¹

Many chemicals are added to concrete in small proportions (0.03 to 0.15%) to control the setting time, plasticity, pumpability, water content, freeze-thaw resistance, strength, and color.⁶² Some additives are fairly benign and have little environmental impact (e.g. sugar-based chemicals), while others yield toxins and carcinogens such as formaldehyde. The use of additives depends on the manufacturer and the desired type of concrete produced.

Concrete wastes are associated primarily with demolition, though construction also results in waste. The American Institute of Architects (AIA) Environmental Resource Guide determined that concrete comprises up to 67% by weight (or 53% by volume) of construction and demolition wastes, with only a small percentage recycled.⁶³ Concrete not ground for re-use as roadbed aggregate or fill around buildings is sent to landfills, incurring transportation costs as well as taking up potentially valuable space in waste disposal location.

Brick

The solid structural walls in the greenhouse protrude above the surface, and extend up to about 2.5 feet above the ground. These walls are made of brick, with a minimal amount of concrete on the interior walls.

Manufacturing brick requires three main steps. First a brick manufacturer must mine clay or shale. Next, these materials are refined and shaped into the desired form. Finally, the brick is

⁵⁷ Portland Cement Association, < http://www.cement.org/basics/concretebasics_faqs.asp>.

⁵⁸ Portland Cement Association, < http://www.cement.org/basics/concretebasics_faqs.asp>.

⁵⁹ Portland Cement Association, < http://www.cement.org/basics/concretebasics_faqs.asp>.

⁶⁰ Portland Cement Association, < http://www.cement.org/basics/concretebasics_faqs.asp>.

⁶¹ Electronic Code of Federal Regulations (eCFR). “Title 40: Protection of the Environment”. 411.11, 12. [39 FR 6591, Feb. 20, 1974, as amended at 60 FR 33950, June 29, 1995] and [40 FR 6440, Feb. 11, 1975, as amended at 60 FR 33951, June 29, 1995]

⁶² Portland Cement Association, < http://www.cement.org/basics/concretebasics_faqs.asp>.

⁶³ Portland Cement Association, < http://www.cement.org/basics/concretebasics_faqs.asp>.

fired in a kiln.⁶⁴ In the first step of manufacturing, mining disrupts the landscape at clay and shale mining sites. Federal programs, however, require that all land involved in the mining of clay and shale be returned to a standard of natural quality, which minimizes the negative impact of this step in brick manufacture.⁶⁵ The process of shaping “green” or unfired bricks has negligible impact on the environment. The shaping process makes such efficient use of materials that there is little to no waste, and little energy is required at this stage. Firing is one of two large energy inputs in the lifecycle of brick.

The other main energy sink in the life cycle of brick is transportation. Both the raw materials and the finished product are very heavy and take a great deal of energy to move. For this reason, brick kilns are usually located very close to or on clay and shale mining sites.⁶⁶ Brick is a material for which buying locally manufactured items will greatly reduce the impact that the product’s life cycle will have on the environment.

Implementation of brick in design is environmentally benign and even beneficial to the function of the building. Brick is considered to be highly durable and has an “almost limitless” life-span. Furthermore, brick has a high thermal mass, which can reduce heating and cooling costs. Brick does not contribute to so-called “sick building” indoor air quality.⁶⁷

At the end of the life cycle of a brick walkway or building, the brick material may be reused, recycled or thrown away. Antique brick has an aesthetic appeal to some building and landscape architects, and they employ reused brick in their designs. Some companies specialize in reclamation and resale of bricks from old roads, buildings, and abandoned brickyards for these reuse projects.⁶⁸ Crushed brick may be used in landscaping as well, and finely crushed brick may also be returned to the brick manufacturing process.⁶⁹

Steel

Steel composes the framing for the glass walls and roofs of the greenhouses, and the structural support of PNE. Steel provides support as rebar, thin supporting metal rods, in walls and in stairwells.

Steel is an alloy consisting of a mixture of iron and carbon with small amounts of sulfur, phosphorus, silicon, and oxygen.⁷⁰ It can be produced from virgin materials (integrated route) or from recycled steel (electric arc furnace route (EAF)). The integrated route melts iron, coke, and limestone in a blast furnace and then an oxygen furnace. The EAF route uses only one furnace to re-melt the recycled steel with additional ingredients. The integrated route produces 60 percent of the world’s steel while the EAF route produces approximately 34 percent.⁷¹

⁶⁴ Brick Development Association, *A Sustainability Strategy for the Brick Industry*, (2002), accessed 03/13/2007, at <http://www.brick.org.uk/publications/PDFs/BDA_%20Dec_2002_Sustainability.pdf>.

⁶⁵ The Brick Industry Association, *Brick Revisited*, accessed 03/13/2007, at <<http://www.bia.org/pdfs/GreenNew.pdf>>.

⁶⁶ The Brick Industry Association, <<http://www.bia.org/pdfs/GreenNew.pdf>>.

⁶⁷ Build Green, *Conserving Natural Resources: Brick*, (2005), Build Green: Washington State Built Green Programs, accessed 03/13/2007, at <<http://www.builtgreen.net/features.html>>.

⁶⁸ Gavin Historical Bricks, *Build Green*, accessed 03/13/2007, at <http://www.historicalbricks.com/build_green.html>.

⁶⁹ Build Green, <<http://www.builtgreen.net/features.html>>.

⁷⁰ Thomas Net, “More About Steel Fabrication,” accessed 04/01/2007, at <<http://www.thomasnet.com/about/steel-fabrication-79941605.html>>.

⁷¹ World Steel: International Iron and Steel Institute, *About Steel*, accessed 04/01/07, at <http://www.worldsteel.org/faq_what.php>.

Steel is a common building material due to its cost-effectiveness, versatility, and durability even in extreme temperatures.⁷² Steel has a very high embodied energy, however, and its production leads to environmental degradation. Raw materials must be mined, which involves heavy explosives and causes pollution and disruption to the local ecosystem. Toxic waste chemicals from the manufacturing process often lead to water pollution.

Steel is the most commonly recycled metal. Recycling feeds steel back into the manufacturing process of its life cycle where it is melted and mixed to produce different types of steel. Recycled steel has 1/3 the embodied energy of virgin steel.

Drywall

Drywall panels make up the interior walls of PNE, which previously consisted of asbestos-laden wire lath plaster installed in the 1930s. Drywall is made from gypsum, recycled paper (newspapers, phonebooks, and cardboard) and corn or wheat starch binders that have replaced binders made from petroleum-based polymers. Drywall's main component is gypsum, a naturally occurring mineral with rich reserves. Gypsum is relatively inert, so it does not cause any health problems related to substance toxicity. Mining and transportation of gypsum, however, damages surrounding ecosystems. Particulates are emitted to the air and water during mining and processing, which cause silting of watercourses and effect aquatic ecosystems and also cause air pollution, with particular consequences for local populations.⁷³ Burning of petroleum-based fuel to operate machinery and vehicles required for mining and transport of gypsum produces harmful emissions, including carbon dioxide that contributes to global climate change.

Drywall production is a relatively low-waste process, with approximately 95 percent of the raw materials that enter a plant leaving as finished product.⁷⁴ The remaining five percent is cut into small strips and reused as the packaging for the drywall. Gypsum products are often covered with cardboard produced from a minimum of 90 percent recycled cellulose.⁷⁵

Instead of disposing of drywall in landfills, manufacturers have increasingly started to reclaim the boards from construction sites. The boards can be burned at high temperatures to eliminate the paper and return the drywall boards to their original gypsum state.⁷⁶ Builders and contractors are now also recycling drywall at the construction site. Scrap drywall is separated and pulverized by a mobile grinder. The result can be used as a soil amendment or plant nutrient.⁷⁷

Despite the fact that drywall is naturally fire resistant, extra fire-retardants such as perlite, vermiculite, boric acid and fiberglass are often added to drywall. Side-effects of these additives include water contamination, respiratory problems, and skin irritation.⁷⁸

⁷² Steel Recycling Institute, *Steel: The Clear Cut Alternative to Building Homes*, accessed 04/01/2007, at <<http://www.recycle-steel.org/PDFs/brochures/residenfram.pdf>>.

⁷³ Tom Woolley and Sam Kimmins, *Green Building Handbook: A Guide to Building Products and Their Impact on the Environment, Volume 2* (London: Spoon Press 2002), 33.

⁷⁴ CGC, Inc., *Sustainable Design: Selecting and Specifying Sustainable Walls, Ceilings and Substrates*, accessed 04/10/2007, at <<http://www.cgcinc.com/home.asp?nav=247&mkt=30&bc=5.247>>.

⁷⁵ Bjorn Berge, *The Ecology of Building Materials* (Oxford: Architectural Press, 2000), 264.

⁷⁶ Wikipedia, *Drywall*, (2007), accessed 03/13/2007, at <<http://en.wikipedia.org/wiki/Drywall>>.

⁷⁷ Drywall Recycling, *Recycling Gypsum Drywall at the Construction Site*, accessed 03/13/07, at <<http://www.drywallrecycling.org/>>.

⁷⁸ U.S. Environmental Protection Agency, *Q&A: Asbestos-Containing Vermiculite*, (08/02/2006), accessed 03/13/2007, at <<http://www.epa.gov/asbestos/pubs/oppt.pdf>>.

DuPont, *Fiberglass Handling*, (2006), accessed 03/13/2007, at <http://www2.dupont.com/Personal_Protection/en_US/tech_info/articles_fiberglass.html>.

Wood

In buildings on Wellesley's campus, wood is most often found in molding, paneling, and flooring. Some of the interior glass walls of the greenhouses are framed with painted wood, and all interior doors are made of painted wood and glass panels. In PNE, there are oak finishes and wooden blocking in office walls, which allows professors to "put up as many bookshelves as they can fit."⁷⁹ All woodwork came from a local carpenter's shop in New Hampshire.⁸⁰

Wood has minimal negative environmental impacts compared to those of aluminum or steel. Regeneration and harvesting have an environmental impact of less than 5% of the total energy consumption. Clear-cutting, the removal of all trees from a given tract of land, has severe effects on the environment including removal of carbon sinks (leading to a build-up of greenhouse gases) elimination of wildlife, and increased susceptibility of the land to flooding and erosion.⁸¹ Non-wood alternatives usually consume significantly more energy to manufacture than wood products. The greatest amount of energy-use associated with lumber production occurs in the manufacturing stage. The drying of lumber and veneer, and the final pressing of composite products, uses over 90% of energy consumed.⁸²

Slate

Slate is the most common roofing material on the Wellesley campus. It comes in a variety of colors and thicknesses, and may last up to 75 years.⁸³ PNE's slate roof is roughly one inch thick and has not needed replacement since its original installation.

Slate is a metamorphic rock formed from shale under high heat and pressure, and is used in the roofing industry because it easily breaks into sheets.⁸⁴ Slate is generally acquired from new sources and cut specifically for each building but has a long lifetime. If a roof requires maintenance or re-shingling at any point, old slate shingles that remain in good condition may be on the same buildings. If the building is torn down at any time, the slate shingles can be salvaged for use in other projects.

Most of the environmental impacts of slate result from mining techniques and processing.⁸⁵ Mining occurs both underground and in quarries, where workers are exposed to extremely dangerous conditions. Black powder and dynamite are used to blast away the "waste rock" in which slate is often embedded. The "waste rock" is piled next to the mining site where it is left unused. Additionally, large slate quarries ruin the local landscape and habitats through the clearing of vegetation. Quarrying activities can also alter groundwater flows.⁸⁶ The primary energy use associated with slate production remains lower than other comparable forms of stone production such as granite or sandstone. Problems associated with the slate industry, however,

⁷⁹ Michael Culcasi, personal communication, 04/02/07

⁸⁰ Michael Culcasi, personal communication, 04/02/07.

⁸¹ National Resources Defense Council, *What is Clearcutting*, accessed 04/01/2007, at <http://www.nrdc.org/land/forests/fcut.asp>.

⁸² Maureen E. Puettmann and James B. Wilson, *Life-Cycle Analysis of Wood Products: Cradle-to-Gate LCI of Residential Wood Building Materials*, (December 2005), accessed 03/12/2007, at www.corrim.org/reports/2005/swst/18.pdf.

⁸³ Vermont Structural Slate Company, *Slate Roofing*, accessed 03/27/2005 at http://www.vermontstructuralslate.com/slate_roofing.htm.

⁸⁴ Houghton Mifflin College Division, *Glossary: S*, accessed 03/27/2005, at <http://college.hmco.com/geology/resources/geologylink/glossary/s.html>.

⁸⁵ Slate Valley Museum, Personal Communication, 03/28/05, in 2005 ES300 class, *Another Green Hall*, 36.

⁸⁶ Bjorn Berge, *The Ecology of Building Materials*, pp. 110-115.

include the release of greenhouse gases, particulate matter, contributions to acid rain and reduced air quality in mining areas.⁸⁷

2.3 Indoor Environmental Quality

Indoor environmental quality (IEQ) should be one of the topmost priorities in any new building. Not only does IEQ have important implications for the physical health and well-being of a building's occupants, but it also indicates conditions that may eventually compromise the structural integrity of a building. Environmental impacts of a building as they relate to IEQ also compose some of the most visible parts of the building, and make a public statement about the environmental standards of the building as a whole.

Wellesley has taken measures to ensure that the health and well-being of its students, faculty, staff and administrators remains a top priority, particularly with regard to IEQ. All new carpet installations use low-emitting adhesives. All new and newly renovated buildings include HANSA® systems, highly advanced air conditioning systems that abide by the European standards for indoor air quality and are more restrictive than those used in the United States. The college also prohibits smoking in buildings and designates smoking areas at least 25 feet away from doors and windows.⁸⁸ The most recent new building on Wellesley's campus, the Wang Campus Center, sets a good example for improved indoor environmental quality by maximizing natural light and views from the building.

A. Laws, Regulations and Incentives

Several legal standards for IEQ apply to buildings at Wellesley. The Occupational Health and Safety Administration (OSHA) has developed standards for ventilation and exposure to hazardous chemicals to which new office spaces must adhere.⁸⁹ The Massachusetts Building Code also includes a section that addresses indoor air quality requirements. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has published voluntary consensus standards for indoor air quality systems and environment.⁹⁰ ASHRAE aims to advance "the arts and sciences of heating, ventilation, air conditioning and refrigeration to serve humanity and promote a sustainable world," and is a leader in its field.⁹¹

B. Baseline Assessment

It is important to keep in mind that the ideal IEQ conditions in a greenhouse differ from those in offices or classrooms. Greenhouse conditions are often dynamic, depending on the specific environmental requirements of various plants. In other words, temperature, relative humidity, light and carbon dioxide (CO₂) concentrations may differ substantially throughout different areas of the greenhouse. Within an office or classroom space, the goal is to maintain IEQ conditions at a level that is healthy and amenable to the building's occupants.

⁸⁷ Berge, 110-115.

⁸⁸ 2005 ES 300 class, *Another Green Hall*, 86.

⁸⁹ U.S. Department of Labor Occupation of Safety and Health Administration (OSHA), *Indoor Air Quality Standards*, (2007), accessed 02/28/2007, at <<http://www.osha.gov/SLTC/indoorairquality/standards.html>>.

⁹⁰ American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), *ASHRAE Standards and Guidelines*, (2007), accessed 05/05/2007, at <<http://www.ashrae.org/technology/page/548>>.

⁹¹ ASHRAE, *ASHRAE Mission*, (2007), accessed 05/05/2007, at <<http://www.ashrae.org/aboutus/>>.

Greenhouses

The Margaret C. Ferguson Greenhouses have more dynamic IEQ than do other buildings on the Wellesley College campus. In the greenhouses, a safe and comfortable space must be provided for plants as well as human occupants. For this reason, rather than providing a stable, homogenous indoor environment, the greenhouses maintain several separate rooms with different climates that fluctuate on daily and seasonal timescales. This baseline assessment focuses on the dynamic environmental quality needs particular to the Wellesley College greenhouses, which include climate control and lighting. Whereas currently lighting needs are adequately met in the greenhouses with the exception of late afternoon shading by the Science Center, the indoor climate cannot be regulated to the degree that the staff at the greenhouse would prefer.⁹²

Indoor Climate Control

The greenhouses at Wellesley College regulate temperature and humidity in a number of different ways. From May to August, the greenhouses use solar gain, venting and water evaporation to control temperature and humidity. In the colder months, from September through May, the greenhouses also use steam heat provided by the College.⁹³ Fans are sometimes used to facilitate ventilation and homogenize climate conditions. Though each of the greenhouse rooms ought to be kept within precise ranges of temperature and humidity according to daily and seasonal cycles, current climate maintenance capabilities at the greenhouse do not allow for precise such control.⁹⁴

This inability to control indoor temperature and humidity makes IEQ at the greenhouses fluctuate with variations in the weather outdoors. Due to the inherent inaccuracy of quantitative indoor climate measures at the greenhouses, this analysis of IEQ is qualitative. Instead of analyzing quantitative data, a series of three interviews and tours were conducted with Tony Antonucci, Senior Horticulturalist at the greenhouses and the most reliable source for indoor climate data at the greenhouse. The various methods of regulating temperature and humidity in the greenhouse are reported, including steam heat, ventilation, evaporation and whitewashing.

The steam heating system in the greenhouses is “notoriously unreliable” for temperature accuracy.⁹⁵ When the greenhouse staff decides to use steam for heat, they either open the valves that allow three main pipes under the floor of the greenhouse to fill with steam and provide radiant heat, or turn on the thermostats that monitor room-specific temperature and let aboveground steam pipes heat up when a room is too cold. The radiant floor heating system delivers a constant flow of heat regardless of the temperature of each of the greenhouse rooms, and can only be turned on and off by a manual switch.⁹⁶

Temperature and humidity are controlled by a variety of methods in the greenhouses. Vents on either side of each room increase air delivery from outdoors when manually opened. Currently optimal venting is impossible, since some of the vents are broken and cannot be opened, making cooling by this method difficult to control. Watering the floors and walls to allow evaporation to cool the greenhouse is another imprecise method used to control indoor

⁹² Tony Antonucci, personal communication, March 9, 2007.

⁹³ Tony Antonucci, personal communication, March 9, 2007.

⁹⁴ Tony Antonucci, personal communication, March 9, 2007.

⁹⁵ Tony Antonucci, personal communication, March 5, 2007.

⁹⁶ Tony Antonucci, personal communication, March 9, 2007.

climate. In the spring and summer, the greenhouse staff prevents excessive solar gain by whitewashing the outside panels of the greenhouse. Whitewashing is done when the last snow melts in late March or early April and is maintained until the first snowfall in the following autumn.⁹⁷ Whitewashing cannot be used to correct temperatures that exceed safe limits; it is strictly preventative. All three of these cooling techniques are regularly employed while the heat is on in the greenhouse, since there is a great deal of variability in temperature needs among greenhouse rooms. One room may require heat while another room needs to be cooled.⁹⁸

For humidity control, floor watering and misting are used. Automated misters spray water into the air at equal time intervals in rooms that require one hundred percent humidity saturation (e.g. the fern room). Otherwise, manual floor watering in the morning and throughout the day provides humidity via evaporation. Floor watering does not create optimal conditions for the plants, because it cannot be finely tuned to the particular needs of the plants in each room.⁹⁹

Lighting

The greenhouses primarily use light from the sun and use little artificial light. The entire surface area of the greenhouses is constructed in glass, allowing maximum light transmission to the indoor space, except when whitewashed as mentioned above. Even when whitewashed, the glass walls remain translucent. There are no shades to limit the amount of light that enters through the walls of the greenhouse. In the tropical house, tall, broad canopy foliage scatters light and prevents direct light from reaching understory plants, enabling the survival of these low-light tolerance plants. In the afternoon, the Science Center shades the greenhouse, at which time eight high intensity discharge (HID) sodium vapor lights are turned on in the research greenhouse to continue providing light to plants that are part of student and faculty research projects. The eight HID lamps are the only artificial lights in the greenhouse.¹⁰⁰

Pendleton East

Following the extensive renovation of Pendleton East during 2000-2001, Wellesley College's Environmental Health & Safety Department worked with Environmental Health & Engineering (EH&E) of Newton, MA to complete a post-construction IEQ audit. A variety of organizations and agencies promulgate standards for IEQ, upon which EH&E bases its methods and makes its evaluations. They include the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), a professional organization that develops standards for industry based on a rigorous peer review process that are not legally binding but are widely regarded as state-of-the-art, and which are reviewed every five years or so to allow for incorporation of the latest scientific findings.¹⁰¹ The Environmental Protection Agency (EPA), Massachusetts Department of Environmental Protection (MADEP) and Occupational Safety and Health Administration (OSHA) are some of the other key agencies involved in determining IEQ standards.

The EH&E audit included measurements of carbon dioxide (CO₂), carbon monoxide, temperature, relative humidity and airborne particulates; mechanical inspection of air handling

⁹⁷ Tony Antonucci, personal communication, March 27, 2007.

⁹⁸ Tony Antonucci, personal communication, March 27, 2007.

⁹⁹ Tony Antonucci, personal communication, March 9, 2007.

¹⁰⁰ Tony Antonucci, personal communication, March 9, 2007.

¹⁰¹ Cynthia D. Campisano, Environmental Health & Engineering (EH&E), *Post-Construction Indoor Environmental Quality Audit at Wellesley College, Pendleton East Building, 106 Central Street, Wellesley, Massachusetts (EH&E 11938)*, (July 12, 2001), Appendix B.

units; and laboratory analysis for volatile organic compounds (VOCs). Results indicate that IEQ in Pendleton East falls within established parameters. Our own samples of basic IEQ—CO₂ concentrations, temperature, relative humidity—taken in March 2007 show that IEQ in Pendleton East’s first floor remains within a healthy range for the building’s occupants. Both EH&E’s and our air sampling measurements of CO₂, temperature and relative humidity were taken using a Q-Trak Model 8550 IAQ Monitor, manufactured by TSI, Inc. (St. Paul, Minnesota).

Measurements of indoor CO₂ concentrations serve as an important indicator of room ventilation rate, since the amount of CO₂ increases in inverse proportion to amounts of outdoor air supplied to the room. Adequate ventilation is also important for diluting airborne concentrations of indoor contaminants. ASHRAE standard 62-1999 dictates an outdoor air supply of 20 cubic feet per minute per person as satisfactory comfort criterion for indoor environments such as offices and conference rooms, which corresponds to a CO₂ concentration of less than 850 parts per million (ppm).¹⁰² EH&E monitored CO₂ levels continuously for six hours on January 29, 2001 between 8:30 a.m. and 3:00 p.m. in two office locations and one common area, and found concentrations that ranged between 388 ppm and 743 ppm. Our measurements, taken on March 30, 2007 in Pendleton Well, the hallway outside PNE 133, and in PNE 139 and PNE 151, ranged between 385 ppm and 453 ppm. All of these results indicate that the amounts of outdoor air supplied by the building’s mechanical ventilation system comply with ASHRAE standards.

Both temperature and humidity are fundamental in determining thermal comfort for a building’s occupants. Humidity levels also indicate moisture conditions that could promote the growth of fungi on building materials, as well as the growth of mold and other biological agents that may become sources of indoor air pollutants.¹⁰³ ASHRAE has developed a “thermal comfort envelope” for human occupants, as defined in ASHRAE Standard 55-1992. ASHRAE’s recommendations for temperature and humidity, which specify 60% relative humidity for a winter temperature of 67.5-74 °F, apply to persons dressed in typical seasonal clothing doing light, primarily sedentary activity.¹⁰⁴ EH&E’s measurements of temperature and relative humidity taken concurrently with those for CO₂ concentrations indicated an air temperature in the sampling area on the first floor of Pendleton East at or below 74 °F during 90% of the six-hour monitoring period. Relative humidity in the same area was at or below 15% 90 percent of the time. Our measurements showed a relative humidity that ranged from 13.5% to 15.8 % in approximately the same location. While Pendleton East meets ASHRAE’s temperature guidelines, it does not meet the thermal comfort envelope specifications for humidity. Low relative humidity in winter is typical of buildings in the Northeastern U.S. that do not possess mechanical humidification systems.

EH&E’s IEQ audit also included a survey of airborne particulate concentrations and collection of air samples to be tested for presence of VOCs. Particles in indoor air represent an important category of indoor air pollutants because at high concentrations they may act as irritants to the eyes, skin and respiratory tract, and may also serve as distribution vehicles for chemicals or fungi and bacteria that are absorbed onto their surfaces.¹⁰⁵ EH&E’s survey of

¹⁰² ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality* (Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. 1999), in EH&E 2001, Appendix B.

¹⁰³ EH&E, Appendix B.

¹⁰⁴ ASHRAE Standard 55-1992, *Thermal Environmental Conditions for Human Occupants* (Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. 1992), in EH&E 2001, 5.

¹⁰⁵ EH&E 2001, Appendix B.

airborne particulate concentrations, determined using a DustTrak™, Model 8520, manufactured by TSI, Inc. (St. Paul, Minnesota), revealed dust concentrations that were on average less than 50 micrograms per cubic meter. This result indicates that particulate concentrations were within ranges typically found in office environments and were below exposure limits set by the EPA and OSHA.¹⁰⁶

VOCs, sources of which include adhesives and sealants and emissions from some types of furnishings, are known to have adverse health effects at exposure concentrations greater than 1,000 times typical indoor levels.¹⁰⁷ Paint functions as an additional source of VOCs. The interior walls of PNE were finished with synthetic paint, the most typical wall covering in buildings at Wellesley. The college currently uses conventional paints made with latex, acrylic and other synthetic resins, which, in addition to emitting hazardous chemicals, have production and disposal processes that have significant ecological impacts including high energy input, atmospheric pollution and slow biodegradation.¹⁰⁸ VOCs in paint act as solvents that readily evaporate. VOC emissions cause chemical and photochemical reactions in the atmosphere, leading to the formation of smog that contains secondary pollutants such as ground-level ozone and peroxyacetyl nitrate (PAN). This smog damages vegetation and materials as well as health.¹⁰⁹ As of 1995, production and manufacture of synthetic paints created 55,000 tons VOC pollution per year – nearly as much as the contribution from cars (65,000 tons/year).¹¹⁰

EH&E's laboratory analysis found VOC concentrations for the majority of tested compounds were below the reporting limit for the analysis method. Low levels of thirteen compounds were detected, but were below EH&E's VOC guidelines. Results did not indicate the presence of unusual types or concentrations of compounds that could present adverse health effects. One sample taken from PNE 133 contained a formaldehyde concentration of 38.4 parts per billion (ppb), above the National Institute for Occupational Safety and Health (NIOSH) recommended occupational exposure limit (REL) of 16 ppb. This concentration of formaldehyde was likely due to off-gassing of materials used during construction as well as the presence of completely new office furnishings. EH&E noted that formaldehyde concentrations in this location would likely decrease considerably as time passed, and recommended adequate outdoor ventilation in newly renovated areas to ensure against high VOC concentrations due to off gassing.¹¹¹

In addition to these technical measurements of IEQ, other considerations include the availability of daylight and views and the accessibility of operable windows, lighting, airflow and temperature controls to building occupants. A number of studies have indicated that IEQ improvements to lighting, heating and cooling increase worker productivity. For example, a 1997 article by William Browning in *Building Design and Construction* discusses the result of a study by Rocky Mountain Institute. The study documented eight cases in which energy retrofits to lighting, heating and cooling systems based solely on projected energy and maintenance

¹⁰⁶ EH&E, 2001, 8.

¹⁰⁷ EH&E, 2001, Appendix B.

¹⁰⁸ Association for Environment Conscious Building, *Synthetic Paints*, accessed 05/05/2007, at <http://www.ecoartisan.org/synthpaint.html#main_enviro>.

¹⁰⁹ Tom Woolley et al., *Green Building Handbook: A Guide to Building Products and Their Impact on the Environment, Volume 1* (London: Spon Press, 2001), 135.

¹¹⁰ Tom Woolley et al., 135.

¹¹¹ EH&E, 2001, 11.

savings inadvertently increased worker productivity, decreased absenteeism and/or improved the quality of work performed.¹¹²

2.4 Energy and Atmosphere

In response to rising energy prices, campuses nationwide are finding ways to reduce energy consumption. With short payback periods and small capital investments, energy conservation is the quickest and most economic method for decreasing energy costs. Energy production is, however, not only a financial burden but also an environmental one.

Currently Wellesley's co-generation plant burns oil and natural gas to produce most of the energy used on campus. While natural gas is a cleaner fuel than oil (it releases fewer emissions when burned), combustion of both these fossil fuels depletes natural resources, generates greenhouse gases, and contributes to climate change. Warmer climates hasten the spread of diseases, alter ecosystems, and increase the mortality rate.¹¹³ More frequent and severe droughts induce crop failures and famines. The rise in sea level brought about by melting glaciers and warming oceans causes stronger storms, flooding, and salt water intrusion and displaces those living around coastal areas or on islands. Additionally, water and air pollution such as sulfur oxides from the extraction and transportation of fossil fuels are inevitable and contribute to acid rain, eutrophication and smog.¹¹⁴ The burden of "climate [change falls] disproportionately on the poor,"¹¹⁵ especially those who live in developing countries or cannot afford insurance.

As an institution of higher learning concerned with social responsibility, Wellesley should actively work to address global issues such as climate change, and to set an example of environmental and ethical stewardship. Since buildings consume more than two-thirds of the energy produced in the United States, constructing an energy-efficient building would have a significant impact on Wellesley's energy consumption. Improving energy performance would not only lower operational costs, but would also decrease the amount of pollution emitted and reduce Wellesley's environmental footprint.

Although Wellesley does not currently have a green building on campus, the physical plant does uphold many energy efficient tenets that coincide with green building practices. Using energy efficient technology, the cogeneration plant has an exhaust recovery system that generates energy at 80-84% efficiency¹¹⁶ compared to a standard efficiency of 33%¹¹⁷. The college has also determined an optimum efficiency setting for its generators that maximizes the amount of energy produced from the least possible amount of fossil fuel resources. During the winter months, the cogeneration plant lets the generators run on their optimum efficiency setting and produces a set amount of energy. The college then buys any extra energy needed to satisfy its energy demands from the Town of Wellesley.

¹¹² William D. Browning, "Boosting Productivity with IEQ Improvements," *Building Design and Construction* 38:4 (April 1997), 50(3), 1.

¹¹³ Jonathan Patz et al., "Impact of regional climate change on human health," *Nature* 438, (November 2005), 310–317.

¹¹⁴ Microsoft® Encarta® Online Encyclopedia, *Air Pollution*, (2007), accessed 03/03/2007, at <<http://encarta.msn.com>>.

¹¹⁵ *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, Inter-American Institute for Global Change Research, accessed 03/04/2007, at <http://www.grida.no/climate/ipcc_tar/wg2/index.htm>

¹¹⁶ George Hagg, personal communication March 8, 2007.

¹¹⁷ Doug Hinrichs, "Cogeneration," *Encyclopedia of Energy*, Vol. 1, (2004), 581-594.

Office equipment including computers and fax machines, appliances stocked in the distribution center such as refrigerators, dehumidifiers and fans and the clothes washers and dryers in the residence halls all meet Energy Star standards.¹¹⁸ Even the Pitney Bowes mailing machines that the college's post office uses has an Energy Star label. Additionally, the Purchasing Department ensures that all products procured for departments like televisions and DVD players are Energy Star.¹¹⁹ Every vending machine on campus is also Energy Star compliant. In fact, the newer soda machines are "Enviro-cool" compliant, meaning that the compressors shut down internally and turn on when the beverages become too warm as opposed to staying on continuously.¹²⁰ Wellesley has also been phasing in compact fluorescent light bulbs (CFL) in the residence halls.

Other energy efficiency measures currently employed on campus include under-floor heating in Pendleton, which not only to reduce air-infiltration heat loss but also creates convection currents with the cooling pipes running through the ceiling.¹²¹ To reduce energy consumption by employing smart technology, the Margaret Clapp Library is equipped with sensors that turn the lights off when sufficient daylight is available.¹²² Wellesley was the first institution in the U.S. to begin installing one of the most energy-efficient heating, ventilation and air conditioning (HVAC) systems, the HANSA® system, in its buildings. Since the HANSA® system, created by the German company Hansa Neumann, came online in Green Hall in 1999,¹²³ the college has installed the HANSA® HVAC system in all new and renovated buildings. Additionally, Wellesley installed Vending Misers in Pomeroy Hall motion as well as motion sensors in two of Pomeroy's restrooms. Vending Misers switch the vending machines off into a low energy consuming standby mode when they are not in use. The college plans to expand both of these technologies to the entire campus in the future.¹²⁴

In recent years Wellesley has made efforts to decrease energy demand through education. In the spring of 2006, Wellesley held its first week-long energy competition. With some initial success, the college later transformed this week-long energy competition into a month-long sustainability competition to be held every semester. In spring of 2007, Wellesley placed energy reminder stickers on light switches in Stone-Davis and now has tentative plans for expanding this initiative to all residence halls.¹²⁵

The college also reduces its contribution of harmful automobile emissions (which include CO₂, CO and NO_x) through several transportation initiatives. Wellesley has chartered buses to provide public transportation to and from Cambridge and Boston on an hourly basis, and subsidizes T passes for students. The college makes Zipcars available to students throughout the year. These transportation options reduce the number of cars that students, faculty and staff drive to campus. Additionally, Wellesley is supporting a project to create a campus community bike program.

¹¹⁸ Created by the Department of Energy and the Environmental Protection Agency, the Energy Star label identifies energy efficient products. All Energy Star labeled products must operate significantly more efficiently than its counterparts while maintaining or improving performance.

¹¹⁹ Tom Kane, personal communication, February 28, 2007.

¹²⁰ Tom Kane, personal communication, February 28, 2007.

¹²¹ Peter Zuraw, personal communication, February, 28 2007.

¹²² 2005 ES 300 class, *Another Green Hall*, 54.

¹²³ "Green Hall A/C Project Underway, Galen Tower Starts Soon," *The Wellesley College Illuminator* (March 1999), available at < <http://www.wellesley.edu/PublicAffairs/Illuminator/illuminator399.html> >.

¹²⁴ Tom Kane, personal communication, February 28, 2007.

¹²⁵ Michelle Louie, electronic communication, April 14, 2007.

A. Laws, Regulations and Incentives

The United States Energy Policy Act of 1992 mandated that the technical requirements of ASHRAE 90.1 become the minimum standard for all new commercial buildings in the country. It also expanded the coverage of the Energy Policy and Conservation Act of 1975, which set efficiency targets to include commercial building heating and air-conditioning equipment and water heaters. ASHRAE 90.1 is also currently Massachusetts' statewide standard for energy building code.¹²⁶

The United States provides several tax incentives for constructing energy efficient buildings. The Energy Policy Act of 1995, for example, extends tax credits for wind, biomass, and landfill gas and offers new incentives to promote clean renewable geothermal energy. The Energy Policy Act of 2003 provides tax incentives to build energy-efficient commercial buildings by allowing deductions for property expenditures and providing credit for certain high efficiency machines like electric heat pumps, hot water heaters, and central air conditioners. The Energy Policy Act of 2005 creates yet another tax incentive for constructing energy efficient commercial buildings by granting a tax deduction for expenses related to the design and installation of energy-efficient commercial building systems.¹²⁷ However, a deduction may only be made if the building systems are installed before January 1, 2009.¹²⁸

B. Baseline Analysis

Approaches

We used a quantitative approach to establish a baseline for energy and water consumption for the greenhouses and proposed GES building. For both energy and water consumption we used two different methods to measure the total resource use. Since neither method we used is ideal, having two separate analyses provides some degree of data validation. We call these two methods the top-down and bottom-up approaches.

We describe the concept behind each approach below, and the specific methods used for each is detailed in the corresponding energy or water consumption section.

Top-down Approach

The top-down approach is the simplest method to establish an average baseline for Wellesley's campus. By taking the total annual resource use (for either energy or water) and dividing by the total campus building area (ft²), we calculate an average resource use per square foot of building for one year.

Obviously, buildings consume resources in different ways. For example, the Davis Parking Facility uses minimal (if any) water while the residence halls consume water not only in restrooms, sinks, and dining halls, but also in the form of steam heat. Regardless of these known and real differences in the way building function influences resource consumption, the top-down approach assumes that buildings use resources in the same way. In other words, every square foot of building on campus is assumed to be identical using this method.

¹²⁶ Building Codes Assistance Project, *Massachusetts Overview*, accessed 05/05/2007, at <http://www.bcapp-energy.org/state_status.php?state_ab=MA>.

¹²⁷ The American Institute of Architects, *Energy Efficient Commercial Buildings Tax Deduction*, accessed 03/04/2007, at <http://www.aia.org/adv_commercialbuilding_taxdeduction>.

¹²⁸ U.S. Department of Energy, *The Energy Policy Act of 2005: What the Energy Bill Means to You*, accessed 05/05/2007, at <<http://www.energy.gov/taxbreaks.htm>>.

Although the top-down approach makes an assumption we know to be false, it is an excellent method to establish *average* resource use for the campus. When considering the results of this method, it is useful to think about whether the function and construction of the greenhouses could cause them to consume more or fewer resources than the average.

Bottom-up Approach

In contrast to the general and simple nature of the top-down approach, the bottom-up method is specific and involves many derived estimates of each component of resource consumption. In this method, each source of consumption is quantified and aggregated to add up to the total resource use for a building. Using the known building area of the greenhouses, we estimate resource use per square foot by dividing our estimate of resource use by the greenhouses' building area.

Because we use constants and values we believe to be true for the greenhouses, the assumptions in this method are more reasonable than those in the top-down approach. This has both positive and negative implications. On one hand, the bottom-up approach provides a detailed and specific estimate of resource use that considers everything we deemed a significant source of consumption. On the other hand, because many direct measurements were impossible to make, assumptions are embedded in some calculations that we have no way of evaluating or verifying. Assumptions included things such as the rate of heat loss through glass, and that heat was only lost through glass in the greenhouses. These kinds of assumptions are necessary to make the calculations. As with any model, however, they are oversimplifications of imperfect and complex systems.

C. Methods for Calculation

We have written this section in order to give you a thorough understanding of how we made our calculations without burdening you with raw data. The section is divided between the top-down and bottom-up approaches that we used. For more details and a complete list of formulas, please see Appendix I.

Building Area¹²⁹

We obtained a list of buildings on campus with their associated area in square feet from the comprehensive Facilities Plan that was performed in 2006 by the Physical Plant Administration.¹³⁰ This list included all buildings that receive energy from the co-generators in the Physical Plant and water from the Botany Wells.¹³¹ The area for each building was described as the sum of all internal floor spaces. Thus the area reflects the number of stories in each building, not just ground-coverage alone.

For the greenhouses, we based our calculations on the building area supplied by the Director of the Botanical Gardens, Kristina Jones (7,235 ft²).¹³² This area includes all spaces enclosed by glass. Thus, the spaces between the greenhouses, the Annex and the office spaces and potting area technically located in the Science Center were not included. We confirmed the greenhouses' square foot area by measuring the greenhouse space directly. We found only a 2%

¹²⁹ The building area data are identical for the energy and water consumption baseline analyses.

¹³⁰ Facilities Management Department through the Comprehensive Facilities Master Plan (2006), April 6, 2007.

¹³¹ Wellesley College operates several facilities (e.g. faculty housing, French House, Cheever) that receive electricity and water from the Town of Wellesley.

¹³² Kristina Jones, Personal communication, March 7, 2007.

difference between our own calculations and the Director's figure, and thus feel confident that the value is accurate.

Top-down Energy Baseline Methods

For the top-down baseline, it was necessary first to estimate total energy consumption for buildings in Wellesley's campus. To do this, we obtained fuel consumption data for the calendar year 2006 from George Hagg, Assistant Director of Utilities (Appendix I).¹³³

As explained later in the energy baseline analysis, the co-generation plant consumes both crude no. 6 oil and natural gas to supply the college with heat and electrical energy. The college also purchases energy from the Town of Wellesley on occasion. Because each of these energy sources is measured in different units and used in slightly different ways, it was necessary to convert the fuel consumption into a common energy unit. To do this, we used standard values for fuel to energy conversions, which are listed below in Table 1.

Table 1: Fuel to energy conversion factors¹³⁴

Crude Oil No. 6	153,000	Btu/gallon
Natural gas	1,030	Btu/ft ³
Electricity	3,413	Btu/kilowatt-hour (kWh)

British thermal units (Btus)¹³⁵ are the standard unit used to express energy for heating and cooling systems as well as the embodied energy for fuels, materials, and other resources. We therefore express all of our energy calculations in terms of Btus here.

Several possible methods exist to estimate total campus energy. Our estimate assumes that the co-generation plant achieves the maximum conversion of fuel (i.e., every gallon of crude oil No. 6 produces 153,000 Btus, Table 1), and transmits all of that energy for use on campus. We know this is not the case, however, as no engine is perfectly efficient. In actuality, energy is lost while in transit to various campus buildings. If we had chosen to calculate individual buildings' energy demands, we would have had to account for this inefficiency, and would have ended up with a different estimate.

To calculate the average energy use per building area (Btus/ft²/yr), we divided the campus-wide energy consumption by total campus building area. This value (245,119 Btus/ft²/yr) represents the average energy usage for all buildings on campus.

$$\frac{\text{AverageEnergyUse}}{\text{BuildingArea/yr}} = \frac{\text{Btu}}{\text{ft}^2\text{yr}} = \frac{\text{CampusEnergy} - \text{Btu/yr}}{\text{CampusBuildingArea}} \quad (\text{Eqn. 2.4-1})$$

To determine how much energy the academic buildings, greenhouses, and proposed GES building would use if they were average campus buildings, we multiplied the respective building areas for each by the average (Table 2). A list of academic buildings can be found in Appendix I.

¹³³ George Hagg, Personal communication, April 18, 2007.

¹³⁴ John Bartok, Jr., *Greenhouse Management*, (May 2005), University of Massachusetts Amherst, accessed 03/10/2007, at <http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_fuels.htm>.

¹³⁵ The British thermal unit (Btu) is defined as equal to 1,055 joules. Btus were derived from the amount of energy needed to raise the temperature of one pound of water by one degree Fahrenheit from an initial temperature of 39°F.

$$BuildingEnergyUse = (BuildingArea) \left(\frac{AverageEnergyUs}{BuildingArea/yr} \right) \quad (Eqn. 2.4-2)$$

Bottom-up Energy Baseline Methods

The principle of the bottom-up approach is to add together each individual source of energy consumption within the greenhouses for a total sum that represents the overall consumption rate per year. The first step in this process was to identify the sources of energy consumption.

The greenhouses are connected to both the Science Center and to the Friends of Horticulture building. Although the adjacent buildings have air conditioning systems, the greenhouses do not, thus the only temperature regulation possible is through use of steam pipes (heating) and fans. Besides fans, there are few other electrical appliances in the greenhouses. Though all rooms are equipped with fluorescent lighting, these lights are seldom used. There is a small water pump that runs continuously in the Hydrophyte House, and the research greenhouses often have incandescent lighting in use for various projects. Miscellaneous electrical devices such as a motion-detector system or equipment for student labs are also employed throughout the year.

Of these sources of energy consumption, we reasoned that the greatest energy expenditure in the greenhouses is for heating since the greenhouses are maintained well above the average outdoor temperature.¹³⁶ Furthermore, the greenhouses are constructed largely out of glass, a poor insulator, which is employed in an aluminum framework that has many cracks and leaks where air can escape directly to the outdoors. These factors considered together give us reason to believe that there would be rapid heat-loss from the greenhouses, perhaps to a much greater extent than from other buildings on campus. For our calculations we assumed that most of the energy is consumed to heat the air within the greenhouses.

In order to do this calculation, we estimated the total volume of the greenhouses and used standard values for air density to determine the total mass of air in the greenhouses.¹³⁷ For the total energy consumption, we assumed that the rate of heat consumption was roughly equal to the rate of heat loss to the outdoors plus heat lost internally through heat exchanges between rooms.

The second Law of Thermodynamics states that heat-transfer is unidirectional: heat only flows from higher temperatures to lower ones. In a building this means that if not all rooms (or not all the spaces within a room) are the same temperature, there will be heat transfer, and the greater the difference between temperatures, the faster the transfer.¹³⁸ Heat-loss also depends on what material the heat must be transferred through. Each construction material—whether brick, glass, or drywall—has a value associated with its thermal conductivity (capacity to transfer heat) called a *U-value*. U-values are material-specific values that reflect the thermal conductivity and thickness of a material. They are measured in Btus/hr/ft²/°F and range from 0.20 to 1.20, with lower values corresponding to greater resistance to heat transfer or, in other words, greater insulation.¹³⁹

¹³⁶ During winter months, the greenhouses are kept at an average of 71°F.

¹³⁷ Air density: 1.29 kg/m³

¹³⁸ Diydata, *Sizing Heat Loss From a Building*, accessed 04/10/2007, at http://www.diydata.com/planning/ch_design/sizing.php#roomtemp.

¹³⁹ Diydata, *Typical U Values of Building Construction*, accessed 04/10/2007, at http://www.diydata.com/information/u_values/u_values.php.

Since brick is a much better insulator than glass, we assumed that all heat transfer to the outside occurred through the glass surfaces of the greenhouses. We used a U-value of 1.02 for the glass, a value attributed to single-glazed glass with an aluminum frame.¹⁴⁰ Before we could calculate heat loss, though, we needed two additional pieces of information: outdoor temperatures and the surface area for heat transfer.

For outdoor temperatures, we used average monthly high and low temperature data available from the National Weather Service for Wellesley, Massachusetts (02481).¹⁴¹ To obtain a mean temperature difference from the greenhouse temperatures, we averaged the monthly high and low values and subtracted them from the average greenhouse temperature (71°F). We assumed that this temperature difference was constant throughout the month.

The surface area for heat transfer was assumed to be the glass exterior walls. We measured the wall spaces directly and extrapolated the roof area based on its slope and ground coverage. The total energy required to heat the greenhouses was calculated as:

$$EnergyLoss[Btu/yr] = \sum \left\{ (GlassSurfaceArea)(U_{value}) \left(1.02 \frac{Btu}{(hr)(ft^2)(^{\circ}F)} \right) (\Delta MonthlyTemp)(NumHrs/Month) \right\} \quad (Eqn. 2.4-3)$$

In addition to heating costs due to direct heat loss to the outside, we also considered heat loss from air changes within the greenhouses. Air changes occur because there are temperature differences between adjacent rooms. Heat loss due to air changes is quantified by calculating the energy required to heat the volume of air in a space by the temperature differences. One cubic foot of air requires 1.129 Btus to heat it by 1° Fahrenheit, thus we calculate the energy consumed for air changes as follows:¹⁴²

$$EnergyLost[Btu/yr] = (GreenhouseRoomVolume)(1.129Btu)(NumAirChanges)(\Delta Temp) \quad (Eqn. 2.4-4)$$

We assumed three air changes per hour because it is considered the most conservative and universal number for heat loss estimates.¹⁴³

Two months out of the year (July and August), the average high and low temperature was higher than the mean temperature of the greenhouse, yielding a negative value for the heat loss and, consequently, energy production. We therefore excluded this data from the calculations, and thus the energy use during those months was exclusively from electrical appliances.

Finally we estimated the electrical energy consumption from lights, fans, and the water pump. To do this, we found similar devices online and based our calculations on the power-needs of those appliances.¹⁴⁴ We assumed the water pump was run continuously and that fans were run for at least 90% of the time in any given month. Lights we assumed are turned on for a maximum of 72 hours per month. For these calculations we did the following for each device:

¹⁴⁰ Diydata, *Typical U Values of Building Construction*, accessed 04/10/2007, at http://www.diydata.com/information/u_values/u_values.php.

¹⁴¹ The Weather Channel, *Monthly Averages for Wellesley Hills, MA (02481)*, accessed 04/10/2007, at www.weather.com.

¹⁴² Diydata, http://www.diydata.com/information/u_values/u_values.php.

¹⁴³ Diydata, http://www.diydata.com/information/u_values/u_values.php.

¹⁴⁴ City of Ames, Iowa, *Common Household Appliance Energy Use*, accessed 04/10/2007, at <http://www.city.ames.ia.us/ElectricWeb/energyguy/appliances.htm>.

$$\text{EnergyConsumed[Btu/yr]} = (\text{ApplianceEnergyNeed})(\text{UsageTime}) \quad (\text{Eqn 2.4-5})$$

Factors that were not included in our calculations include: solar heat, heat stored in the concrete or water in the greenhouses, heat required to warm floors or water in the greenhouses, presence of cracks and leaks in the system, and heat from human bodies. These variables were excluded either because we assumed them to be trivial or because we had no reasonable way to estimate or quantify them.

D. Results and Summary

Top-down Approach

We used the top-down approach to calculate the average energy consumption per square foot of building on campus. We found that the average is **245,119 Btu/ft²/yr** (Table 2). Based on this average, the total annual energy consumption of the greenhouses would be **1,773,434,566 Btu/yr**, or roughly 0.3% of the total annual energy consumption. If the proposed GES building used energy like an average campus building, it would consume **4,730,792,968 Btu/yr**.

Bottom-up Approach

The bottom-up approach was based on the specific materials and construction of the current greenhouses. We estimated that the greenhouses consume **3,031,000,000 Btu/yr**. Using this number and the building area of the greenhouses, we estimated that the greenhouses consume **418,936 Btu/ft²/yr**.

Comparison

The rationale for using two methods to perform a baseline analysis was to evaluate the accuracy of each estimate by how closely the data coincide. The top-down and bottom-up baseline calculations were 52% different in this instance, with the bottom-up estimate roughly double the top-down (Figure 4).

The difference between these numbers presents an interesting dilemma. On the one hand, we know the assumption in the top-down approach to be false: the greenhouses do not consume energy like other buildings on campus. It is not clear, however, without being able to measure steam energy, whether they would consume significantly more or less energy than the average building on campus. Although we can be reasonably certain that the greenhouses spend a greater percentage their energy consumption on heat production, whether the average use per area actually exceeds that found in other academic buildings that have extensive electrical and cooling systems is unclear.

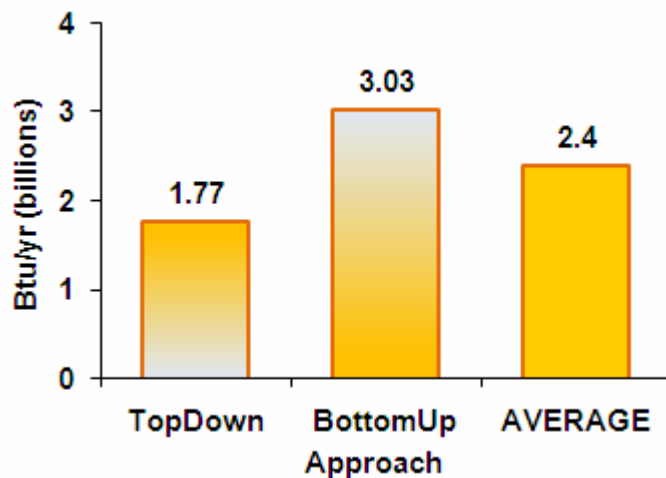


Figure 4: Comparison of top-down and bottom-up estimates of greenhouse energy consumption.

Furthermore, we were unable to measure the rate of heat loss from the greenhouses directly. Without actual measurements, the assumptions we made for the bottom-up approach are the best approximations we can make.

Since the two approaches have a wide range (**1.77 to 3.03 billion Btus/yr**) and there is no obvious indication that one method is more desirable than the other, we have averaged the values of each to give equal representation to each method (Table 2). We are confident that the actual energy consumption of the greenhouses falls within the range calculated by the top-down and bottom-up approaches. The average of the top-down and bottom-up approaches indicates that the greenhouses consume **2,402,217,283 Btus/yr** or **332,027 Btus/ft²/yr** (Table 2).

Table 2: Energy use baseline analysis for Wellesley College academic and greenhouse buildings

Buildings	Total Area (ft²)	Annual Energy Use (Btu/yr)^a	Energy Use per Area (Btu/ft²/yr)
Total Campus	2,267,550	555,819,150,000	245,119
Academic Buildings	849,400 (37%) ^b	208,335,052,923	
Greenhouses	7,235 (0.3%)	2,402,217,283 _{avg} (0.4%)	332,027 _{avg}
Proposed GES Bldg	19,300 (0.9%)	4,730,792,968 ^c (1%)	

^a Data used for calculation is from January 2006 to December 2006.

^b Percentages are percent of Total Campus values

^c Number based on Top-down Approach only

E. Environmental impact of Wellesley College Energy Use

Except during rare periods of power plant maintenance, Wellesley College obtains 100% of its energy from the cogeneration plant located on campus. As a cogeneration facility, the plant uses a combination of natural gas and crude oil to both heat and provide electricity to the campus. The dual purpose of heating and generating electricity enables the Wellesley Physical Plant to obtain greater energy efficiency than an average power plant: 81-84%¹⁴⁵ efficiency compared to a standard 33%.¹⁴⁶

While improved energy efficiencies lessen many environmental impacts associated with energy use by reducing the need for fuel, the cogeneration plant still burns fossil fuels and consequently still produces harmful effects on the environment. The impacts of energy use can be broken into two main categories: the impacts from burning natural gas and the impacts from burning crude oil. These effects can further be subdivided into the stages at which they occur: acquisition, energy production, transportation, and disposal.

The oil and natural gas used in the cogeneration plant began their existence as plant and animal deposits in the Cambrian Period. Over the last 500 million years, the deposits decomposed in an oxygen-free, high pressure environment.¹⁴⁷ The enormous time needed to

¹⁴⁵ Michael Dawley and George Hagg, personal communication with Spring 2007 ES 300, March 7, 2007.

¹⁴⁶ Doug Hinrichs, "Cogeneration," Encyclopedia of Energy, vol.1, 2004, p581-594.

¹⁴⁷ Union of Concerned Scientists, "Clean Energy," (December 2005), accessed 03/30/2007, at <http://www.ucsusa.org/clean_energy/fossil_fuels/offmen-how-oil-works.html>.

form natural gas and oil makes them nonrenewable resources. By using natural gas and oil to operate the cogeneration facility, we are depleting the world's natural resources.

Because oil and natural gas do not inhabit underground pools but are instead trapped within permeable rock like sandstone, acquisition is a work- and energy-intensive process. Both resources must be pumped from wells drilled deep in the ground. This drilling process not only creates high greenhouse gas emissions, but it also inevitably destroys the surrounding habitat. Drilling wells allows methane, a potent greenhouse gas, to escape from the ground in large quantities. The large machinery that is used to extract the oil also emits substantial pollutants as they require large quantities of natural gas or diesel fuel to run.¹⁴⁸

The emissions produced in the acquisition phase have effects beyond the region where they are produced. Greenhouse gases such as methane, carbon dioxide, and nitrous oxides¹⁴⁹ trap heat in the atmosphere,¹⁵⁰ leading to global climate change. Additionally, nitrogenous and sulfurous emissions cause acid rain and poor air quality,¹⁵¹ which can lead to health effects such as asthma, lung disease, and brain damage.¹⁵² While Wellesley College benefits from using crude oil and natural gas, the entire world bears the consequences.

During the transformation of natural gas and crude oil to electricity and heat, additional emissions are released into the atmosphere. These emissions include carbon dioxide, carbon monoxide, sulfur dioxide, and nitrogen dioxides, as well as particulate matter and unburned hydrocarbons.¹⁵³ Table 3 shows national averages for fossil fuel emissions for one million Btus.

Table 3: Fossil fuel emission levels in tons/million Btu of energy input.¹⁵⁴

Pollutant	Natural Gas	Oil
Carbon Dioxide	58,500	82,000
Carbon Monoxide	20	16.5
Nitrogen Oxides	46	224
Sulfur Dioxides	0.5	561
Particulates	3.5	42
Mercury	0	0.0035

Because the cogeneration plant produces heat in addition to electricity, it requires greater quantities of water than standard power plants for cooling. At Wellesley, the cogeneration plant takes the water needed for cooling from Lake Waban. After the water passes through the generators, it goes to the boilers, where it is turned into steam to heat the campus. The water

¹⁴⁸ U.S. Environmental Protection Agency, "Clean Energy," (Jul. 19, 2006), accessed 03/30/2007, at <<http://www.epa.gov/cleanrgy/oil.htm>>.

¹⁴⁹ Energy Information Administration, "What are Greenhouse Gases?" (April 2004), U.S. Department of Energy, accessed 03/30/07, at <<http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html>>.

¹⁵⁰ U.S. Environmental Protection Agency, "Clean Energy," (Jul. 19, 2006), accessed 03/30/2007, at <<http://www.epa.gov/cleanrgy/oil.htm>>.

¹⁵¹ Natural Gas Supply Association, "Natural Gas and the Environment," accessed 03/30/2007, at <<http://www.naturalgas.org/environment/naturalgas/asp>>.

¹⁵¹ Union for Concerned Scientists, "Clean Energy".

¹⁵² Lawrence Berkeley National Lab, "Health Effects of Air Pollution," U.S. Department of Energy, accessed 04/01/2007, at <<http://www.lbl.gov/Education/ELSI/Frames/pollution-health-effects-f.html>>.

¹⁵³ Energy Information Administration, "Oil and the Environment," (January 2006), U.S. Department of Energy, accessed 03/30/2007, at <<http://www.eia.doe.gov/kids/energyfacts/sources/non-renewable/oil.html#Environment>>.

¹⁵⁴ Natural Gas Supply Association, "Natural Gas and the Environment."

eventually returns to Lake Waban, though there is some risk that it could be in less than pristine quality, the decrease in water quality could potentially cause adverse effects to the lake's biota and ecosystem.

Fuel transportation causes the most severe environmental impact incurred during the lifecycle of natural gas and crude oil. Natural gas is transported via pipelines from which gas may escape through small leaks in valves. The gas that escapes from the pipeline can cause both ecosystem degradation and human health effects. According to the Department of Transportation's Office of Pipeline Safety, there are approximately seven deaths per year associated with natural gas transportation and distribution.¹⁵⁵ While this number is well under the 100 deaths per year from electric transmission lines, it is still significant.

Between 1973 and 1993, there were over 200,000 oil spills in US waters.¹⁵⁶ When spilled in water, crude oil spreads over the surface where it prevents oxygen from diffusing into the water—creating hypoxic conditions—and can coat the feathers of aquatic birds, causing them to sink and eventually drown. In coastal areas, oil can destroy mangrove swamps and coral reefs.

Burning crude oil in power plants produces waste water sludge and other solid waste that may contain high levels of metal and toxic compounds, most commonly chromium, cadmium, and nickel.¹⁵⁷ If ingested or inhaled these heavy metals can cause organ failure, reduced nervous system function, and low energy level. Long term exposure can lead to degenerative diseases such as multiple sclerosis and Parkinson's disease.¹⁵⁸

2.5 Water Efficiency

We depend on pure, fresh water for the operation of nearly every aspect of our lives—whether that is for the function of our bodies or basic heating and cooling systems in our buildings. Yet in Eastern Massachusetts, efficient water use is rarely a topic of concern. Geography is a simple explanation. Massachusetts is not currently experiencing a water shortage, and water conservation at Wellesley can provide only moderate economic benefits since the college has significant control over the aquifer and wells that supply the campus and does not pay for the water consumed. Moreover, conservation at Wellesley won't benefit the millions worldwide who do suffer from an inadequate water supply. Despite these reasons that water conservation has not been a priority in the past, the college has much to benefit from efficient and conscientious water-usage.

We live on a planet dominated by water, yet only one-fifth of one percent of that water is accessible and fresh and of that, only 30 percent is potable (0.06% overall).¹⁵⁹ The majority of water consumption occurs in buildings (approximately 80%).¹⁶⁰ Common sense dictates that making the most of a limited resource is not only practical, but also a necessary precaution. No one can predict the challenges the future will bring; we only know that there *will* be challenges. The advent of global climate change emphasizes the need for precautionary and forward thinking. Furthermore, Wellesley College has no guarantee that the aquifers currently supplying the

¹⁵⁵ Office of Pipeline Safety, "Incident and Accident Data," (Jan. 22, 2007), Department of Transportation, accessed 04/01/2007, at < <http://ops.dot.gov/stats/IA98.htm> >.

¹⁵⁶ Union for Concerned Scientists, "Clean Energy".

¹⁵⁷ P.A. Essoka, A.E. Ubogu and L. Uzu, "An overview of oil pollution and heavy metal concentration in Warri area, Nigeria, *Management of Environmental Quality*, (2006), vol. 17, issue 2, p209-215.

¹⁵⁸ Life Extension Foundation, "Heavy Metal Toxicity," (June 2003), accessed 03/31/2007, at <<http://www.lef.org/protocols/prtcl-156.shtml>>.

¹⁵⁹ Jacob Kalff. *Limnology*. Prentice Hall: Upper Saddle River, NJ, 2002: 41.

¹⁶⁰ "Water Conservation," The Robert Redfield building, The National Defense Council, 2004.

campus will continue to do so for the duration of Wellesley's existence. Conserving water usage now can extend the life of the aquifer and save on future costs. Because Wellesley is located on top of its water supply, any efforts to increase infiltration, decrease wastewater export, and reduce consumption benefits the college and surrounding environment. These measures presented below provide economic, educational, and environmental benefits to the college and should be included in the design of proposed Greenhouses and Environmental Studies (GES) building.

What Wellesley Has Already Done

Traditionally, Wellesley has used state and federal regulations to guide its water conservation efforts. The college has implemented numerous water saving devices in accordance with the 1977 Clean Water Act and 1992 Energy Policy Act. These acts specify water flow limitations for faucets, showerheads, and toilets, and are geared towards conserving water on a per person basis. The college also reduces wastewater flow by diverting some rainwater runoff into filtered channels that empty into Lake Waban. These storm drains are outfitted with devices that filter out potentially harmful agents such as oil and gasoline products. Large green areas make the campus conducive to reabsorbing runoff, thus promoting groundwater recharge. The college has also restored Brownfields by decontaminating affected areas and replacing them with wetlands, such as with the creation of Alumnae Valley, a green space that also offsets the impact of the Lulu Chow Wang Campus Center and Davis Parking Facility by decontaminating affected areas and replacing them with wetlands, such as with the creation of Alumnae Valley, a green space that also offsets the impact of the Lulu Chow Wang Campus Center and Davis Parking Facility.¹⁶¹

Conservation efforts by the college are restricted to some degree by old plumbing and sewage systems. In an effort to improve overall water efficiency, however, the college takes proactive steps to replace outdated or leaking systems. The replacement of several chill towers in 2005 was an investment that reduced water consumption by thousands of gallons per day.¹⁶² Wellesley has recently made efforts to install systems that use non-potable water for irrigation. To this effect, the college has installed irrigation for the Campus Center, athletic fields, and Tower Hill landscapes that are fed by Lake Waban rather than the Botany Wells. Some administrators at the college also believe that efforts to increase the Wellesley community's awareness of water use—to take shorter showers, use fewer dishes, etc—have helped reduce overall consumption.¹⁶³

In the past, Wellesley has implemented water conservation measures where it was affordable and convenient to do so. Since the college is granted water access per person and wastewater treatment is far-removed from the source, there have been few, if any, external pressures to force the college to be more conservative with its water use. Wellesley's policies are changing, however. Decision-makers at the college are at least discussing issues of sustainable practice and environmental impact for new projects, more so now than ever before. As the dialogue increases, so do the benefits to Wellesley College and its inhabitants. That is not

¹⁶¹ "The term 'Brownfield site' means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." Public Law 107-118 (H.R. 2869) - "Small Business Liability Relief and Brownfields Revitalization Act" signed into law January 11, 2002.

¹⁶² Patrick Willoughby, personal communication, April 6, 2007.

¹⁶³ Patrick Willoughby, personal communication, April 6, 2007.

to say that there is not significant room for improvement, but that Wellesley has begun to think with an eye for responsible sustainable practice.

A. Laws, Regulations and Incentives

The primary regulations for water efficiency are the 1977 Clean Water Act and the 1992 Energy Conservation Act. The acts require that sinks be fitted with low-flow fixtures, toilets use no more than 1.6 gallons per flush, and that showerheads use no more than 2.5 gallons per minute (gpm) at 80 pounds of pressure.¹⁶⁴

In addition, the college is restricted by the volume of water it can remove from the aquifer. This number, determined by the Massachusetts Department of Environmental Protection (DEP), is based on a certain number of gallons per person per day. The maximum draw the college could pull from the aquifers without disrupting recharge is 900 gallons per minute.¹⁶⁵

B. Baseline Assessment

We performed a baseline analysis of the water consumption on campus in order to evaluate the average water use on campus, the amount of water consumed by the greenhouses, and estimate how much water the proposed GES building would use if it were an average building on campus. Our analysis is a combination of a top-down and bottom-up approach. These approaches and the assumptions that follow are explained in Section 2.4 (p 28).

C. Methods for Calculation

We have written this section in order to give you a thorough understanding of how we made our calculations without burdening you with raw data. The section is divided between the top-down and bottom-up approaches that we used. For more details and a complete list of formulas, please see Appendix II.

Building Area

Building area for the entire campus as well as academic buildings, greenhouses, and the proposed GES building are summarized in Table 4. For a description of the campus building area, please refer to Section 2.4 (p 29), as the data are identical to those used for the energy-use analysis.

Top-down Approach to Estimate Water-use

Wellesley College measures its water use by the number of gallons pumped from the water tower on the east side of campus. According to Manager of Maintenance Services Donald Rivers, Wellesley College pumped 96,314,100 gallons for the 2006 calendar year.¹⁶⁶ Of that amount, 24% was used for outdoor irrigation, leaving a total of **73,504,546 gallons** for water consumption in buildings.

Perhaps of note is that the 2006 amount was considerably lower than the 2005 total campus water consumption of 109 million gallons.¹⁶⁷ Although it is not clear why there is an

¹⁶⁴ “Energy Policy Act of 1992,” (Jan. 23, 2002), NOAA Coastal Services Center, accessed 03/02/2007, at <http://www.csc.noaa.gov/cmfp/reference/Energy_Policy_Act_1992.htm>.

¹⁶⁵ Peter Zuraw, personal communication, February 28, 2007.

¹⁶⁶ Donald Rivers, electronic communication with Laura van der Pol, March 27, 2007.

¹⁶⁷ Donald Rivers, “Consumer Confidence Report for the Year 2005”, Wellesley College Water Supply System, December 2005, accessed 03/28/2007 at: <<http://www.wellesley.edu/Safety/LocalOnly/CCR.pdf>>.

almost 13 million gallon difference in water use from 2005 to 2006, the college did make several improvements that could explain a significant portion of the water-savings. In late 2005 the college replaced several inefficient chill towers that wasted thousands of gallons each day. In addition, Wellesley began to use Lake Waban for several new irrigation systems on campus, further reducing well-water consumption.¹⁶⁸ Since we did not have information regarding how much water was used for irrigation in 2005, all of our calculations are based on 2006 data.

In order to calculate the average water-use by buildings on campus, we divided the total water use for buildings by the total campus area. We multiplied this campus-wide average (28 gal/ft²/yr) by the building area of academic buildings, the greenhouses, and the proposed GES building to determine how much water each would consume if were an average building on campus.

$$Total \left[\frac{gal}{yr} \right] = Avg \left[\frac{gal}{ft^2 \cdot yr} \right] * A [ft^2] \quad (Eqn. 2.5-1)$$

Total = Total water consumption

Avg. = Average water use on campus (28 gal/ft²/yr)

A = Building area

Bottom-up Approach to Estimate Water-use

For the bottom-up approach to water-use, we considered only parts of the greenhouses that contain plants. Thus the office spaces, potting area, shower, and water fountains that are technically part of the Science Center were excluded from our analyses. We chose to exclude these potential sources of water consumption primarily because we wanted the area covered by the water baseline to correspond with the energy baseline analysis.

Within the greenhouses, we identified five primary components of water consumption: indoor plants, outdoor plants, misters, pond water, and whitewash. Plants in the greenhouses are currently watered by hand. From estimates provided by the Greenhouse Horticulturalists, staff use an average of 300 gallons per day to water indoor plants, which account for the majority of the water consumed annually (Figure 5).¹⁶⁹ These calculations are based on the amount of time needed to water each day (up to 3 hours) and the flow rate from the hose (~ 5 gal/min).¹⁷⁰

The outdoor plants consist of those in the Cameron Garden that is located between the Friends of Horticulture Building and the easternmost wing of the greenhouses. These plants are watered with a soaker-hose. Because the hose is outside and out of the way for the normal activities of the staff, the hose is often left running for longer than necessary.¹⁷¹ This explains

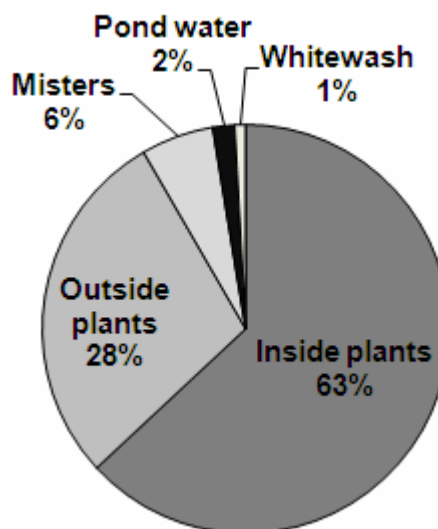


Figure 5: Bottom-up estimate of the relative contribution to total water consumption from each water source in the Wellesley College Greenhouses

¹⁶⁸ Patrick Willoughby, electronic communication with Laura van der Pol, April 6, 2007.

¹⁶⁹ Anthony Antonucci, personal communication with Anita Yip, March 31, 2007.

¹⁷⁰ Anthony Antonucci, personal communication with Anita Yip, March 31, 2007.

¹⁷¹ Patricia Diggins, personal communication, May 4, 2007.

how a relatively small garden could account for nearly 30% of the water used in the greenhouses (Figure 5).

Smaller contributors to the greenhouse water consumption are misters, pond water, and whitewash. Misters are used in the Cryptogram and Propagation Houses. Several nozzles spray automatically for several seconds each minute (See Appendix II for exact calculations). Pond water must periodically be changed and refilled. Our calculations assume that the pond is completely refilled 3 times in one year. Whitewash is a lime-putty that is mixed with water and applied to the roof of the Display House in order to reflect excess sunlight during the summer. We have included whitewash here because it fades over time, and thus must be applied every year.

For the total greenhouse water use, we simply added our estimates from each source of water consumption. By dividing the total (173,664 gal/yr) by the building area of the greenhouses, we obtained an average water use per square foot per year.

D. Results and Summary

Top-down Approach

We used the top-down approach to calculate the average water consumption per square foot of building on campus. We found that the average is **32 gallons/ft²/yr** (Table 4). Based off of this average, the total annual energy consumption of the greenhouses would be **234,529 gal/yr**, or roughly 0.3% of the total annual water consumption. If the proposed GES building used water like the average building on campus, it would consume **625,626 gal/yr**.

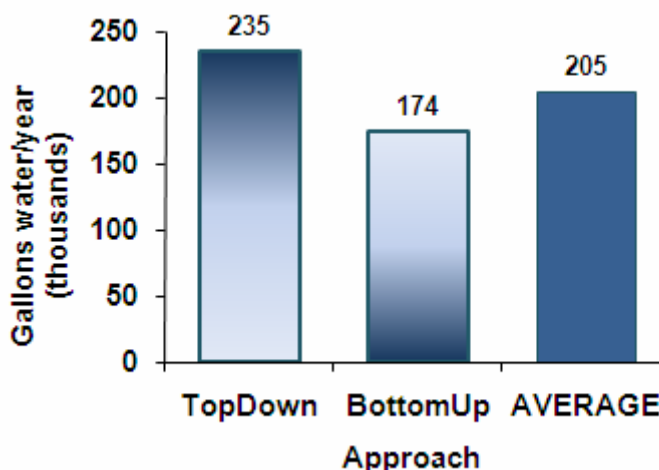


Figure 6: Comparison of top-down and bottom-up estimates of greenhouse water consumption

Bottom-up Approach

The bottom-up approach was a method based on the five major uses of water in the greenhouses. Due to the complex nature of this method, we only performed a baseline analysis for the greenhouses using this approach. We estimated that the greenhouses consume **173,664 gal/yr**. Using this number and the building area of the greenhouses, we estimated that the greenhouses consume **24 gal/ft²/yr**.

Comparison

The rationale for using two methods to perform a baseline analysis was to evaluate the accuracy of each estimate by how closely the data coincide. The top-down and bottom-up baseline calculations were 30% different in this instance, with the bottom-up estimate about one third less than the top-down (Figure 6).

Although different, the values found by each approach converge upon a relatively narrow range (**174 to 235 thousand gal/yr**). Surprisingly, the top-down approach produced a water-use estimate that was larger than the bottom-up approach. This conclusion is surprising because we

might predict that the greenhouses would consume more water than the average building on campus, and thus expect the bottom-up approach to yield the higher number. The large heating and cooling systems on campus, however, could cause a high average water-use per building area that would not be reflected in the bottom-up baseline analysis since the greenhouses do not contain any such systems of their own.

There is no clear directive that would invalidate either approach we used for the baseline analysis, thus, as we did for the energy baseline, we have averaged the values from each method to represent the value at the middle of our calculated range (Table 4). We are confident that the actual water consumption of the greenhouses falls within the range calculated by the top-down and bottom-up approaches. The average of the top-down and bottom-up approaches estimates that the greenhouses consume **204,096 gal/yr** or **28 gal/ft²/yr** (Table 4).

Table 4: Water use baseline analysis for Wellesley College academic and greenhouse buildings

Buildings	Total Area (ft²)	Total Annual Water Use (gal/yr)^a	Water Use per Area (gal/ft²/yr)
Total Campus	2,267,550	73,504,546 ^b	32
Academic Buildings	849,400 (37%)	27,551,360 (37%)	
Greenhouses	7,235 (0.3%)	204,096 _{avg} (0.5%)	28 _{avg}
Proposed GES Bldg	19,300 (0.9%)	625,626 ^c (1%)	

^a Data used for calculation is from January 2006 to December 2006

^b Total water use was: 96,314,100 in 2006. These percentages reflect % of total; the “Total Campus” number, therefore, reflects building usage excluding the 24% of water used for irrigation.

^c Number based on Top-down Approach only.

E. Impact of Wellesley’s Water-Use

Like the majority of the inhabitants in the Charles River watershed, Wellesley College uses groundwater rather than surface water.¹⁷² Wellesley’s two Botany Wells (PWS ID # 3317001) are drilled to a depth of 49 feet and in 2005, they supplied 98.7% of the college’s potable water.¹⁷³ The college purchased the remainder from the Town of Wellesley. By law, Wellesley can draw a maximum of 900 gallons of water per minute (gpm).¹⁷⁴ However, assuming uniform pumping rate throughout the year, in 2006 the college averaged only 183 gpm.¹⁷⁵

Due to its proximity to Lake Waban and the upstream surface waters of Morse Pond and Paintshop Pond, the college is in a particularly favorable location to draw high volumes (>250 gpm) of groundwater.¹⁷⁶ Surface water enables water removed from the aquifers to be replaced

¹⁷² Leslie DeSimone, *Testing ground-water management alternatives in the Upper Charles River Basin*, (2003), Eastern Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 042-03, accessed 03/30/2007, at <<http://pubs.usgs.gov/fs/fs-042-03/>>; E.H. Walker, S.W. Wandle, Jr., and W.W. Caswell, U.S. Geological Survey, *Hydrology and water resources of the Charles River Basin, Massachusetts*, (1975).

¹⁷³ Donald Rivers, *Consumer Confidence Report for the Year 2005*, (2005), Wellesley College Water Supply System, accessed 03/28/2007, at <<http://www.wellesley.edu/Safety/LocalOnly/CCR.pdf>>.

¹⁷⁴ Peter Zuraw, personal communication, March 1, 2007.

¹⁷⁵ Donald Rivers, personal communication, March 28, 2007.

¹⁷⁶ E.H. Walker et al., (1975).

by what is called induced infiltration whereby surface water is drawn into an aquifer as the result of pumping. Following this mechanism, Lake Waban and nearby waters create a buffer from the potential negative affects of Wellesley's water use, as water is directed into the aquifer from the lake before the water table declines significantly.¹⁷⁷

Because the college is located directly on top of the water supply, the aquifer is vulnerable to contamination from local road salting, oily road runoff, leakage from underground storage containers (e.g. fuel tanks by the Physical Plant), and excess fertilizers, herbicides, and other harmful chemicals entering the watershed.¹⁷⁸ The aquifer is composed entirely of sand over a mostly granite bedrock, so there is very little protection against harmful chemicals and excess ions as is typical of alluvial (clay-lined) aquifers.¹⁷⁹ Even the act of drawing large volumes of water from the aquifer could itself induce contamination to the water supply. If the water-flow from Lake Waban into the Morse Pond Aquifer were fast enough to suspend particulates, harmful microorganisms or contaminated sediments could enter the groundwater supply.

The greatest environmental impact of the college's water use is through its wastewater export. In 2006, the college exported 73,504,546 gallons of water as waste.¹⁸⁰ The college sends water to the Deer Island Treatment Plant, which then processes the waste to secondary treatment standards, removing 85% of suspended solids, 85% of oxygen consuming material (BOD), and up to 90% of toxic contaminants.¹⁸¹ The plant then sends the effluent to an outfall point in Boston Harbor approximately 9.5 miles east of Deer Island.¹⁸² Effluent leaving Deer Island is not treated for nitrogen removal, however, a concern because excess nitrogen can lead to eutrophication of water bodies. Four hundred diffusers release effluent at a depth below the thermocline, 100 feet. This depth was chosen to maximize the effluent to seawater ratio (1:100) and prevent concentrated nutrients from entering surface waters.¹⁸³ Since 2000, neither the Massachusetts Water Resources Authority (MWRA) nor independent researchers have found significant adverse effects of the outfall despite continuous monitoring.¹⁸⁴ In fact, since its inception, the outfall has allowed Boston Harbor water quality to improve.¹⁸⁵ MWRA has been careful to minimize potential effects of the outfall through careful research and innovative technologies such as a water diffusion system at the end of the outfall tunnel.

The impact of Wellesley's wastewater to Boston Harbor is an externality that needs to be considered in the overall ecological footprint the college has in the region. Wellesley College

¹⁷⁷ E.H. Walker et al., (1975).

¹⁷⁸ Massachusetts Department of Environmental Protection, *Source Water Assessment and Protection (SWAP) Report for Wellesley College*, (2003), accessed 03/30/2007, at <<http://www.mass.gov/dep/water/drinking/3317001.pdf>>.

¹⁷⁹ Arthur E. Nelson, *Surficial Geological Map of the Natick Quadrangle, Middlesex and Norfolk Counties, Massachusetts*, (Washington, D.C.:U.S. Geological Survey, 1974).

¹⁸⁰ Donald Rivers, personal communication, March 28, 2007.

¹⁸¹ MWRA Environmental Quality Department, *The Effluent Outfall: Boston Harbor and Massachusetts Bay*, accessed 03/30/2007, at <http://www.mwra.state.ma.us/harbor/html/outfall_update.htm>.

¹⁸² MWRA Environmental Quality Department, <http://www.mwra.state.ma.us/harbor/html/outfall_update.htm>.

¹⁸³ MWRA Environmental Quality Department, <http://www.mwra.state.ma.us/harbor/html/outfall_update.htm>.

¹⁸⁴ Suh Yuen Liang, Dough Hersh, and Wendy Leo, *Management and use of a long-term water quality monitoring database for Boston Harbor and Massachusetts Bay*, (2003), Environmental Quality Department, Mass. Water Resource Authority, accessed 03/30/2007, at <http://www.mwra.state.ma.us/harbor/pdf/database_poster.pdf>.

¹⁸⁵ D.I. Taylor, *5 years after transfer of Deer Island flows offshore: an update of water-quality improvements in Boston Harbor*, (2006), Boston: Massachusetts Water Resources Authority, accessed 03/28/2007, at <<http://www.mwra.state.ma.us/harbor/enquad/pdf/2006-16.pdf>>, 77.

already produces, however, nearly 40% less wastewater per person than the greater Boston average.¹⁸⁶ Compared to the region, Wellesley's impact seems minimal. Despite Wellesley's relatively minimal impact, however, the effect of dumping aquifer water into the ocean is a significant concern at a local level.

Dry riverbed and reduced water flow are not the environmental concerns that typically come to mind for eastern Massachusetts, a part of the state that on average receives 45-inches of rain per year.¹⁸⁷ Yet because surface waters account for much of the aquifer recharge, one potential impact of groundwater export is the seasonal disappearance or reduced flow of local rivers and streams.¹⁸⁸ Although this potential effect has not been examined in the Morses Pond Aquifer, the absence of scientific research is not evidence that detrimental impacts do not exist. In fact, the Ipswich River, whose watershed borders that of Morses Pond and comes within 5 miles of Wellesley, ran completely dry in the years 1995, 1997, and 1999 due to excessive groundwater pumping and export.¹⁸⁹

Not enough research or monitoring has been done in the Morses Pond Aquifer recharge zone to quantify the impact of Wellesley's water consumption and wastewater export. A careful examination of similar communities indicates, however, that while not the sole cause of any major environmental problem, Wellesley contributes to a regional concern of freshwater export and aquifer depletion. When Ipswich residents' river ran dry, they lost more than simply a popular recreational area. As is true for land in the Charles River watershed, the health of floodplain forests, marshes, estuaries, and wildlife sanctuaries depends on the water-flow from the river as well as a high groundwater table. Low flow in Ipswich devastated fish populations and riparian vegetation as well as fostered excess algae and harmful microorganism growth (such as fecal coliform bacteria) as the flushing rate and dissolved oxygen concentration declined.¹⁹⁰ Such extensive habit degradation takes years to recover. Thus, even though the Charles River and surrounding surface waters to date have not run dry, the fact that a neighboring water body has, indicates that there is an all-too-real potential for groundwater export to have tremendous environmental consequences.

3. Options Analysis and Recommendations

Section 3.1: The GES Building

Now that we have established a baseline resource consumption for the greenhouses and proposed GES building, this second portion of the paper is devoted to exploring several ways that we could improve upon that baseline. We consider options for specific materials and systems within each sector and go on to describe which of those we also recommend for the GES project. Before diving into our Options Analysis, however, first we will describe in detail the space that we have considered these options for, so as to put them into clearer context.

¹⁸⁶ Assuming a population of 3000, Wellesley College residents produced an average of 67 gal/person/day (or 92 gal/person/day assuming population of 2200). The greater Boston average is 140 gal/person/day. Calculation performed using data from Donald Rivers and MWRA Environmental Quality Department, <http://www.mwra.state.ma.us/harbor/html/outfall_update.htm>.

¹⁸⁷ Robert Glannon, *Water Follies*, (Washington, D.C.: Island Press, 2002), 101.

¹⁸⁸ E.H. Walker et al., 1975.

¹⁸⁹ Robert Glannon, *Water Follies*, (Washington, D.C.: Island Press, 2002), 101.

¹⁹⁰ Robert Glannon, 102-3.

Proposed Building Design

The layout for our proposed design can be viewed in Figure 7 (p 46). In order to create this design, we first needed to gauge the interest in additional Environmental Studies space, what the needs of such a space might be, as well as the needs of the greenhouses and the desires of the greenhouse staff. In order to do this, we met with relevant parties, such as Professor Kristina Jones, who is the director of the Botanical Gardens, in addition to surveying faculty and students who have an interest in Environmental Studies. The design we propose is not representative of every response we received, but it is a reasonable integration of the needs of potential users and the constraints of the site.

The GES design can be categorized into three main parts: the permanent greenhouse collections, the research houses, and the Environmental Studies space.

Permanent Collections

As some of the plants in the current greenhouses are rooted directly in the ground and the greenhouses need to remain connected to the Friends of Horticulture building, these permanent collections in the GES design remain in the same location (Figure 7). In order to improve heating efficiency and humidity control, we have consolidated the Hydrophyte and Tropical Houses so that the pond can provide natural moisture that is currently difficult for the greenhouses to maintain.

The greenhouses as they are now have not logical flow pattern. Visitors are forced to retrace their steps in order to travel through the greenhouses. In our proposed GES design, we have created a circular flow-pattern through the houses to facilitate movement. The connecting hallway that establishes this directional movement also provides access to the canopy of the Tropical and Warm Temperate Houses, allowing visitors to experience the plants in a way not possible from the ground. Furthermore, the proposed design grants easy access to all houses by the greenhouse staff.

Environmental Studies Space

In our proposed design, there are three classrooms—each sized differently to accommodate lectures, seminars, and general classes. In addition, there is also a space for a conference room, a kitchen nook, a library, and an ES program office. Two of the classrooms (general and seminar) are located upstairs, while the lecture and conference rooms are on the ground floor. The offices, of which there are five in addition to one for the director of the ES program, are positioned so that they face the permanent greenhouse collections, thus allowing for a refreshing view with natural light.

At the center of the ES program space is an open area that could be used as a lounge for community gathering and events, studying, and relaxation. There is room for a few tables, lounge chairs, perhaps a projector or even a computer station. The space is central to the building and open on one side to natural lighting in order to foster a comfortable, integrated shared space.

Research houses

The research and propagation houses are located on the second floor of our proposed design. In this way they are separated from the permanent collections, and thus protected from curious visitors. Also on the second floor is a potting, preparation, and storage area for use by

the greenhouse staff and researchers. We have proposed a Quarantine House as well for plants new to the greenhouses that may have pests or diseases.

The research greenhouses are currently under-utilized at Wellesley. Many professors are leery of devoting time and resources to research projects that could be disrupted by careless passers-by.¹⁹¹ Separating the research houses in this way and providing them with additional space may encourage more faculty and students to utilize this wonderful resource at Wellesley for future projects.

We have not conceived of every need or possible use of a potential greenhouse and Environmental Studies space. We created this design to provide ourselves with a tangible basis for comparison so that we could consider options and recommendations in reference to a particular space. Even though we have made many of our analyses in reference to this GES building proposal, our recommendations hold true for any green building design.

¹⁹¹ Martina Koniger, personal communication, November 2006.

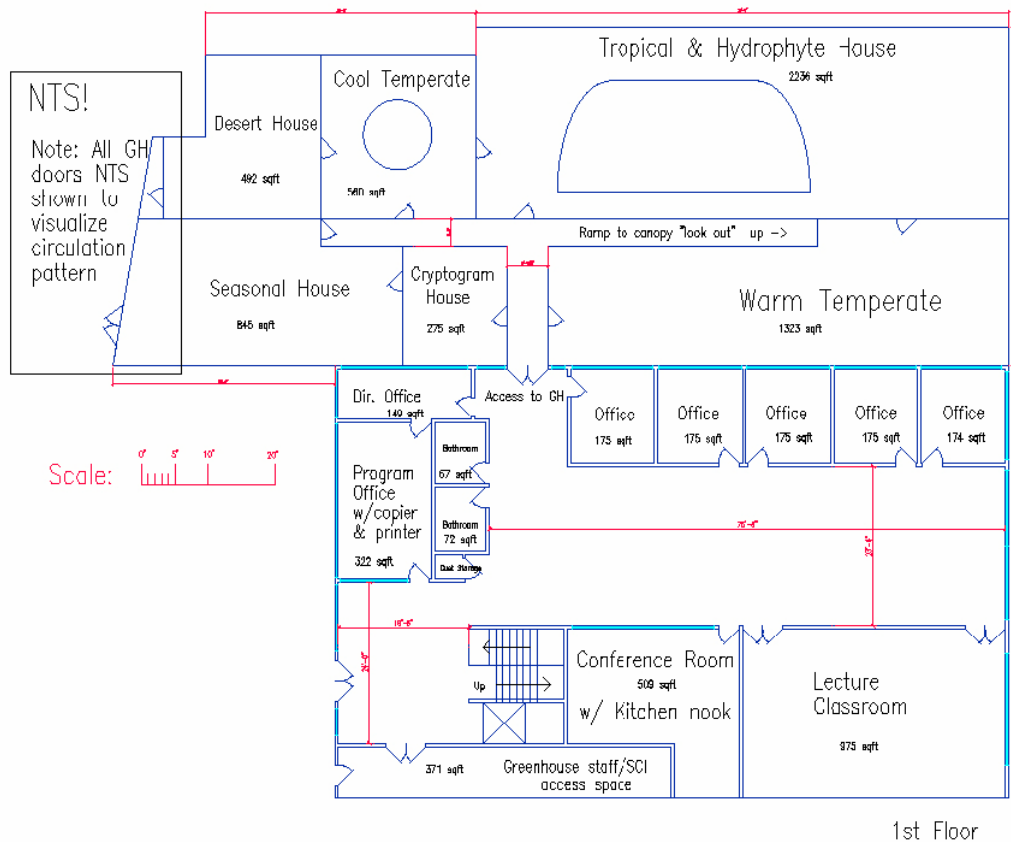
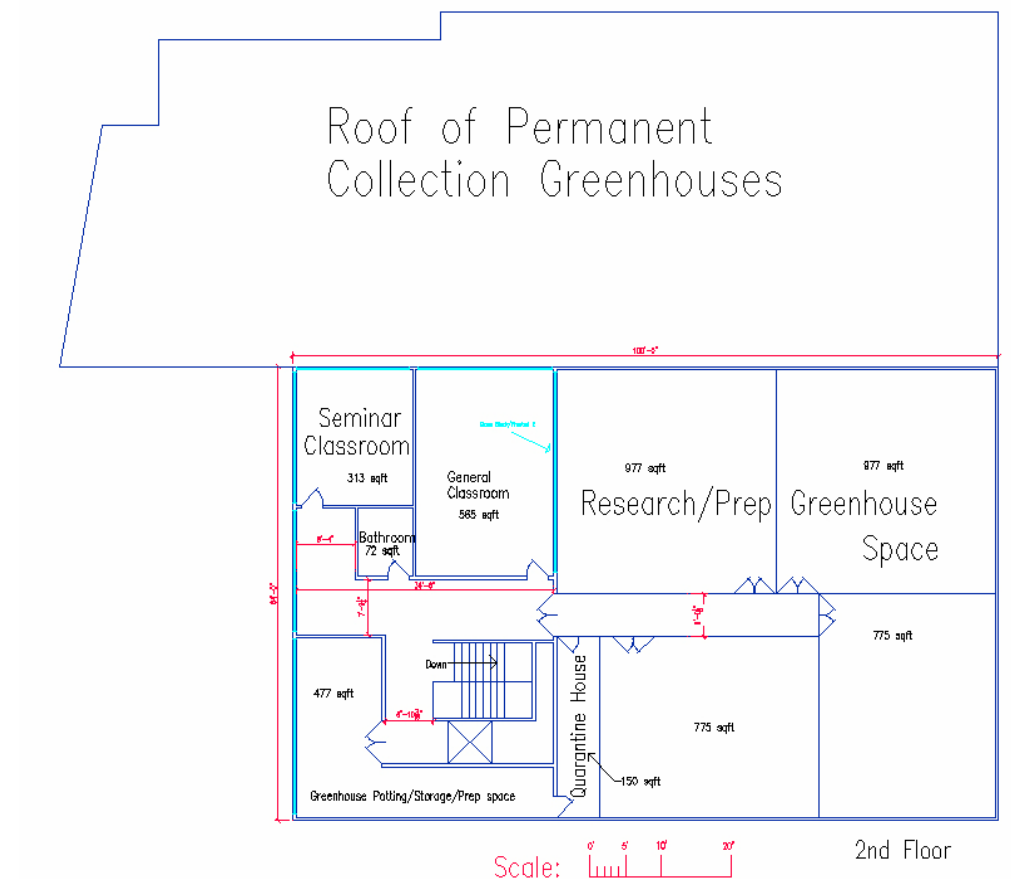


Figure 7: Design of the proposed GES building

Overview of the Options Analysis

An options analysis, presented in the following section, provides a means of evaluating and comparing alternatives for each sector. Alternatives selected for in-depth consideration were chosen pragmatically, so as to avoid investigation of options inappropriate or impossible for our proposed building. For example, we did not analyze erection of a large wind turbine or a building constructed entirely of rammed earth, but we did examine the possibility of microturbines and a rammed earth interior wall. We have taken a life-cycle approach to our options assessment, including discussion of both the production and use and disposal of products. The decision to construct a new building, including a green building, necessarily involves consideration of more than environmental costs and benefits. In recognition of this, we have also attempted to include information regarding the feasibility of each option, including cost, performance and functionality and local availability. We have also designed a chart template—divided into three sections titled production, use and disposal and feasibility—to provide visual representations of the benefits and disadvantages of each product. Each option has been assigned a rank of better, worse or the same as the baseline (See Section 1.5 D, *p* 7) for each characteristic considered. Based on the options analysis, we have determined recommendations for all of the categories examined that we feel are both environmentally beneficial and feasible.

3.2 Sustainable Sites

Construction

In addition to specific options to maintain site hydrology and avoid excessive water or pesticide/fertilizer use (see Landscaping and Outdoor Paving option assessments), construction projects should seek to minimize and control sediment and erosion, minimize and control runoff, and recycle materials. The Construction Waste Management Database, created in 2002 by the U.S. General Services Administration's (GSA) Environmental Strategies and Safety Division, contains information on companies that haul, collect and process recyclable debris from construction projects.¹⁹² Agencies such as the EPA and the Minnesota Pollution Control Agency have published extensive documents outlining best management practices to reduce sediment, erosion and runoff at construction sites. Without management of soil disruption and movement during construction, there is increased erosion and degraded water quality from additional sediments, toxicants and nutrients. According to the EPA, alterations to a site, such as clearing and grading, increase the erosion rate by as much as 1,000 times the pre-construction rate,¹⁹³ and consequently increase the amount and flow of water across the site. Erosion and sedimentation control plans should seek to minimize the amount of disturbed soil on site, prevent runoff from offsite areas across construction areas, slow runoff that flows across the site and remove sediment from onsite runoff before it leaves the site.¹⁹⁴ Specific methods employed depend greatly on the site and construction occurring, but a brief sample of practices includes: geotextiles, creation of vegetated buffer zones, temporary storm drain diversions and sediment traps.

¹⁹² U.S. General Services Administration (GSA), *Construction Waste Management Database*, (2007), accessed 04/11/2007, at < <http://www.wbdg.org/tools/cwm.php> >.

¹⁹³ U.S. EPA, "Sediment and Erosion Control," *Storm Water Management for Construction Activities*, EPA Document No. EPA-832-R-92-005, accessed 04/11/2007, at < http://www.epa.gov/npdes/pubs/chap03_conguide.pdf >.

¹⁹⁴ U.S. EPA, < http://www.epa.gov/npdes/pubs/chap03_conguide.pdf >.

Landscaping

Native and Adapted plants

Though there will be very little room for landscaping around the proposed GES building site, landscaping remains an important factor to consider for both aesthetic reasons and site resource use considerations. Wellesley College values its landscape and invests a large amount of money in maintaining it. One easy way to reduce maintenance costs is to plant native or adapted plants. Currently the College plants non-native resource intense grass on part of the site. Native plants, on the other hand, do not require as much care and attention in the form of supplementary watering or applications of fertilizer.¹⁹⁵ Adapted plants also need little additional resources or care.¹⁹⁶ Planting of native species could serve as a trial run for the remainder of campus. If native and adapted plants were proven to be as aesthetically pleasing as non-native plants and to require less resources and maintenance, the college might proceed to use native and adapted plants in future landscaping projects around campus.

Outdoor Paving Options

The GES building would require new exterior pathways. The pathways in the area are currently paved with asphalt, but there is no reason that future pathways must also be asphalt; other paving options exist. While considering the various options, we must keep in mind both the basic functions of pavement and the environmental impact of its manufacture, use and eventual disposal. At the greenhouse, pavement exists to provide an inexpensive firm surface upon which visitors may walk. The pavement must also be flat to allow for disability access and plowing in the winter. Permeable pavers can accomplish these basic requirements while achieving additional environmental benefits, most notably the infiltration of water through the material. Whereas the existing asphalt at the greenhouses makes water pool and run off, permeable pavers allow water to pass through the pavement and filter through the ground before recharging the groundwater.¹⁹⁷ The end result is increased natural filtration of pollutants and decreased erosion.¹⁹⁸ Among permeable pavement options are permeable concrete, permeable asphalt, block pavers and gravel. Since gravel interferes with winter plowing and disability access, we do not consider gravel as a viable option.

The EPA recommends permeable pavement as a Best Management Practice (BMP) for managing stormwater runoff.¹⁹⁹ The EPA also includes permeable pavement in its Low-Impact Development (LID) BMP recommendations, because using permeable pavement eliminates the need for stormwater pipe installation, which further disturbs the site.²⁰⁰ Additionally, since permeable concrete integrates pavement and stormwater management, the initial cost of

¹⁹⁵ U.S. EPA, *Benefits of Native Landscaping*, (August 2005), Office of Solid Waste and Emergency Response, accessed 04/13/2007, at <<http://www.epa.gov/GreenScapes/pubs/wntcrk.pdf>>.

¹⁹⁶ The Library Garden, *Use Adapted Plants*, accessed 5/4/07, at <<http://www.librarygarden.com/adaptedplants.php>>.

¹⁹⁷ Eban Z. Bean et al., *The Surface Infiltration Rate of Permeable Pavements*, (May 26, 2004), Interlocking Concrete Pavement Institute, accessed 4/12/2007 <<http://www.bae.ncsu.edu/info/permeable-pavement/icpi.pdf>>.

¹⁹⁸ National Association of Home Builders (NAHB) Research Center, *Permeable Pavement*, (2006), accessed 4/13/2007, at <<http://www.toolbase.org/Technology-Inventory/Sitework/permeable-pavement>>.

¹⁹⁹ Swarna Muthukrishnan, Richard Field and Daniel Sullivan, *Types of Best Management Practices*, (01/11/2006), U.S.EPA, accessed 4/13/2007, at <<http://www.epa.gov/NRMRL/pubs/600r04184/600r04184chap2.pdf>>.

²⁰⁰ Swarna Muthukrishnan, Richard Field and Daniel Sullivan, <<http://www.epa.gov/NRMRL/pubs/600r04184/600r04184chap2.pdf>>.

permeable paving options per square foot can be less than the initial average combined cost of a stormwater management system and asphalt.²⁰¹

Permeable Concrete

Permeable (porous) concrete may be mixed and applied using the same equipment that is used for standard concrete. Rather than sand, gravel-sized rock makes up the substrate for permeable concrete, creating a porous, pebbled surface. Before drying, the surface is roller-compacted like asphalt to level the surface.²⁰²

In addition to aiding stormwater management, permeable concrete has additional advantages compared to asphalt. Permeable concrete is lighter in color than asphalt, resulting in less heat-gain from solar absorption.²⁰³ Since the solar reflectance for new asphalt is 5% compared to 35-45% for concrete, using permeable concrete cuts down on the outdoor heat island affect.²⁰⁴ Permeable concrete does, however, require more maintenance, however, to maintain permeability. When sediments like dust and sand collect on the surface of porous concrete, its permeability is compromised. For this reason, the Boston Metropolitan Area Planning Council (MAPC) recommends against using porous concrete where frequent winter sanding is necessary. MAPC also advises that porous concrete should be vacuumed at least three times a year.²⁰⁵ There is a lack of consensus about whether porous concrete is especially vulnerable to frost heave; while some claim that permeable concrete drains so quickly that frost would not pose a problem, others warn against it.²⁰⁶ Permeable concrete also has higher embedded energy compared with asphalt.²⁰⁷

Permeable Asphalt

Permeable asphalt is similar to permeable concrete. Like permeable concrete, permeable asphalt has the advantage of requiring the same mixing and application equipment as standard asphalt does. The main difference is the use of porous bituminous material in the pavement and a slight increase in the amount of asphalt binder required. Permeable asphalt has the same solar heat-gain as standard asphalt (i.e. higher than permeable concrete), because they are the same color. Permeable asphalt is between two to six times less expensive than permeable concrete per

²⁰¹ Portland Cement Association, *Heat Island Reduction*, (2007), accessed 4/14/2007, at <<http://www.concretethinker.com/Papers.aspx?DocId=10>>.

²⁰² National Association of Home Builders (NAHB) Research Center, *Permeable Pavement*, (2006), accessed 4/13/2007, at <<http://www.toolbase.org/Technology-Inventory/Sitework/permeable-pavement>>.

²⁰³ National Association of Home Builders (NAHB) Research Center, <<http://www.toolbase.org/Technology-Inventory/Sitework/permeable-pavement>>.

²⁰⁴ Portland Cement Association, <<http://www.concretethinker.com/Papers.aspx?DocId=29>>.

²⁰⁵ Boston Metropolitan Area Planning Council (MAPC), *Massachusetts Low-Impact Development Toolkit: Permeable Pavement Factsheet*, accessed 4/14/2007, at <http://www.mapc.org/regional_planning/LID/permeable_paving.html>.

²⁰⁶ Portland Cement Association, *Pervious Paving*, (2007), accessed 4/14/2007, at <<http://www.concretethinker.com/Papers.aspx?DocId=10>>.

Boston Metropolitan Area Planning Council (MAPC), <http://www.mapc.org/regional_planning/LID/permeable_paving.html>.

²⁰⁷ Centre for Building Performance Research, Victoria University of Wellington, New Zealand, *Embodied Energy Coefficients*, accessed 4/14/2007, at <<http://www.vuw.ac.nz/cbpr/documents/pdfs/ee-coefficients.pdf>>.

square foot, making permeable asphalt a more cost-effective option.²⁰⁸ The same concerns about sediment clogging and frost exist for permeable asphalt as for permeable concrete.²⁰⁹



Figure 8: Example of block pavers

Block Pavers

Block pavers are more expensive than both permeable asphalt and permeable concrete. In a case study conducted in Kingston, North Carolina that compared the initial cost of installing a stormwater management system with block pavers *versus* installing asphalt, however, showed that the block pavers were less expensive.²¹⁰ Because they look like brick or interlocking stone, block pavers have a more aesthetically pleasing appearance than asphalt, porous asphalt and permeable concrete (Figure 8).²¹¹ The unique design of the material would be eye-catching and attract questions, adding to its educational value.

²⁰⁸ Low Impact Development Center, *Permeable Paver Costs*, (2002), accessed 4/14/2007, at <http://www.lid-stormwater.net/permeable_pavers/permpaver_costs.htm>.

²⁰⁹ National Association of Home Builders (NAHB) Research Center, <<http://www.toolbase.org/Technology-Inventory/Sitework/permeable-pavement>>.

²¹⁰ Low Impact Development Center, <http://www.lid-stormwater.net/permeable_pavers/permpaver_costs.htm>.

²¹¹ National Association of Home Builders (NAHB) Research Center, <<http://www.toolbase.org/Technology-Inventory/Sitework/permeable-pavement>>.

Table 5a: Lifecycle costs and impacts compared to ASPHALT

		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)				△ ■ ●	
	Human Health Risk			●		
	Habitat Degradation			●		
	Energy Consumption		△ ■	●		
	Air and Atmosphere Quality			●		
	Waste Production			●		
	Other Significant Impacts			△ ● ■		
	Environmental Benefits			△ ● ■		
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost		△ ● ■			
	Human Health Risk				△ ● ■	
	Habitat Degradation					△ ● ■
	Energy Consumption			△ ● ■		
	Air and Atmosphere Quality			△ ● ■		
	Waste Production			●	△ ■	
	Other Significant Impacts			△ ● ■		
	Environmental Benefits			△ ● ■		

Material	Symbol
Permeable Concrete	△
Permeable Asphalt	●
Block Pavers	■

Table 5b: Feasibility of options compared to Asphalt

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility			△ ● ■		
	Reduction of Cost (short run)				△ ■ ●	
	Performance & Functionality				△ ● ■	
	Overall Environmental Impact				△ ● ■	
	Local Availability		■	△		
	Educational Value				△ ●	■

Recommendations:

Given the more extensive maintenance needs of both permeable asphalt and permeable concrete, block pavers would be most desired for the site despite their higher relative cost. Block pavers also have the added advantage of a more visible presence on the site, and provided the opportunity to teach visitors.

3.3 Materials and Resources

Glass

While glass allows light to penetrate the walls and roof of the greenhouses, it is an inefficient insulator. For this reason, greenhouse glass should be double- or even triple-layered to increase heating efficiency and decrease breakage.²¹² Depending upon the level of insulation required, two or more layers of glass can be layered in windows. Sealed units—two or three sheets of glass with a layer of air sealed between them—have become a common means to increase insulation. An inert gas such as argon can replace the air between the layers, which improves the thermal and sound insulation of the window because it circulates more slowly than air. Plastic or metal sections connect the sheets of glass, and elastic, plastic-based mastic (resin) seals them.²¹³ In this section, we examine different types of glass and glass substitutes that could potentially replace the single-paned glass that surrounds the greenhouses today.

Energy Star® Glass

Energy Star labeled windows meet a stringent energy efficiency specification set by the Department of Energy, and have been tested and certified by the National Fenestration Rating Council (NFRC). The NFRC is an independent, third-party certification agency that assigns specific energy efficiency measures such as U-factor and Solar Heat Gain Coefficient to the complete window system, not simply the glass. Energy Star qualified windows may have two or more panes of glass, warm-edge spacers between the window panes, improved framing materials, and Low-E coating(s), microscopically thin coatings that help retain heat during the winter and disperse heat during the summer.²¹⁴

Standard clear glass has almost unlimited durability, but colored heat-absorbing glass can break if part of it is permanently in the shade while the rest is exposed to sun. If only one of the panes of glass splits, the whole window must be replaced. While pure, clear glass can be recycled, this is not the case for metal-coated glass and glass containing laminations of foil, reinforcement etc.

Plastics

Alternatives to glass such as Polymethylmetacrylate (plexiglass) and polycarbonate have recently appeared on the market. Glass substitutes also include fiberglass, acrylic sheets, and polyethylene film that are mainly used in roof lighting, greenhouses and conservatories. All plastics resist hailstone damage and are shatterproof, a distinct advantage over glass. Rigid plastics are stiff, but not brittle. They can flex to fit a curved surface and are available in large

²¹² Service Magic, *Greenhouses*, (2007), accessed 4/13/2007, at <http://www.servicemagic.com/article.show.Greenhouses.9522.html>.

²¹³ Berge, 376-377.

²¹⁴ Energy Star Customer Help, *What is an ENERGY STAR qualified window? How does it differ from other windows?*, (12/01/2006), accessed 4/13/2007, at <http://energystar.custhelp.com>.

sheets. Using plastics reduces the number of potential air leaks by lessening the number of joints in the covering. The sheeting products are mounted in a similar way to sealed units.²¹⁵

In terms of environmental impacts, transparent plastic products are petroleum-based, and generally consume high levels of primary energy. Their manufacture produces pollution that is harmful to both the environment and human health.²¹⁶ There may be minimal emissions from plastic-based putty, mastics and sealants depending upon the type of plastic and the mounting technique.²¹⁷

Fiberglass

Another practical replacement for glass, fiberglass usually comes in rolls or corrugated sheets and is translucent rather than transparent. Though you cannot see through it, light transmission through fiberglass is roughly equal to transmission through glass. Fiberglass diffuses light that passes through, virtually eliminating shadows. Fiberglass retains heat more efficiently than glass (but not as well as insulated plastics like multiwall polycarbonate or two layers of inflated polyethylene film) while transmitting less heat into the greenhouse, a benefit in both winter and summer.²¹⁸ Owners must be especially careful to maintain the gel coat on fiberglass, because eventually the sun will degrade it, or it will yellow and collect dirt, decreasing the amount of light that can enter the greenhouse.

Polycarbonate

UV-treated polycarbonate provides much of the clarity of glass, yet is stronger and more resistant to impact than other greenhouse glazings.²¹⁹ Double-Wall Polycarbonate Panels will not crack or shatter, will retain heat in the winter, diffuse light for even plant growth, and block 98% of the harmful UV rays. The impact strength of polycarbonate is 30 times greater than acrylic, and 200 times greater than glass.²²⁰

²¹⁵ Greenhouse Cover Options, accessed 4/13/2007, at

<<http://www.servicemagic.com/article.show.Greenhouses.9522.html>>.

²¹⁶ Bjorn Berge, *The Ecology of Building Materials* (Oxford: Architectural Press, 2000), 151-154.

²¹⁷ Service Magic, *Greenhouses*, (2007), accessed 4/13/2007, at

<<http://www.servicemagic.com/article.show.Greenhouses.9522.html>>.

²¹⁸ Service Magic, *Greenhouse Cover Options*, accessed 04/13/2007, at

<<http://www.servicemagic.com/article.show.Greenhouses.9522.html>>.

²¹⁹ Service Magic, *Greenhouse Cover Options*, accessed 04/13/2007, at

<<http://www.servicemagic.com/article.show.Greenhouses.9522.html>>.

²²⁰ Sunshine Greenhouse FAQ's, Sunshine Greenhouse FAQ's, accessed 4/13/2007, at

<http://www2.yardiac.com/long.asp?item_id=2384>.

Table 6: Greenhouse Covering Insulation (R) Values

4 mil polyethylene	0.83	6 mm twinwall polycarbonate	1.54
6 mil polyethylene	0.87	8 mm twinwall polycarbonate	1.61
Fiberglass / polycarbonate (single layer)	0.83	10mm twinwall polycarbonate	1.89
6 mil polyethylene double layer (inflated)	1.43	16 mm triplewall polycarbonate	2.50
3 mm glass (single layer)	0.95	Low-E Glass	3.13
Two layers of glass (insulated)	2.00	Low-E Glass with 2 suspended films	5.05

R value is a commercial unit used to measure the effectiveness of thermal insulation. A larger number represents a higher insulation value and therefore greater heating and cooling efficiency. Specific, brand-name, product R values may vary slightly from these figures.²²¹

Table 7a: Lifecycle costs and impacts compared to Double Paned Glass

		Worse		Same as Standard		Better	Options	Symbol
PRODUCTION	Initial Cost (\$)		△		●		Energy Star Glass	△
	Human Health Risk			● △			Plastic Paneling	●
	Habitat Degradation		●	△				
	Energy Consumption		●	△				
	Air and Atmosphere Quality		●	△				
	Waste Production		●	△				
	Other Significant Impacts							
	Environmental Benefits			● △				
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost			●	△			
	Human Health Risk			● △				
	Habitat Degradation		●	△				
	Energy Consumption		●			△		
	Air and Atmosphere Quality			●		△		
	Waste Production			● △				
	Other Significant Impacts							
	Environmental Benefits			● △				

²²¹ Greenhouse Buying Guide, ACF Greenhouses, accessed 3/13/2007, at <http://www.littlegreenhouse.com/guide.shtml>.

Table 7b: Feasibility of options compared to Double Paned Glass

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility		●	△		
	Reduction of Cost (short run)		△			●
	Performance & Functionality				●	△
	Overall Environmental Impact		●	△		
	Local Availability			● △		
	Educational Value			●	△	

Options	Symbol
Energy Star Glass	△
Plastic Paneling	●

Recommendations:

Given the quantity of covering that is needed for a greenhouse combined with an academic building, the most efficient choice would be to use an Energy Star certified glass. Glass will have the longest lifetime, will need little maintenance, and Energy Star glass will be the most efficient insulator, ensuring that large quantities of heat are no longer lost to the great outdoors.

When selecting an insulation material, the most important environmental considerations are performance and suitability for your application. Over the lifespan of a building, the energy saved with a well-insulated building "envelope" far outweighs the environmental impacts of insulation's manufacture. The North American Insulation Manufacturers Association (NAIMA) has found that the insulation produced annually in the United States saves 12 times the energy its manufacture consumes.²²² While this calculation may ignore the energy required to extract and process materials used to make insulation, it provides an idea of how much energy insulation can save.

One should consider the environmental impact of each product's manufacture and disposal when comparing two materials of equal performance. Some insulation materials are made from almost entirely nontoxic, abundant or renewable materials, while others are made from limited petroleum resources and are difficult or impossible to recycle.²²³

Insulation materials can affect indoor air quality, though most impacts are small when materials are installed properly. Concerns that may arise include irritation from airborne fibers entering living spaces and emissions from glues, flame retardants or other additives, especially if they are bioaccumulative.²²⁴

Cellulose and Cotton insulation are both efficient and have lower environmental impacts than traditional fiberglass. Cost must be taken into account, however, as they can be up to twice as expensive as traditional fiberglass due in part to their relatively new place in the construction world.

²²²GreenHomeGuide, *Choosing the Right Insulation Delivers Energy Savings*, accessed 4/13/2007, at <http://bayarea.greenhomeguide.com/index.php/knowhow/entry/784/>.

²²³ Tom Woolley et al., *Green Building Handbook: A Guide to Building Products and Their Impact on the Environment, Volume 1* (London: Spoon Press 2001), 41-50.

²²⁴ Tom Woolley et al., 41-50.

Insulation Materials

Plastic foams

The petrochemical industry produces many plastic foams such as polystyrene, polyethylene and formaldehyde foams that share a similar impact and are sometimes almost indistinguishable. Oil and natural gas are the main raw materials for petrochemical plastics. Plastics account for 4% of the world's oil consumption. Emissions of particulates, oil, phenols, heavy metals and scrubber effluents are all associated with petrochemical manufacture. Petrochemical industries are responsible for over half of all emissions of toxics to the environment.²²⁵ Petrochemical refineries are major emitters of the acid rain forming gases SO₂ and NO_x.²²⁶

Plastic foams offer some significant benefits, however, including higher thermal resistance (R-values) for a given thickness and improved air sealing of surfaces. Over the lifespan of a home, foams will save more energy per inch of insulation than conventional fiberglass batt insulation because of their high R-values and durability.

There are two types of polystyrene: extruded (XPS) and expanded (EPS), also called blueboard and beadboard, respectively. While there is no minimum recycled content limit for polystyrene, products may contain some amount of recycled content because polystyrene itself can be recycled. EPS is the more environmentally preferable of the two, since XPS is the only foam that still uses HCFCs as a blowing agent, and will likely do so for the next four to five years. Polystyrene foams contain brominated flame-retardants that raise serious health and environmental concerns, since some brominated compounds are bioaccumulative. XPS is more moisture resistant and suitable for below-grade applications; EPS can be used below-grade if coated with a plastic or foil film. XPS is more expensive than EPS and has a slightly higher R-value.²²⁷

Fiberglass

Fiberglass insulation is made of silica sand and recycled glass, both abundant resources. The EPA requires that 20 percent of fiberglass materials come from recycled sources, either post-consumer or post-industrial, and some products contain up to 40 percent recycled content. Fiberglass insulation production requires melting the materials in a fossil fuel-burning furnace, which consumes substantial amounts of energy and generates greater amounts of air pollution than the production of other insulation types.²²⁸

If installed properly, there is little danger of inhaling fibers, which are throat, eye and skin irritants. Although OSHA still requires cancer warning labels on fiberglass insulation products, the American Lung Association states that glass fibers are not linked to increased cancer risk, even among glass fiber manufacturing workers.²²⁹

Fibers can escape into the air during installation, becoming a problem for residents if ductwork around the insulation is not sealed properly. Because of the concern that fiberglass emits phenol-formaldehyde, some manufacturers have switched to nontoxic acrylic binders or

²²⁵ M.K. Tolba & O.A. El-Kholy, (eds.), *The World Environment 1972-1992 – Two Decades of Challenge* (London: Chapman & Hall for the United Nations Environment Programme, 1992).

²²⁶ Tom Woolley et al., 46.

²²⁷ Green Home Guide, *Choosing the Right Insulation*, <<http://bayarea.greenhomeguide.com/index.php/knowhow/entry/784/>>.

²²⁸ Green Home Guide, *Choosing the Right Insulation*, accessed 05/11/2007, at <<http://bayarea.greenhomeguide.com/index.php/knowhow/entry/784/>>.

²²⁹ Green Home Guide, <<http://bayarea.greenhomeguide.com/index.php/knowhow/entry/784/>>.

have had their products certified by Greenguard as low-emitting products that emit half of what the EPA considers elevated formaldehyde levels.²³⁰

Loose-fill fiberglass seals air spaces best since it is blown in, preventing air movement and heat loss. Low-density batts are most commonly used, but can lose up to 50 percent of their R-value in cold climates due to moisture infiltration; high-density batts cost more but have a higher R-value. They will pay back the difference in lower energy bills and are more suitable for cold climates.²³¹

Cellulose

Cellulose insulation consists primarily of recycled paper. About 75 percent of the material used to produce cellulose insulation is post-consumer waste paper, making it one of the insulation options with the highest percentage of recycled content. Manufacturing cellulose insulation involves a fraction of the energy use and associated pollution involved in mineral wool and fiberglass insulation manufacture. Additionally, scrap cellulose generated during installation can be reused, decreasing waste.²³²

Cellulose insulation has no significant effect on indoor air quality. Outgassing of volatile organic compounds (VOCs) contained in ink on newspaper waste used in cellulose insulation is not a health concern, since some ink is removed while recycling paper into pulp and much of the ink used is vegetable based. Boron, used as a flame retardant in cellulose, is harmful only if ingested.²³³

Cellulose insulation is blown into wall and ceiling cavities as well as onto attic surfaces, though to stick to attic ceilings it must be contained by netting or sprayed on wet with an acrylic binder to prevent settling. Like all sprayed or blown insulations, it can be installed into wall cavities through a series of small holes in the wall, causing little disturbance during remodeling. It is not suitable for application below grade (below or at the perimeter of the foundation) or in other locations where it would be exposed to moisture.²³⁴

Cellulose can absorb moisture, which decreases its R-value over time, and if it is exposed to moisture for long periods it will rot and grow mold. In some instances a vapor barrier should be installed once the insulation has fully dried (typically in two weeks) to prevent moisture from reaching the insulation.²³⁵

Cotton Insulation

Cotton is a natural, renewable resource that is mixed with a small amount of boron as a flame retardant and some polyester to make insulation. Cotton insulation has a similar R-value to cellulose for a given thickness of insulation.²³⁶

²³⁰ Green Home Guide, <<http://bayarea.greenhomeguide.com/index.php/knowhow/entry/784/>>.

²³¹ Green Home Guide, <<http://bayarea.greenhomeguide.com/index.php/knowhow/entry/784/>>.

²³² Green Home Guide, *Choosing the Right Insulation Delivers Energy Savings*, accessed 4/14/2007, at <<http://www.greenhomeguide.com/index.php/knowhow/entry/784/C236>>.

DuPont, *Fiberglass Handling*, (2006), accessed 03/13/2007, at <http://www2.dupont.com/Personal_Protection/en_US/tech_info/articles_fiberglass.html>.

²³³ Green Home Guide, <<http://www.greenhomeguide.com/index.php/knowhow/entry/784/C236>>.

DuPont, <http://www2.dupont.com/Personal_Protection/en_US/tech_info/articles_fiberglass.html>.

²³⁴ Green Home Guide, <<http://www.greenhomeguide.com/index.php/knowhow/entry/784/C236>>.

DuPont, <http://www2.dupont.com/Personal_Protection/en_US/tech_info/articles_fiberglass.html>.

²³⁵ Green Home Guide, <<http://www.greenhomeguide.com/index.php/knowhow/entry/784/C236>>.

²³⁶ Green Home Guide, <<http://www.greenhomeguide.com/index.php/knowhow/entry/784/C236>>.

DuPont, <http://www2.dupont.com/Personal_Protection/en_US/tech_info/articles_fiberglass.html>.

The majority of cotton used in insulation is recovered from scrap generated in denim manufacturing. Cotton farming is very water and pesticide intensive, though manufacturing cotton insulation overall is not an energy-intensive process. Cotton insulation contains no formaldehyde, and its fibers do not cause respiratory or skin problems unless you are specifically allergic.

One may apply batts of cotton insulation to the same places appropriate for fiberglass or mineral wool batts: between open roof rafters, ceiling joists or wall studs. Loose fill cotton insulation is also suitable for attic floors and wall cavities. As with any cavity insulation and any natural material, elevated moisture levels should be avoided. Cotton insulation can cost twice as much as fiberglass for similar insulation effectiveness. One can save money by installing it oneself, since there are no health concerns associated with cotton and it can be handled without safety equipment.

One example of cotton insulation is UltraTouch, a natural cotton fiber insulation made from 85% post industrial recycle natural fibers, including jeans.²³⁷ Unlike traditional insulation, UltraTouch contains no chemical irritants and requires no warning labels. UltraTouch also contains no VOCs. Additionally, UltraTouch can be used with single or double sided foil. The single-side foil allows sound to be absorbed into the natural fibers. The dual-sided foil provides an excellent radiant heat barrier to resist heat flow.

Table 8a: Lifecycle costs and impacts compared to Fiberglass Insulation						
		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)		● ■	△		
	Human Health Risk			△	● ■	
	Habitat Degradation			△	■	●
	Energy Consumption			△	● ■	
	Air and Atmosphere Quality			△	● ■	
	Waste Production			△		● ■
	Other Significant Impacts					
	Environmental Benefits			△		● ■
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost				△ ■	●
	Human Health Risk		△		● ■	■
	Habitat Degradation			△	● ■	
	Energy Consumption			● ■	△	
	Air and Atmosphere Quality		△	●	■	
	Waste Production				△ ● ■	
	Other Significant Impacts					
	Environmental Benefits			△	●	■

Options	Symbol
Plastic Foams	△
Cellulose	●
Cotton	■

²³⁷ UltraTouch, *Bonded Logic*, accessed 4/14/2007, at <<http://www.bondedlogic.com/ultratouch.htm>>.

Table 8b: Feasibility of options compared to Fiberglass Insulation						
		Worse		Same as Standard		Better
FEASIBILITY	Feasibility		●	△		■
	Reduction of Cost (short run)	● ■		△		
	Performance & Functionality			● ■	△	
	Overall Environmental Impact			△		● ■
	Local Availability			△ ● ■		
	Educational Value		△		● ■	

Options	Symbol
Plastic Foams	△
Cellulose	●
Cotton	■

Recommendations:

Given cellulose insulations potential to retain moisture, vapor barriers would need to be installed, especially given the close proximity to the greenhouses. Cotton insulation would be most desired because of its ease of installation, lack of maintenance requirements, and high percentage of recycled fibers, which lower its overall ecological impact.²³⁸

Foundation Materials

Concrete

While concrete's structural properties have contributed to its universal use as a building material, it has relatively large environmental impacts (see discussion of concrete in baseline analysis, section 2.2). Several methods exist to reduce these impacts: changing the composition of the concrete itself, using building practices that minimize the use of concrete, and substituting another building material to for concrete.

Concrete with fly ash

Adding fly ash to the cement, water, sand and stone that comprise concrete reduces concrete's negative environmental impacts. Fly ash is a byproduct of coal-fired electrical power generation.²³⁹ In the United States alone, millions of tons of fly ash are produced each year.²⁴⁰ Traditionally, fly ash is sent to landfills. As it is already a manufacturing byproduct, diverting it from a landfill to use in place of raw materials reduces its negative environmental impact.²⁴¹ Structurally, fly ash improves the physical properties of concrete, making it easier to work with in liquid form, increasing its strength and decreasing its permeability.²⁴² Concrete made with fly ash also requires less water than traditional concrete, so it is less prone to cracking during

²³⁸ Green Home Guide, *Choosing the Right Insulation*, accessed 05/11/2007, at <http://bayarea.greenhomeguide.com/index.php/knowhow/entry/784/>.

²³⁹ Sustainable Building Sourcebook web version, *Fly Ash Concrete*, (Aug. 4, 2006) Sustainable Sources, accessed 04/12/2007, at < <http://www.greenbuilder.com/sourcebook/Flyash.html>>.

²⁴⁰ Toolbase Services: NAHB Research Center, *Fly Ash Concrete: Inexpensive replacement for Portland Cement*, (2006), accessed 4/12/2007, at <<http://www.toolbase.org/Technology-Inventory/Foundations/fly-ash-concrete>>.

²⁴¹ Toolbase Services: NAHB Research Center, <<http://www.toolbase.org/Technology-Inventory/Foundations/fly-ash-concrete>>.

²⁴² Sustainable Building Sourcebook web version: Sustainable Sources, <<http://www.greenbuilder.com/sourcebook/Flyash.html>>.

drying.²⁴³ Fly ash concrete is comparable to traditional concrete in terms of cost.²⁴⁴ Coal mined in different areas has different properties, however, as does the fly ash resulting from coal combustion. The fly ash from coal burned in the western half of the country is traditionally used for structural concrete,²⁴⁵ meaning it must be transported across a large distance for use in New England. The further the fly ash must be transported before use, the more fuel is required and the greater the overall cost of the concrete.

When adding recycled content to a product in place of conventional materials, one should always ensure that it does not increase health risks. Adding fly-ash to concrete does not appear to present a health or safety threat to humans in terms of either radioactivity or radon gas.

According to a report by the U.S. Geological Survey (USGS),

the radioactivity of typical fly ash is not significantly different from that of more conventional concrete additives or other building materials such as granite or red brick. One extreme calculation that assumed high proportions of fly-ash-rich concrete in a residence suggested a dose enhancement, compared to normal concrete, of 3 percent of the natural environmental radiation.²⁴⁶

The USGS report also notes that while direct measurement of fly-ash concrete's contribution to indoor radon is complicated by the much larger contribution of underlying soil and rock, "The emanation of radon gas from fly ash is less than from natural soil of similar uranium content. Present calculations indicate that concrete building products of all types contribute less than 10 percent of the total indoor radon."²⁴⁷

Frost Protected Shallow Foundations (FPSF)

An alternative to changing the composition of concrete in order to reduce its environmental impacts is to use less of the material by adopting different building practices. In building construction in the Northeast, the footings of a building are traditionally placed below the frost line so that the foundation doesn't heave as the ground freezes and thaws over time. If the ground can be kept above freezing closer to the surface, however, the footings need only be below whatever the newly created frost line is, which can be as shallow as twelve inches.²⁴⁸ This method of creating a warm microclimate within and surrounding the building footprint is called a Frost Protected Shallow Foundation (FPSF) and has been successfully employed in Scandinavian countries for decades.²⁴⁹ Insulation and drainage techniques around the foundation create this microclimate.²⁵⁰ Because of the added insulation, less heat escapes from the building,

²⁴³ Toolbase Services: NAHB Research Center <<http://www.toolbase.org/Technology-Inventory/Foundations/fly-ash-concrete>>.

²⁴⁴ Sustainable Building Sourcebook web sources: Sustainable Sources, <<http://www.greenbuilder.com/sourcebook/Flyash.html>>.

²⁴⁵ Toolbase Services: NAHB Research Center, <<http://www.toolbase.org/Technology-Inventory/Foundations/fly-ash-concrete>>.

²⁴⁶ Central Region Energy Resources Team, *Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Impacts*, Fact Sheet FS-163-97, (October 1997), accessed 05/05/2007, at <<http://greenwood.cr.usgs.gov/energy/factshts/163-97/FS-163-97.html>>.

²⁴⁷ Central Region Energy Resources Team, <<http://greenwood.cr.usgs.gov/energy/factshts/163-97/FS-163-97.html>>.

²⁴⁸ Energy Source Builder #43, *Shallow, Insulated Foundations Lower Construction Costs*, (February 1996), Iris Communications, accessed 4/12/2007, at <<http://oikos.com/esb/43/foundations.html>>.

²⁴⁹ Toolbase Services: NAHB Research Center, *Alternatives to Concrete*, (July 2004), accessed 4/12/2007, at <<http://www.toolbase.org/Design-Construction-Guides/Foundations/concrete-alternatives>>.

²⁵⁰ Toolbase Services: NAHB Research Center, <<http://www.toolbase.org/Design-Construction-Guides/Foundations/concrete-alternatives>>.

which saves energy.²⁵¹ FPSF also requires less site disturbance because of the shallowness of the foundation pit and the lower amount of backfill needed to shore up the finished foundation walls.²⁵²

Rammed Earth

Rammed earth in the pisé style (see interior walls, category D, #4, for further explanation) consists of sand, fine gravel, and clay along with additives that is shaped into walls by applying pressure to the earth while it is encased in a form.²⁵³ Typical additives include lime, Portland cement, and natural fibers that work to bind the earth together more strongly, reduce water penetration and avoid shrinkage and warping.²⁵⁴ When finished, walls should be sealed with hydraulic lime or lime cement render.²⁵⁵ Exterior walls exposed to extreme weather, such as those on the Wellesley Campus, require further protection from the elements.

While the addition of cement to the mixture would appear to increase the negative environmental impact of rammed earth walls, the amount of cement used in a rammed earth wall is minimal compared to the amount used in a concrete wall. It is also important to compare the physical properties of concrete and rammed earth walls. Rammed earth walls have a higher insulation value than concrete, but overall their insulation value is low.²⁵⁶ Moisture also affects rammed earth differently than concrete. Rammed earth walls effectively regulate humidity, but because moisture can damage the walls it is important to protect them from excessive amounts of dampness. One should also avoid lining rammed earth with a moisture barrier because the water stopped by the barrier will damage the walls.²⁵⁷ Although rammed earth walls would have to be thicker than traditional concrete walls, structurally rammed earth would be able to support a building of the size we propose.²⁵⁸

²⁵¹ Energy Source Builder #43: Iris Communications, <<http://oikos.com/esb/43/foundations.html>>.

²⁵² Energy Source Builder #43: Iris Communications, <<http://oikos.com/esb/43/foundations.html>>.

²⁵³ Bjorn Berge, *The Ecology of Building Materials*, (Oxford: Architectural Press, 2000), 212-213.

²⁵⁴ Berge, 210, 211.

²⁵⁵ Berge, 216.

²⁵⁶ Berge, 210.

²⁵⁷ Berge, 210, 217.

²⁵⁸ Berge, 209.

Table 9a: Lifecycle costs and impacts compared to Concrete

		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)		■	△	●	
	Human Health Risk			△ ●	■	
	Habitat Degradation				△ ● ■	
	Energy Consumption				△ ● ■	
	Air and Atmosphere Quality				△ ● ■	
	Waste Production				△ ● ■	
	Other Significant Impacts			△	● ■	
	Environmental Benefits			●	△ ■	
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost		■	△	●	
	Human Health Risk			△ ●	■	
	Habitat Degradation			△ ●	■	
	Energy Consumption			△	● ■	
	Air and Atmosphere Quality			△ ●	■	
	Waste Production			△	● ■	
	Other Significant Impacts			△ ●	■	
	Environmental Benefits			△ ● ■		

Options	Symbol
Concrete w/ fly ash	△
FPSF	●
Rammed Earth	■

Table 9b: Feasibility of options compared to Concrete

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility		△ ■	●		
	Reduction of Cost (short run)			△ ■	●	
	Performance & Functionality		■		△ ●	
	Overall Environmental Impact				△ ● ■	
	Local Availability		△		● ■	
	Educational Value			△	●	■

Recommendations:

A combination of methods should be employed to reduce the environmental impact of concrete. We recommend a FPSF foundation for the ES portion of the proposed space. Due to moisture conditions it is inadvisable to use a FPSF foundation for the greenhouse portion of the structure. This will minimize the use of concrete for a purpose where there is no practical substitute. When concrete cannot be avoided we recommend choosing concrete with fly ash instead of conventional concrete. Rammed earth should also be considered, but it may be difficult to find a company that specializes in rammed earth building in this part of the country. Adoption of one or all of these alternatives would result in a smaller environmental impact than continued use of concrete that contains no fly ash.

Wall Materials

Drywall

Several forms of drywall exist that eliminate or significantly reduce the need for extraction and processing of natural gypsum. These include synthetic drywall, reclaimed or recycled drywall, and Enviro Board.

Synthetic Drywall

Synthetic drywall derives its name from its main component, synthetic gypsum. In order to reduce sulfur dioxide emissions, power plants have installed scrubbers that use a flue gas desulfurization (FGD) process. Synthetic gypsum is a byproduct of this process. So-called power-station gypsum has similar technical properties to natural gypsum, including similar content of heavy metals and radioactivity,²⁵⁹ and has become a major source of gypsum for drywall production. Ecology Action's Green Building Materials Guide states that synthetic gypsum accounts for twenty percent of U.S. raw gypsum use, and that more than eighty percent of coal fly ash sold in the U.S. is used in gypsum board.²⁶⁰ Because synthetic gypsum eliminates the need to mine, transport and process raw gypsum, and also diverts fly ash from the waste stream and landfills, synthetic drywall has a lower negative environmental impact than conventional drywall. It should be kept in mind, however, that synthetic gypsum results from "dirty" power generation technology. Synthetic drywall may be more expensive than conventional drywall because synthetic gypsum is slightly more costly to obtain, but requires no change in installation practices.

Recycled/Reclaimed Drywall

While synthetic drywall production has developed fairly quickly, production of drywall with recycled content has not. The gypsum industry has traditionally been quite centralized, which works as an economic disincentive to recycle gypsum products.²⁶¹ Furthermore, gypsum is an inexpensive material that may require intensive labor to separate for recycling, while most recycled gypsum in drywall products comes from drywall manufacture.²⁶²

²⁵⁹ Berge, 184.

²⁶⁰ Ecology Action, *Green Building Materials Guide: Gypsum Board (Drywall)*, accessed 04/10/2007, at http://www.ecoact.org/Programs/Green_Building/green_Materials/gypsum.htm.

²⁶¹ Berge, 316.

²⁶² Ecology Action, http://www.ecoact.org/Programs/Green_Building/green_Materials/gypsum.htm.

Post-consumer gypsum waste can be recycled into new gypsum panels that meet the same quality standards as natural and synthetic gypsum.²⁶³ The recycling process includes the removal of metal, plastic and other debris and the separation of the paper liner from the gypsum core. Recyclable gypsum may be transported back to drywall manufacturers, where it is combined with virgin rock or synthetic gypsum to make new wallboard. Studies by New West Gypsum Recycling (NWGR), a leading gypsum recycling company, indicate that wallboard can include in excess of 25% recycled gypsum.²⁶⁴ Builders and contractors have also begun recycling drywall at the construction site. They use a mobile grinder to separate and pulverize scrap drywall, and the result can be used as a soil amendment or plant nutrient.²⁶⁵ Minimizing the need for trimming during assembly is another comprehensive means of reducing material and energy waste. Producers of both synthetic and recycled gypsum products are located throughout the United States, and include U.S. Gypsum, located in Boston.²⁶⁶ It would be possible, therefore, to obtain drywall with synthetic or recycled gypsum content from local sources.

Enviro Board

The Enviro Board Corporation has developed a patented technology for production of building panels from agricultural waste fibers, such as such as rice, wheat, rye, barley and oat straws, flax and sugar cane. These waste fibers are often disposed of by burning, which releases pollutants, including carbon dioxide, into the atmosphere. Production of building panels makes use of these agricultural wastes while simultaneously providing biologically-based, energy efficient, low cost building materials.

Enviro Board panels are created by compressing the fibers at high pressure, and then enclosing them in recycled paper adhered with naturally-based resin. The panels increase energy efficiency, are non-toxic, fire-, termite-, mold-, and mildew-resistant, and earthquake and hurricane stable. Additionally, use of Enviro Board in a building allows builders to earn a LEED point for using bio-based building materials. Because of Enviro Board's thermal efficiency characteristics, builders can earn up to ten additional points for over 42% efficiency gain. The approximate cost of an Enviro Board Home Kit, which includes all materials necessary to construct a small house (exterior and interior wall panels, light steel framing, and complete electrical and plumbing for kitchen and bathroom), is \$10 per square foot.²⁶⁷

Rammed Earth

Pisé construction, or earth ramming technique, provides a means of building both interior and exterior walls and floors. Rammed earth walls are created by placing and securing wooden forms called shuttering where the wall is to be built. Wet earth composed of sand, gravel, clay and a small percentage of cement, lime or natural fibers to act as binder are loaded into the shuttering and compressed to create a wall layer by layer. Earth is an abundant and naturally-occurring resource that requires extremely minimal processing compared to other construction

²⁶³ Ecology Action, <http://www.ecoact.org/Programs/Green_Building/green_Materials/gypsum.htm>.

²⁶⁴ New West Gypsum Recycling, *The Gypsum Recycling Process*, (2003), accessed 04/10/2007, at <<http://www.drywallrecycling.org/>>.

²⁶⁵ Construction Materials Recycling Association, *Recycling Gypsum Drywall at the Construction Site*, accessed 04/10/2007, at <<http://www.drywallrecycling.org/>>.

²⁶⁶ U.S. Gypsum, *Committed to the Environment*, (2002), accessed 04/10/2007, at <<http://www.gypsumsolutions.com/newscenter/news/fiberboard/x2598.pdf>>.

²⁶⁷ The Enviro Board Corporation, *The Panels*, (2006), accessed 04/10/2007, at <<http://www.enviroboardcorporation.com/panels>>.

materials, requires no toxic additives and is biodegradable. Due to the phenomenon of thermal mass, rammed earth walls prevent heat transfer and improve interior temperature stability. They also reduce sound travel through walls, leading to improved sound-proofing. Rammed earth walls may be comparatively expensive, however, because they are labor intensive to construct.²⁶⁸

Table 10a: Lifecycle costs and impacts compared to Drywall								
		Worse		Same as Standard		Better	Options	Symbol
PRODUCTION	Initial Cost (\$)						Synthetic Drywall	△
	Human Health Risk				△ ●	■ ○	Recycled Drywall	●
	Habitat Degradation				△ ●	■ ○	Enviro Board Panels	■
	Energy Consumption				△ ●	■ ○	Rammed Earth	○
	Air and Atmosphere Quality				△ ●	■ ○		
	Waste Production					■ ○ △ ●		
	Other Significant Impacts							
	Environmental Benefits				△ ●	■ ○		
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost			△ ●		○		
	Human Health Risk			△ ●		○		
	Habitat Degradation			△ ●		■ ○		
	Energy Consumption			■ △ ●		○		
	Air and Atmosphere Quality					○		
	Waste Production			△ ●	■	○		
	Other Significant Impacts							
	Environmental Benefits			△ ●	■	○		

²⁶⁸ See Berge, 210-217; Terra Firma Builders, Ltd., accessed 4/11/2007, at <<http://www.terrafirmabuilders.ca/>>; Rammed Earth Development, Inc., accessed 4/11/2007, at <<http://www.rammedearth.com/>>.

Table 10b: Lifecycle costs and impacts compared to Drywall						
		Worse		Same as Standard		Better
FEASIBILITY	Feasibility	■ 0	●	△		
	Reduction of Cost (short run)	0		△ ●	■	
	Performance & Functionality			■ △ ●		0
	Overall Environmental Impact				△ ●	■ 0
	Local Availability	■ 0		△ ●		
	Educational Value			△ ●		■ 0

Options	Symbol
Synthetic Drywall	△
Recycled Drywall	●
Enviro Board Panels	■
Rammed Earth	0

Recommendations:

Given the relative ease of obtaining either drywall made from synthetic gypsum or drywall containing recycled/reclaimed gypsum, we recommend either of these options for the interior walls of our proposed GES building. We also recommend including at least one wall constructed with Enviro Board Panels or, preferably, rammed earth. Both of these materials provide the opportunity to educate students and other visitors about building materials derived from renewable resources.

Flooring Materials

Currently, the floors in both of our reference buildings are made of concrete. In the proposed GES building, however, it is important to keep options open and consider alternative flooring choices. Other flooring options include earthen floors (a.k.a. rammed earth or dirt floors), linoleum, wood, and concrete with fly ash. The different functions of the ES space and greenhouses may require two different flooring options, as what is appropriate for an office or classroom floor may not be applicable to the greenhouses. In both spaces, a firm, smooth surface will be necessary. In addition, the greenhouses would benefit from having a floor with a high thermal mass that would slowly absorb heat during the day and slowly release heat at night. Since the floor in the greenhouses is exposed to large amounts of water daily, the flooring option chosen must be impervious to water damage. Ideally the floor would be able to evaporate water to maintain humidity and regulate temperature.²⁶⁹ Conversely, the ES space would benefit from flooring that is aesthetically pleasing and functions well with furniture. Flooring materials with educational value (i.e. those produced from abundant or renewable resources) would benefit both spaces.

Earthen Floors

Earthen floors, though uncommon in New England, are hardly new; millions of people around the globe have dirt floors.²⁷⁰ Earthen floor installation is easy and requires little energy. Numerous methods exist to construct earthen floors, but generally earth rich in clay is combined

²⁶⁹ Tony Antonucci, personal communication, March 9, 2007.

²⁷⁰ David Gelles, "Down and Dirty," *New York Times* (Feb. 8, 2007), accessed 04/14/2007, at <http://www.nytimes.com/2007/02/08/garden/08dirt.html?ei=5088&en=aa3bd499058c4308&ex=1328590800&partner=rssnyt&emc=rss&pagewanted=all>.

with lime and sand, spread over a horizontal surface (either foundation, wood or smoothed ground), tamped down to a 15-20 cm depth and finished with beeswax and linseed oil.²⁷¹ With proper grain-size sorting, sand from the building site itself could be used in the construction of an earthen floor, adding to its educational value and local appeal while reducing the need for fuel to transport materials. When it is time for demolition of a building, all of the materials used to construct an earthen floor may return to the earth without any ecological disturbance. They also have high thermal mass, and, like aging leather, change in appearance over time.²⁷² Earth has “vastly lower embodied energy” than concrete,²⁷³ and is the most environmentally friendly floor material available.²⁷⁴

Earthen floors are not without disadvantages. While sealants like beeswax make earthen floors water resistant, they are not waterproof. Continuous contact with water, as would occur in a greenhouse, destroys earthen floors. Furthermore, they can dent under point pressures such as high heels or table legs.²⁷⁵ Other aspects of rammed earth are discussed in the concrete options assessment (category C, number 3) of this report.

While earthen floors are certainly impractical for the greenhouses section of our proposed building, they may be appropriate for the ES space. Earthen flooring has great educational value, because it is uncommon in New England and Wellesley College may be the first time students have the opportunity to see an earthen floor. It also makes an excellent case study of an environmentally-friendly practice implemented in rural areas that can be adjusted to fit an urban or suburban design. Earthen floors are aesthetically pleasing, and employing an earthen floor specialist to install the flooring may help ensure against denting of the floor surface. Earthen floors cost about \$5 per square foot, including installation.²⁷⁶

Linoleum

Although many people confuse linoleum with vinyl flooring, the two are very different.²⁷⁷ Vinyl flooring is made of polyvinyl chloride (PVC), which contributes harmful emissions of phthalates, aliphatic and aromatic hydrocarbons, phenols, aldehydes and ketanes during manufacture, use and disposal.²⁷⁸ Linoleum is comparably priced (about \$4 per square foot),²⁷⁹ but it is made from linseed oil, cork, softwood resin, limestone and wood flour, none of

²⁷¹ Berge, 327; David Gelles,
<<http://www.nytimes.com/2007/02/08/garden/08dirt.html?ei=5088&en=aa3bd499058c4308&ex=1328590800&part=ner=rssnyt&emc=rss&pagewanted=all>>.

²⁷² David Gelles,
<<http://www.nytimes.com/2007/02/08/garden/08dirt.html?ei=5088&en=aa3bd499058c4308&ex=1328590800&part=ner=rssnyt&emc=rss&pagewanted=all>>.

²⁷³ Tom Woolley et al., *Green Building Handbook: A Guide to Building Products and Their Impact on the Environment, Volume 1* (London: Spoon Press 2001), 55.

²⁷⁴ Berge, 327.

²⁷⁵ David Gelles,
<<http://www.nytimes.com/2007/02/08/garden/08dirt.html?ei=5088&en=aa3bd499058c4308&ex=1328590800&part=ner=rssnyt&emc=rss&pagewanted=all>>.

²⁷⁶ David Gelles,
<<http://www.nytimes.com/2007/02/08/garden/08dirt.html?ei=5088&en=aa3bd499058c4308&ex=1328590800&part=ner=rssnyt&emc=rss&pagewanted=all>>.

²⁷⁷ Tom Woolley, et al., 196.

²⁷⁸ Berge, 154.

²⁷⁹ Green Resource Center, *Natural Linoleum Flooring*, (Jul. 2004), accessed 04/14/2007 at
<<http://www.greenresourcecenter.org/MaterialSheetsWord/NaturalLinoleum.pdf>>.

which endanger human health.²⁸⁰ Since vinyl is equivalent in cost yet more hazardous to humans and the environment, we do not consider vinyl as an option.

Linoleum is manufactured from rapidly renewable resources,²⁸¹ but does require a hard floor surface (like concrete) to which it may be attached. Attention should be paid to adhesive selection, since some adhesives that fasten linoleum to the floor contain toxins. Though linoleum cannot be recycled, it can be safely combusted or composted. Improper disposal may increase nutrient loading to groundwater or surface waters.²⁸²

There are a few notable ways in which linoleum and earthen floors differ. Linoleum is more commonly available than rammed earth, decreasing its educational value but increasing its feasibility. It does not dent as an earthen floor does, but it is sensitive to water exposure and is not an appropriate option for the greenhouses.²⁸³

Fly-ash Concrete

Fly-ash concrete provides the best option for flooring in the greenhouse. Functionally, it is very similar to standard concrete. It costs no more than standard concrete, but it incorporates material that otherwise would be waste.²⁸⁴ For more information about fly-ash concrete, please see the concrete section of building materials baseline analysis (Section 2.2 B p16).

Table 11a: Lifecycle costs and impacts compared to Concrete Flooring						
		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)			■	● △	
	Human Health Risk			■	● △	
	Habitat Degradation			■ △ ●		● △
	Energy Consumption					● △
	Air and Atmosphere Quality				■ △ ●	
	Waste Production					● △
	Other Significant Impacts			■ △ ●	● △	
	Environmental Benefits			■ △ ●		
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost			■	●	△
	Human Health Risk			■	● △	
	Habitat Degradation			■		● △
	Energy Consumption			■		● △
	Air and Atmosphere Quality			■	● △	
	Waste Production			■		● △
	Other Significant Impacts			■ △ ●		
	Environmental Benefits			■ △ ●		

Options	Symbol
Earthen Floor	△
Linoleum	●
Fly-ash Concrete	■

²⁸⁰ Berge, 361.

²⁸¹ Green Resource Center, <<http://www.greenresourcecenter.org/MaterialSheetsWord/NaturalLinoleum.pdf>>.

²⁸² Berge, 362.

²⁸³ Berge, 362.

²⁸⁴ National Association of Home Builders (NAHB) Research Center, *Fly Ash Concrete*, (2006), accessed 4/13/2007, at <<http://www.toolbase.org/Technology-Inventory/Foundations/fly-ash-concrete>>.

Table 11b: Feasibility of options compared to Concrete Flooring

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility		■ △	●		
	Reduction of Cost (short run)			■ △	●	
	Performance & Functionality		● △		■	
	Overall Environmental Impact				■	● △
	Local Availability		■ △	●		
	Educational Value			■	●	△

Options	Symbol
Earthen Floor	△
Linoleum	●
Fly-ash Concrete	■

Recommendations:

We recommend that linoleum be strongly considered as a flooring option for the proposed ES space. Additionally, installing at least one earthen floor in the GES building would, like a rammed earth wall, provide the opportunity to educate students and visitors about alternative building materials that have fewer negative environmental impacts than conventional flooring found in other campus buildings.

3.4 Indoor Environmental Quality

Finishes (interior walls)

Paint is one of the most common interior wall finishes at Wellesley. In addition to releasing VOCs (see IEQ baseline analysis for specific information), paint production and disposal result in other negative environmental impacts. Many resins and solvents used in paint are petroleum-based, and therefore are produced using high energy processes that deplete non-renewable petrochemical resources. Petrochemical manufacture forms a major source of NO_x, CO₂, and methane, all greenhouse gases significantly associated with climate change, as well as SO₂, which, along with NO_x, is responsible for acid deposition. Paint production is also a wasteful process: the production of one ton of paint can result in up to 30 tons of waste of mostly low biodegradability.²⁸⁵ Titanium dioxide, which usually acts as the “base” of paint and provides opacity, makes up one quarter of a can of paint. It is energy intensive, accounting for the majority of the energy consumed in producing paint, and can cause respiratory problems, skin irritation and may be a possible carcinogen. Heavy metals such as lead, cadmium and chromium are also often found in conventional paint pigments. To avoid or reduce these negative environmental impacts, low-emitting, naturally-based or recycled paints should be used when possible.

Natural Paint

The binders, resins, pigments and solvents included in natural paints are derivations of plants and minerals, such as linseed oil, citrus peel oil, beeswax, lime, and chalk, and contain no synthetic, petrochemical based products. They therefore do not emit hazardous chemicals that

²⁸⁵ Tom Woolley and Sam Kimmins, *Green Building Handbook, A Guide to Building Products and their Impact on the Environment*, Vol. 2 (London: Spon Press 2000), 27.

lead to air pollution and health concerns. Natural paints are completely biodegradable, meaning they do not need to be treated as chemical or hazardous waste as conventional paint does, and will break down naturally over time without disrupting ecosystems. Some natural paints may be more expensive due to low demand²⁸⁶ or result in a more labor-intensive installation process,²⁸⁷ but the ecological and human health benefits of natural paint are substantial.

Low-emitting Paint

Growing awareness of the negative health and environmental impacts of VOC emissions from conventional paint has led paint producers to introduce an increasing number of Low-VOC paints. Many of these paints use water as a carrier as opposed to petroleum-based solvents, substantially reducing their environmental and health impacts. Water-based paints often still contain toxic chemicals (see introductory section), however, and the consumer should investigate paint ingredients to determine exact contents. Green Seal, a non-profit organization that certifies environmental products, has certified over 70 paint products that meet its criteria for hideability, wearability, scrubability, maximum VOC limits and prohibited heavy metals and toxic organic substances.²⁸⁸ Low-emitting, less toxic paint may in fact be less expensive than conventional paint. A 1999 study conducted at the Aberdeen Proving Ground by the U.S. Army to identify and recommend environmentally preferable paints found that those paints causing less harm to the environment cost an average of \$1.76 less per gallon.²⁸⁹

Recycled Paint

As its name suggests, recycled paint is made from unused paint acquired through public and private collection programs, and contains between 20 and 100 percent recycled content. There are two types of recycled paint: reprocessed and rebled. Reprocessed paint is mixed with virgin materials (resins and colorants), extensively tested before resale and may contain a low percentage (20%) recycled paint. Rebled paint is simply remixed, with minimal addition of virgin materials or testing before repackaging.²⁹⁰ The environmental benefit of recycled paint derives largely from its substantial resource-use reduction, since it uses waste paint as a raw material. However, quality and color ranges may be limited. VOC content and fungicides may still be a problem due to the consolidation of paint into one large quantity and the possible mixing of interior and exterior paints.²⁹¹ Recycled paint is often substantially less expensive than conventional or natural paint, although it is still a relatively new product that may be less-easily available than other forms of paint.

²⁸⁶ *The Environmentally Preferable Purchasing Guide*, (2002), accessed 04/11/2006, at http://greenguardian.com/EPPG/10_5.asp#Laws%20and%20Guidelines.

²⁸⁷ Green Resource Center, *Greener Paints*, (2004), accessed 04/11/2007, at <http://www.greenresourcecenter.org/MaterialSheetsWord/GreenerPaints.pdf#search='paint%20options:%20organic%20low%20emitting'>.

²⁸⁸ *The Environmentally Preferable Purchasing Guide*, http://greenguardian.com/EPPG/10_5.asp#Laws%20and%20Guidelines.

²⁸⁹ *The Environmentally Preferable Purchasing Guide*, http://greenguardian.com/EPPG/10_5.asp#Laws%20and%20Guidelines.

²⁹⁰ *The Environmentally Preferable Purchasing Guide*, (2002), http://greenguardian.com/EPPG/10_5.asp#Laws%20and%20Guidelines.

²⁹¹ Woolley, 2000; Green Resource Center, <http://www.greenresourcecenter.org/MaterialSheetsWord/GreenerPaints.pdf#search='paint%20options:%20organic%20low%20emitting'>.

Rammed Earth, a No-Paint Option

Given the health and environmental problems that may result from most types of paint, it is worthwhile to consider building practices and materials that do not require any paint application at all. Rammed earth (See Options Analyses for concrete (p59) and drywall (p63)) is one such material. While a variety of finishes, including plasters and mineral or casein paints, exist for rammed earth, the walls may be left as they are once sealed (usually with a naturally-based sealant like linseed oil). A myriad of materials, including shells, glass and different types of stone, may be added to rammed earth to achieve different kinds of texture. Mosaics may also be set into rammed earth walls (Figure 9). In short, there are many creative ways to enhance a rammed earth wall that do not include paint.



Figure 9: Example of mosaic (left) and rammed earth walls (right).

Table 12a: Lifecycle costs and impacts compared to SYNTHETIC PAINT					
		Worse		Same as Standard	Better
PRODUCTION	Initial Cost (\$)	△ 0		●	■
	Human Health Risk			■	● △ 0
	Habitat Degradation				● △ ■ 0
	Energy Consumption				● △ ■ 0
	Air and Atmosphere Quality			■	△ ● 0
	Waste Production			●	△ ■ 0
	Other Significant Impacts				
	Environmental Benefits			●	△ ■ 0
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost			● ■	△ 0
	Human Health Risk			■	△ ● 0
	Habitat Degradation				● △ 0
	Energy Consumption				
	Air and Atmosphere Quality			■	△ ● 0
	Waste Production			● ■	△ 0
	Other Significant Impacts				
	Environmental Benefits			■	● △ 0

Options	Symbol
Natural Paint	△
Low-emitting Paint	●
Recycled Paint	■
Rammed Earth	0

Table 12b: Feasibility of options compared to Synthetic Paint

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility		△ ■ ○	●		
	Reduction of Cost (short run)	○	△	●		■
	Performance & Functionality			△ ● ■	○	
	Overall Environmental Impact				■	△ ● ○
	Local Availability			●	△ ■ ○	
	Educational Value			● ■		△ ○

Options	Symbol
Natural Paint	△
Low-emitting Paint	●
Recycled Paint	■
Rammed Earth	○

Recommendations:

The above table that compares the various paint options against our synthetic paint baseline shows that in production, use and disposal, all of these options are as good as or better than synthetic paint, with one exception. In terms of initial cost, both natural paint and rammed earth are more expensive than synthetic paint. Still, the table shows that both natural paint and rammed earth are far more environmentally friendly than the baseline and both out-compete low-emitting paint and recycled paint in environmental benefits, habitat degradation and waste production. Though these two options cost more than the baseline and are less commonly available, we recommend using either or both natural paint and rammed earth in the proposed ES space due to their environmental benefits and high educational value.

Furniture

Though furniture is an important contributor to indoor environmental quality, it is rarely included in the initial design and proposal of a building. Planned installation of green furniture may improve indoor air quality by reducing the amount of off-gassing of VOCs that occurs over time. Green furniture includes furniture created from rapidly renewable materials, designed for easy future recycling or created from recycled and reclaimed materials. We do not recommend specific types of furniture or manufacturers. Instead, we make a recommendation based on a comparison of guidelines for regulating furniture.

Environmental Choice Program Certification for Office Furniture and Panel Systems

The Environmental Choice^M program is an eco-labeling program sponsored by the Canadian government. Environmental Choice uses a labeling system, EcoLogo^M, similar to the United States' Energy Star program for energy conservation. They test products, and those companies that meet designated standards may include the EcoLogo label on their products and packaging or in related advertising. The guidelines that most directly apply to our proposed space are for "Office Furniture and Panel Systems" (CCD-033). The guidelines set limits for emissions of VOCs, particularly formaldehyde.²⁹² The standards also take a life cycle-style perspective of the products they regulate. Facilities that manufacture the products must enact a

²⁹² TerraChoice Environmental Services Inc., *Environmental Choice^M Program: Certification Criteria Document CCD-033*, (Apr. 19, 1996), Ottawa, Ontario, accessed 4/12/2007, at http://www.environmentalchoice.com/images/ECP%20PDFs/CCD_033.pdf.

plan to reduce waste at all steps in the lifecycle of the product.²⁹³ Products must be labeled so that the different types of plastics included in the products are distinguished and clearly identified to aid future recycling efforts.²⁹⁴ All wood used in products must meet Convention on International Trade in Endangered Species (CITES) regulations.²⁹⁵ Overall, the EcoLogo program takes a broad approach to IEQ.

Greenguard Product Emission Standard for Children & Schools

The Greenguard Product Emission Standard for Children and Schools is much less broadly focused. This certification standard is created and awarded to manufacturers by a U.S. based non-profit organization, Greenguard Environmental Institute.²⁹⁶ The standards are designed for K-12 schools, though there is nothing preventing their application to classrooms on a college campus. Greenguard standards focus solely on emissions from products, though they test for a much broader range of chemicals, including Phthalates, which have been linked to endocrine disorders and asthma.²⁹⁷ Emissions thresholds set by Greenguard are lower than the Canadian standards because the primary individuals exposed are children, who have higher inhalation rates per pound than adults and are therefore more at risk.²⁹⁸ Low (or non-existent) VOC emissions would positively affect IEQ in our proposed space even though children would not be the primary users of the space.

²⁹³TerraChoice Environmental Services Inc., at http://www.environmentalchoice.com/images/ECP%20PDFs/CCD_033.pdf >.

²⁹⁴TerraChoice Environmental Services Inc., at http://www.environmentalchoice.com/images/ECP%20PDFs/CCD_033.pdf > .

²⁹⁵TerraChoice Environmental Services Inc., at http://www.environmentalchoice.com/images/ECP%20PDFs/CCD_033.pdf >.

²⁹⁶ GREENGUARD Environmental Institute, *About GREENGUARD Environmental Institute*, (2006), accessed 4/12/2007, at <http://www.greenguard.org/Default.aspx?tabid=22>>.

²⁹⁷ *GREENGUARD Children & Schools*, (2007), GREENGUARD Environmental Institute, accessed 04/12/2007, at <http://www.greenguard.org/Default.aspx?tabid=110>>.

²⁹⁸ GREENGUARD Environmental Institute, at <http://www.greenguard.org/Default.aspx?tabid=110>>.

Table 13a: Lifecycle costs and impacts compared to Standard Furniture

		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)					
	Human Health Risk				△ ●	
	Habitat Degradation			△	●	
	Energy Consumption			△ ●		
	Air and Atmosphere Quality			△ ●		
	Waste Production			△	●	
	Other Significant Impacts			△ ●		
	Environmental Benefits			△ ●		
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost			△	●	
	Human Health Risk				●	△
	Habitat Degradation			△ ●		
	Energy Consumption			△ ●		
	Air and Atmosphere Quality				●	
	Waste Production			△	●	
	Other Significant Impacts			△ ●		
	Environmental Benefits			△ ●		

Option	Symbol
GREENGUARD	△
EcoLogo	●

Table 13b: Feasibility of options compared to Standard Furniture

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility		●	△		
	Reduction of Cost (short run)					
	Performance & Functionality				△ ●	
	Overall Environmental Impact				△ ●	
	Local Availability		●	△		
	Educational Value				△ ●	

Recommendations:

Though the Canadian EcoLogo program takes a more holistic approach to IEQ regulations for furniture, and is thus more desirable for overall reduction of harmful emissions, the American Greenguard program is a more practical option. Wellesley College is not located in Canada, so it may be hard to obtain furniture that meets EcoLogo standards, and other attributes of the furniture, such as fire retardant levels, may not meet American standards. Another potential difficulty is that the Canadian guidelines are geared towards offices so it may be difficult to find a school style desk and chair that have been tested for the EcoLogo standards. This difficulty obviously does not apply to the school-focused Greenguard standards. Although the Canadian program has a smaller negative environmental impact overall, both programs are an improvement over disregarding IEQ altogether when purchasing furniture. Thus we recommend both certification programs, with the EcoLogo program as a preferred choice.

Ventilation

The two different spaces in our proposed building design require two different kinds of ventilation. The greenhouses require ventilation and air circulation machinery as tools for maintaining different climates for plants in the various greenhouse rooms.²⁹⁹ In the ES space, ventilation is necessary for human health and comfort. Wellesley College has made the progressive decision to install HANSA® systems in all new and renovated buildings.³⁰⁰ HANSA provides indoor air quality on par with European standards, which are more stringent than domestic standards.³⁰¹ Since the college's existing plan for providing healthy ventilation exceeds legal requirements, we will not review the ES space ventilation system; we will only consider alternatives to existing ventilation systems in the greenhouse.

There are several design choices for greenhouse ventilation systems, including arrays of sidewall vents, open-roof ventilation and a variety of fan sizes and configurations.³⁰² We believe that ventilation design for the greenhouses ought to be chosen in collaboration with the experts who work in the greenhouses. We do believe, however, that an automated system that would open and close vents and turn fans on and off when programmed temperatures were reached would be an improvement over the existing system. Such a ventilation system would be better equipped to provide the greenhouse plants with the conditions they need.

Recommendations:

We recommend that the ES space have a HANSA HVAC system installed and that the greenhouses in the GES building have an automatic ventilation system.

Carpeting

The main environmental issues related to floor coverings are the negative impacts of synthetic sheet, fiber, rubber and foam manufacture, and the health issues linked with the emissions of VOCs from synthetic floor coverings. The issue of VOC emissions from carpets has been linked to Sick Building Syndrome.

²⁹⁹ Tony Antonucci, personal communication, March 9, 2007.

³⁰⁰ 2005 ES 300 class, *Another Green Hall*, 86.

³⁰¹ 2005 ES 300 class, *Another Green Hall*, 86.

³⁰² University of Connecticut Integrated Pest Management, *Greenhouse Ventilation*, (May 2005), accessed 4/15/2007, at < <http://www.hort.uconn.edu/IPM/greenhs/bartok/htms/greenhouseventilations.htm>>.

Wool and acrylic tend to be used in ‘high quality’ carpets, which are usually the most durable. Synthetic carpet tends to be less durable, not because of the synthetic fibers themselves, but because synthetic carpets are often manufactured to be low cost and temporary, thus having a greater environmental impact in the long run.³⁰³

The most environmentally beneficial carpet option is wool carpet with Hessian backing, using a recycled felt underlay. These tend to be of mid to high cost. Synthetic carpets with synthetic foam or PVC backing (usually fixed using solvent based glues) dominate the low cost end of the market. Synthetic carpets have negative impacts on both the environment and health. The difference between most of the fiber materials in synthetic carpeting is marginal, with the exception of Nylon, which has the most harmful impact.³⁰⁴ Latex backings are generally more benign than synthetics, and have higher durability. The additional impact of using foam depends on the blowing agent used. Agents include hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) or other ozone depleting greenhouse gases, although more environmentally benign blowing agents are becoming more common.³⁰⁵

The green option for fitting carpet with regard to occupant health is to use grippers or tacks rather than solvent based adhesives. For carpet tiles and lightweight carpeting for which these are not appropriate, non-solvent based adhesives are available.³⁰⁶

Recommendations:

If the ES space has carpeting, it ought to have wool carpet, a more expensive but healthier and more environmentally-friendly option. Although the College currently uses low-emitting carpet adhesives, the use of no adhesives or hook and loop fastener strips would be even better options in terms of IEQ and overall environmental impact. The use of no adhesive would seem to be the best option of the two. The panel carpeting that can be applied without adhesives, however, has its own detrimental effects on the environment and IEQ. Hook and loop fasteners would be the best option for the College to use as an adhesive, as they release no unwanted fumes, provide secure attachment of the carpet, can be applied to any carpet and allow for temporary removal of the carpet, which increases the carpet’s consumer use life.

It should be noted that carpet would not be necessary in the proposed GES building. The greenhouses cannot have carpet, and the ES space may use any of the alternatives outlined in the flooring section of the building materials options analysis. We encourage considerations of these no-carpet options in addition to the carpeting recommendations above.

³⁰³ A. Fox & R. Murrell, 1989.

³⁰⁴ Tom Woolley et al., *Green Building Handbook, A Guide to Building Products and their Impact on the Environment, Volume 1* (London: Spon Press 2000), 196-206.

³⁰⁵ U.S. EPA, *Foam Blowing Agents* (10/27/2006), accessed 05/05/2007, at <http://www.epa.gov/ozone/snap/foams/qa.html>.

³⁰⁶ Tom Woolley et al., 196-206.

3.5 Energy and Atmosphere

Wellesley College currently uses on the order of 672 Btus per square foot daily. From the calculation shown in the baseline assessment, we see that the current greenhouses use 968 Btus per square foot daily. In order to reduce the energy impact in the proposed GES building, we provide an options assessment broken down into four categories: lighting, heating systems, additional energy sources, and energy saving materials. Each section is summarized in a table following the text.

Electrical Lighting

Office buildings typically have a lighting power density of 2.5 watts per square foot, but that can be reduced to 1 watt per square foot or less by installing more efficient light fixtures and optimizing natural light.³⁰⁷ Because half of the proposed GES building will be greenhouses, which use direct sunlight to light up the rooms, the options presented here primarily apply to the ES portion of the proposed space.

Standard Lighting

Wellesley is in the process of replacing incandescent light bulbs with compact fluorescents and installing motion sensors in the residence halls. Buildings such as Pendleton, the Wang Campus Center and the Science Center contain mostly fluorescent lighting along with some incandescent light bulbs still in place.

Compact Fluorescent Light Bulbs

Compact fluorescent light bulbs (CFL) come in wattages of 40 to 150, and use 2/3 less energy and last up to 10 times longer than incandescent bulbs while providing the same amount of light. They generate 70 percent less heat and can reduce energy costs from cooling.³⁰⁸ One compact fluorescent can save over 450 pounds of emissions from a power plant over its lifetime.³⁰⁹

It is important to note, however, that while Wellesley purchases incandescent light bulbs manufactured by Sylvania in Pennsylvania, it purchases CFLs manufactured by Greenlite in China. CFLs save a substantial amount of energy over their life time, but we should remember that substantial fuel is required to ship Greenlite CFLs via ocean freight by container ship to California (likely Long Beach), and then railroad and/or truck them to various distribution points throughout the U.S. and eventually to Wellesley.³¹⁰

Compact fluorescent bulbs are made in special shapes to fit in standard household light sockets. There are also bulbs specially designed for use with dimming switches, but unfortunately they are not widely available.³¹¹ Compact fluorescents function best in ventilated spaces. Recessed fixtures that are completely enclosed can reduce the life span of the bulb.

³⁰⁷ BuildingGreen, Inc., *Linear Fluorescent Lighting*, (May 2001), accessed 04/15/2007 at <http://www1.eere.energy.gov/femp/pdfs/29267-5.4.1.pdf>.

³⁰⁸ Energy Star, *Compact Fluorescent Light Bulbs*, accessed 04/15/2007, at http://www.energystar.gov/index.cfm?c=cfls.pr_cfls.

³⁰⁹ Energy Star, http://www.energystar.gov/index.cfm?c=cfls.pr_cfls.

³¹⁰ Tom Kane, personal communication, May 11, 2007.

³¹¹ R. Neal, *Everything you wanted to know about Compact Fluorescent Bulbs, including the mercury problem*, accessed 05/05/2007, at <http://www.libertypost.org/cgi-bin/readart.cgi?ArtNum=186277>.

Another downside to a compact fluorescent light bulbs is that they emit more ultraviolet (UV) light than incandescent light bulbs. Thankfully the amount of UV light emitted does not harm people. Eight hours of exposure to a compact fluorescent bulb would be the same as spending one full minute in sunlight. Photoreactive chemicals used in furniture finishes, however, may degrade from the exposure to UV over time.³¹² Additionally, compact fluorescents contain on average 5 mg of mercury, which has problematic human health effects and therefore requires proper disposal.

Table 14a: Lifecycle costs and impacts compared to an incandescent bulb

		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)		△			
	Human Health Risk				△	
	Habitat Degradation			△		
	Energy Consumption			△		
	Air and Atmosphere Quality		△			
	Waste Production			△		
	Other Significant Impacts					
	Environmental Benefits			△		
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost					△
	Human Health Risk		△			
	Habitat Degradation			△		
	Energy Consumption					△
	Air and Atmosphere Quality					△
	Waste Production				△	
	Other Significant Impacts					
	Environmental Benefits				△	

Option	Symbol
Compact Fluorescent Lights	△

Table 14b: Feasibility of options compared to incandescent bulb

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility			△		
	Reduction of Cost (short run)				△	
	Performance & Functionality					△
	Overall Environmental Impact				△	
	Local Availability	△				
	Educational Value				△	

³¹² R. Neal, <<http://www.libertypost.org/cgi-bin/readart.cgi?ArtNum=186277>>.

Recommendations:

Switching from traditional incandescent light bulbs to compact fluorescent light bulbs is an easy change. Having small upfront costs and a quick return on investment, compact fluorescent light bulbs should replace any incandescent light bulbs illuminating rooms and hallways. Although nearby recycling facilities, including Wellesley's Recycling and Disposal Facility, only recycle fluorescent lamps at present, they will likely include compact fluorescent light bulb recycling in the near future as compact fluorescent light bulbs become increasingly prevalent. Compact fluorescent light bulbs do not easily burn out either. If a compact fluorescent light bulb is left on for eight hours everyday, it will last a little less than 3.5 years. So by the time a compact fluorescent light bulb burns out, a system for recycling them will most likely be in place.

Daylighting

Daylighting is a principle of design that optimizes the amount of natural light in a space to increase comfort and productivity. Incorporating daylighting into building design can reduce energy costs by substituting electrical heating and lighting energy with natural sunlight. In general, reducing energy demand also reduces the load to the cogeneration facility that is powered by fossil fuels. Skylights and solar tubes are two ways to incorporate daylighting into building design.

Standard Daylighting

There are many skylights built into the roof of the Science Center, but classrooms and offices rely primarily on fluorescent lights since they receive insufficient, if any, natural light.

Sylighting

Skylighting is one inexpensive method of allowing daylight into the core of low-rise buildings, which is ideal for the classrooms and the stairway on the second floor of the proposed GES building. Typically about 4'x4' or 4'x8', skylights are made from a white-diffusing plastic material with a shaft beneath them and a lens to evenly distribute the light, thereby eliminating glare and overheating. They require little maintenance, are aesthetically pleasing, and are correlated to increased productivity and sales.³¹³ Some skylights also include blades for ventilation, such as a louvered skylight (Figure 10).³¹⁴ Louvers automatically adjust themselves, opening and closing in relation to the amount of sunlight outside.

³¹³ Heschong Mahone Group, *Skylighting and Retail Sales: An Investigation into the Relationship Between Daylighting and Human Performance*, (August 1999), accessed 04/15/2007, at http://www.pge.com/003_save_energy/003c_edu_train/pec/daylight/di_pubs/RetailDetailed820.PDF.

³¹⁴ Solar Industries, Inc., *Louvered Skylights*, (2001), accessed 04/15/2007, at http://www.solarindustriesinc.com/alum_cm_louvered_skylights.html.



Figure 10: Louvered skylight.³¹⁵

Solar Tubes

Solar tubes are another way to allow light into the building interior and can be installed on sloping roofs. They are essentially clear domes on the rooftop with reflective coating to increase the amount of incoming light that reflects light down to a diffuser on the ceiling (Figure 11). Varying in size, they can sufficiently light a small room, hallway or staircase. Not only are they less expensive than skylights, but they are also less likely to leak, form condensation, or cause heating problems.



Figure 11: Solar tube.³¹⁶

³¹⁵ Solar Industries, Inc., *Louvered Smoke Hatch Skylights*, accessed 05/04/2007, at http://www.solarindustriesinc.com/alum_cm_louvered_smoke_hatch_skylights.html.

³¹⁶ Inhabitat, *Solar Tube Skylights*, accessed 05/05/2007, at <http://www.inhabitat.com/2006/12/28/solar-tube/>.

Table 15a: Lifecycle costs and impacts compared to no daylighting

		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)	△ ●				
	Human Health Risk			△ ●		
	Habitat Degradation			△ ●		
	Energy Consumption	△	●			
	Air and Atmosphere Quality	△	●			
	Waste Production		△ ●			
	Other Significant Impacts					
	Environmental Benefits		△ ●			
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost			△ ●		
	Human Health Risk			●	△	
	Habitat Degradation			△ ●		
	Energy Consumption			△ ●		
	Air and Atmosphere Quality			△ ●		
	Waste Production		△ ●			
	Other Significant Impacts					
	Environmental Benefits			△ ●		

Options	Symbol
Louvered Skylights	△
Solar Tubes	●

Table 15b: Feasibility of options compared to no daylighting

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility					△ ●
	Reduction of Cost (short run)				●	△
	Performance & Functionality				●	△
	Overall Environmental Impact				△ ●	
	Local Availability		△ ●			
	Educational Value				△ ●	

Recommendations

Skylighting is easy to install and has other benefits in addition to reducing the amount of air conditioning needed. For this reason, we recommend outfitting louvered skylights on top of the classrooms on the second floor of the proposed GES building. Louvered skylights have blades that open and close depending on the amount of sunlight outside, and they help ventilate the room. Even though fluorescent lighting is fairly efficient, studies show a significantly consistent positive relationship between daylighting and improved test scores.³¹⁷ In general, better lighting and ventilation has a positive correlation with productivity. They also show a trend of improving peoples' moods and reducing absenteeism.³¹⁸ Wellesley would only have to ensure that incorporating skylighting does not lead to excessive solar heat gain. Solar tubes would be suitable alternatives to skylights in the proposed GES building.

Lighting Controls

Daylighting can result in increased thermal loads, so the addition of electric lighting controls can help maximize the benefits of daylighting.³¹⁹ Light levels can be controlled through the use of light sensors. Occupancy sensors and timers can eliminate unnecessary energy use.

Standard Lighting Controls

Wellesley has only just begun installing occupancy sensors in the residence halls in small, experimental pilot projects. There are also light sensors installed in Clapp Library.

Light Level Sensors

Light sensors detect changes in the ambient light level and dim the lights from 20 to 100 percent accordingly. Although the dimming system is relatively expensive, user satisfaction is greater since the light level is constant. One can also set threshold on and off values for specific lighting levels.³²⁰ Nevertheless, these would only be effective on the second floor of the proposed ES space if the rooms were to have skylighting. If Wellesley also wants to use CFLs, it must buy those that are specifically designed to work in conjunction with the sensors.

Occupancy Sensors

Occupancy sensors detect when a space is occupied by using infrared or ultrasonic sensors. Once there is no heat or movement detected, after a preset delay time the sensor will automatically turn off or dim the lights. These are ideal for classrooms and meeting rooms where lights are frequently left on and unoccupied for large periods of time. Installing these

³¹⁷ Heschong Mahone Group, *Daylighting in Schools: An Investigation Into the Relationship Between Daylighting and Human Performance*, (20 August 1999), Heschong Mahone Group, Inc., accessed 05/06/2007, at <<http://www.h-m-g.com/downloads/Daylighting/schoolc.pdf>>.

³¹⁸ Russell P. Leslie, "Capturing the daylight dividend in buildings: why and how?" *Building and the Environment* 38:2, (February 2003), 381-385.

³¹⁹ U.S. Department of Energy, *DOE Building Technologies Program: Daylighting*, accessed 04/15/2007, at <<http://www.eere.energy.gov/buildings/info/design/integratedbuilding/passivedaylighting.html>>.

³²⁰ U.S. Department of Energy, <<http://www.eere.energy.gov/buildings/info/design/integratedbuilding/passivedaylighting.html>>.

sensors can reduce energy use by as much as 30%.³²¹ Some occupancy sensors, however, have a noise frequency that affects students with hearing aids.³²²

Electronic Timers

Electronic timers can be configured to turn on and off indoor or outdoor lights on a set schedule. In general, they can ensure that lights are on when necessary. Electrical timers are useful and cost effective for common spaces and hallways that need to be lit for security or safety purposes only at night. In some electric timers, a small amount of electricity runs through the timer while it is turned off. This makes CFLs continually try to turn on when the proper supply voltage is not present. Electronic timers should not be used with CFLs, because they shorten the lifespan their lifespan.³²³

Table 16a: Lifecycle costs and impacts compared to manual light switch						
		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)	△	● ■			
	Human Health Risk		△ ● ■			
	Habitat Degradation		△ ● ■			
	Energy Consumption		△ ● ■			
	Air and Atmosphere Quality		△ ● ■			
	Waste Production		△ ● ■			
	Other Significant Impacts			△ ● ■		
	Environmental Benefits		△ ● ■			
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost		△ ● ■			
	Human Health Risk			△ ● ■		
	Habitat Degradation			△ ● ■		
	Energy Consumption				△ ● ■	
	Air and Atmosphere Quality				△ ● ■	
	Waste Production		△ ● ■			
	Other Significant Impacts			△ ● ■		
	Environmental Benefits		△ ● ■			

Options	Symbol
Light Level Sensors	△
Occupancy Sensors	●
Electronic Timers	■

³²¹ Flex Your Power, *Controls and Sensors*, accessed 04/15/2007, at http://www.fypower.org/ind/tools/products_results.html?id=100119.

³²² The Beverley School Department and Symmes Maini and McKee Associates, *Early Stage Feasibility Study Report: Beverly High School, Beverly, MA*, (Jun. 24, 2003), accessed 05/05/2007, at http://www.mtpc.org/Project%20Deliverables/GB_GSI_FeasibilityStudy_Beverly_1.pdf.

³²³ Michigan Department of Information Technology, *Compact Fluorescent Lamps*, accessed 05/11/07, at <http://www.deq.state.mi.us/documents/deq-ess-p2-brightidea-FAQ.doc>.

Table 16b: Feasibility of options compared to a manual light switch					
		Worse		Same as Standard	Better
FEASIBILITY	Feasibility				△ ● ■
	Reduction of Cost (short run)			△ ● ■	
	Performance & Functionality			△ ■	●
	Overall Environmental Impact			△ ● ■	
	Local Availability	△ ● ■			
	Educational Value		△ ■	●	

Options	Symbol
Light Level Sensors	△
Occupancy Sensors	●
Electronic Timers	■

Recommendations:

To maximize energy savings, we recommend a combination of skylighting and lighting controls for the proposed GES building. Installing light level sensors with skylights lacking louver blades to regulate natural light levels can then help offset the amount of sunlight classrooms do not receive. For classrooms and meeting rooms without skylighting, we recommend installing occupancy sensors that either detect both heat and movement or that occupants can override for a set amount of time, much like electrical timers. We do not recommend, however, having electronic timers because of its incompatibility with compact fluorescent light bulbs or lamps.

Installing light control systems is a simple, low-cost investment with future savings. The beauty of all these options is that these light controls are all automated. Energy savings here do not depend on occupants' change of behavior. They do, however, educate occupants about the usefulness of smart systems on a more subtle level. People entering a classroom with occupancy sensors, for example, will immediately notice the lights turning on without having to flip a switch. If they step outside of the room and return a few minutes later, they will notice that the lights have turned off. This type of system helps to reinforce people's habit of turning off the lights when they leave so that they always come back to a dark room, as opposed to one wasting energy unnecessarily.

Additional Sources of Energy

Traditionally, at least 10% of generated power is lost during transmission. Distributed energy generation (DEG) systems eliminate these losses.³²⁴ Locating smaller power supplies closer to their final destinations minimizes losses. A DEG system could lower Wellesley College's dependence on natural gas because of its increased efficiency. At Wellesley College, the ideal small power supplies would be solar panels and microturbines.

Currently steam is piped from the co-generation facility through the greenhouses and into the Friends of Horticulture (FOH) building. Because the same set of pipes are used to heat both buildings, the greenhouses cannot control the amount of steam released without adversely

³²⁴ U.S. Department of Energy, *What is Distributed Energy Generation in the States?*, (Dec. 7, 2006), accessed 03/04/07, at <http://www.eere.energy.gov/state_energy_program/topic_definition_detail.cfm/topic=203>.

affecting the temperature of the FOH building. If the FOH building had its own power supply such as in a DEG system, the greenhouse would be able to regulate its energy use and effectively cut down energy consumption.

Solar panels

Enough solar energy reaches the earth in one day to meet the global population's energy needs for an entire year. Solar panels, otherwise known as photovoltaic cells, transform this renewable energy from the sun into electricity. Usually made from crystalline silicon, the photovoltaic cells are small, square-shaped panel semi-conductors. When sunlight hits each cell, a chemical reaction occurs, generating an electric current and consequently electric power.³²⁵

Over time, solar cells do become less efficient and subsequently release part of the generated power as infrared heat. The amount of power a solar panel produces depends on the quality, materials and technology used in construction and its age. Therefore it is important to consider more than the dollar to watt ratio.³²⁶

Because silicon is the second most abundant material on Earth,³²⁷ there is no worry that creating solar panels will deplete a precious natural resource. Additionally, during use, solar panels do not consume fossil fuels. By not utilizing fossil fuels, solar panels save natural resources and don't pollute the atmosphere with harmful emissions.

Photovoltaic cells can tie into a main electrical grid. When they generate excess power, the power can be sold to the power utility. Wellesley College is not, however, eligible for the power buyback system because the college does not obtain its electricity from a utility.

Systems range in cost from \$13,000 to \$35,000.³²⁸

Microturbines

Microturbines are about the size of a small refrigerator and output 25-500 kW. This power is generated from natural gas and/or crude oil. Because in a DEG system the microturbine minimizes transportation losses, a microturbine located at the proposed GES building's site would reduce fossil fuel inputs when compared to current practices. Microturbines also produce few emissions and typically run on methane mixed with compressed air but can also on waste fuels.³²⁹ When used in combination with waste heat recovery, microturbines can achieve efficiencies greater than 80%.³³⁰ They are compact and lightweight so can fit well in small spaces. An ideal location for the proposed GES building would be tucked along one of the outside walls. Microturbines are, however, still very expensive. Their price can range from \$200,000 to \$300,000.³³¹

³²⁵ Solar Panel Depot, *What are Solar Panels?*, accessed 04/12/2007, at < <http://www.solarpanelinfo.com/solar-panels/what-are-solar-panels.php>>.

³²⁶ Solar Panel Depot, < <http://www.solarpanelinfo.com/solar-panels/what-are-solar-panels.php>>.

³²⁷ Solar Depot, *What are photovoltaics?*, accessed 04/14/2007, at <<http://www.solardepot.com/>>.

³²⁸ Solar Depot, *Sol-Gen UT Solar Electric Generators*, (February 2006), accessed 04/14/2007, at <<http://www.solardepot.com/pdf/2007/UTES180.pdf>>.

³²⁹ Nora Goldstein, *Microturbines, Gas Engines Link Biogas to Grid*, Environmental Expert, (September 2006), accessed 04/14/2007, at < <http://www.environmental-expert.com/resultteacharticle4.asp?cid=6042&codi=8097&idproducttype=6&idmainpage=62&level=0>>.

³³⁰ U.S. Department of Energy, *Microturbines*, Office of Electricity Delivery and Energy Reliability, (May 17, 2006), accessed 04/14/2007, at <<http://www.eere.energy.gov/de/microturbines.html>>.

³³¹ Nora Goldstein, < <http://www.environmental-expert.com/resultteacharticle4.asp?cid=6042&codi=8097&idproducttype=6&idmainpage=62&level=0>>.

Table 17a: Lifecycle costs and impacts compared to the Co-generation facility

		Worse		Same as Standard		Better	Options	Symbol
PRODUCTION	Initial Cost (\$)	●	△				solar panels	△
	Human Health Risk			●		△	microturbine	●
	Habitat Degradation				●	△		
	Energy Consumption				●	△		
	Air and Atmosphere Quality				●	△		
	Waste Production				●	△		
	Other Significant Impacts							
	Environmental Benefits				●	△		
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost			△ ●				
	Human Health Risk				△ ●			
	Habitat Degradation				●	△		
	Energy Consumption				●	△		
	Air and Atmosphere Quality				●	△		
	Waste Production				●	△		
	Other Significant Impacts							
	Environmental Benefits				●	△		

Table 17b: Feasibility of options compared to the Co-generation facility

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility		△ ●			
	Reduction of Cost (short run)		△ ●			
	Performance & Functionality			△ ●		
	Overall Environmental Impact				●	△
	Local Availability			△ ●		
	Educational Value				●	△

Recommendations:

We are not currently recommending the use of any additional sources of energy for the proposed GES building. Distributed energy generation, while fantastic for increasing energy efficiencies, is not a feasible option for the proposed GES building because the actual power supplies are not feasible. As an energy supply for DEG, solar panels do not make sense for the GES building. In addition to being largely in the shade and thus not well suited to collect sunlight, the majority of the GES building's roofs must be glass. Solar panels cannot be placed over the glass, as they will block the incoming light to the greenhouses below.

Installing a microturbine as part of a DEG system for the proposed GES building is also impractical. Microturbines are not cost effective because they are very expensive to install and the power that would otherwise be used by the GES building is relatively efficiently produced. We therefore do not recommend any change in the source of energy for the proposed GES building.

Heating Systems

Radiators

Wellesley College currently heats most buildings on campus through the use of radiators. Newer buildings on campus utilize water radiators and while older buildings use steam.

Steam radiator systems are much less efficient than water radiators and other heating systems. To use steam, water must be boiled and then condensed. Heat is lost in this process. Boiling and condensing the water also results in a significant lag time between when the boiler is turned on and when the heat actually arrives in the radiator.³³² The lag-time makes it difficult to accurately regulate temperatures.

To decrease the amount of heat lost during transportation, steam pipes are insulated with fiberglass insulation. Please see the section on insulation for information regarding its environmental impacts and costs. Steam radiators can also warp the floor space surrounding the radiator. In addition to creating an uneven floor, the warping can prevent the water from draining properly. Water that is trapped in the radiator can cause loud, disruptive banging noises.³³³

Hot water radiators are similar to steam and are often visually indistinguishable. Steam is an inefficient means of heating because the temperature must remain above 212 degrees Fahrenheit at all times to avoid condensation. Water does not have this constraint, and so the temperature can be much more finely controlled.³³⁴

Radiators cost between \$500 and \$1000 per radiator.³³⁵ According to the size and number of rooms, installing new radiators in the environmental studies space alone would cost at least \$10,000.

³³² U.S. Department of Energy, *Heat Distribution Systems*, (Sept. 12, 2005), accessed 04/14/2007, at http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12580.

³³³ U.S. Department of Energy, http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12580.

³³⁴ Michael Dawley and George Hagg, personal communication, March 7, 2007.

³³⁵ Steam Radiators, *Steam Radiators: Price and Comparison*, accessed 04/14/2007, at <http://www.steamradiators.com/pricing.html>.

Compressed Air

Central heating compressed air systems generate heat from one point to multiple rooms. The heat is commonly generated in a furnace or boiler and forced as warm air through ducts.

A compressed air system pulls air out of a room, heats it, and forces the air back inside the room. This causes the building to be highly pressurized, pushing warm air out of the building through cracks and openings such as doors.³³⁶ In addition to losing heat through openings, considerable amounts of heat are lost through distribution. With central compressed air systems it is hard to regulate the amount of heat distributed throughout the building. Often unoccupied rooms are heated when there is no need. Regulating room temperature is also difficult because a single thermostat controls multiple rooms, where the amount of heat needed may not be uniform.

There are various environmental impacts associated with compressed air heating systems. The most directly related impacts of compressed air system are health problems associated with particulate matter in the air. As air is blown in and out of a room, dust, mold, and other particulates are spewed throughout the room. This movement of air and other substances can cause inflamed allergies and respiratory problems. Additionally, compressed air heating systems run on the current power supply. If the cogeneration facility is used, the environmental impacts of natural gas and crude oil, described in the Energy and Atmosphere Baseline Assessment, apply.

There are, however, a few logistical matters, which must be considered if a compressed air system were to be installed in the proposed GES building. Because of the wide variety of ventilation practices, it does not make sense for the college to install a compressed air system in the greenhouse portion of the GES building. In order to use a compressed air system in the environmental studies portion of the building, a secondary system must also be installed in the greenhouses. The actual installation of a compressed air system in the environmental studies portion would not, however, be difficult. Many buildings on campus, including the Science Center, utilize compressed air systems so the connection between a compressed air system and the cogeneration plant is already known.

Systems range in cost from \$3000 to \$5000.

In-Floor Radiant Space Heating

In-floor radiant space heating delivers heat to a room by channeling hot water into tubing underneath the floor. Radiant heating is more efficient than conventional forced air systems because radiant heating systems heat actual objects firsthand whereas compressed air must first heat the surrounding air. Also, unlike in compressed air systems, radiant heat is not lost through open doors or poorly sealed walls. Drafts can be felt inside the building, but after the door is closed, the room comes to equilibrium quickly. Because air is not being constantly forced into the building, radiant floor heating does not stir up dust or allergens.³³⁷ In addition to its energy indoor environmental quality benefits, in-floor radiant heating also has educational value. An in-floor radiant heating system in the proposed GES building would provide an excellent opportunity for students to study heat transfer and convection in action.

³³⁶ Alliant Energy, *Compressed Air Systems*, accessed 04/14/2007, at http://www.alliantenergy.com/docs/groups/public/documents/pub/p012390.hcsp#P16_584.

³³⁷ ToolBase Services, *Radiant Floor Heating*, accessed 04/14/2007, at <http://www.toolbase.org/TechInventory/techDetails.aspx?ContentDetailID=626>.

Radiant heating systems are usually installed as cross-linked polyethylene pex tubing directly under the floorboards or embedded into the cement foundation. There are two main reasons that in-floor radiant heat is a preferred alternative over compressed heat. There is increased comfort and significantly reduced energy-input required; spaces heated by radiant heat feel one to two degrees warmer than compressed air-heated spaces.³³⁸ This allows users to lower the thermostat and save additional energy.

The initial cost of radiant heat is more expensive than forced air systems (30-40%) but in the long run, annual operating costs are 20-30% less. Radiant floor heating can well pay for itself over the life of a building.³³⁹ Typical installations cost \$0.85 per square foot.³⁴⁰ At \$0.85 per square, installing an in-floor radiant heat system throughout the ES/Greenhouse space, both upstairs and downstairs would cost \$16,405.

Table 18a: Lifecycle costs and impacts compared to Radiators						
		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)		●		△	
	Human Health Risk		△			●
	Habitat Degradation			△		●
	Energy Consumption		△			●
	Air and Atmosphere Quality		△			●
	Waste Production			△ ●		
	Other Significant Impacts					
	Environmental Benefits		△			●
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost			△	●	
	Human Health Risk		△			●
	Habitat Degradation		△			●
	Energy Consumption		△			●
	Air and Atmosphere Quality		△			●
	Waste Production			△		●
	Other Significant Impacts					
	Environmental Benefits		△			●

Options	Symbol
Compressed air	△
Infloor radiant heat	●

³³⁸ ToolBase Services, <<http://www.toolbase.org/TechInventory/techDetails.aspx?ContentDetailID=626>>.

³³⁹ Solar Depot, *Off-grid Systems*, accessed 05/11/07, at <<http://www.solardepot.com/>>.

³⁴⁰ Radian Tech, *Ball Park Price Estimates*, (2006), accessed 04/14/2007, at <<http://www.radiantec.com/pricing/ballpark-estimates.php>>.

Table 18b: Lifecycle costs and impacts compared to Radiators						
		Worse		Same as Standard		Better
FEASIBILITY	Feasibility			△ ●		
	Reduction of Cost (short run)			●	△	
	Performance & Functionality		△			●
	Overall Environmental Impact		△			●
	Local Availability			△ ●		
	Educational Value		△			●

Options	Symbol
Compressed air	△
Infloor radiant heat	●

Recommendations:

We strongly recommend an in-floor radiant heating system for the proposed GES building. In-floor radiant heating not only minimizes heat loss from drafts (and consequently saves energy) but also provides indoor environmental quality benefits. As opposed to the alternatives, radiators and compressed air, in-floor heating allows building inhabitants a large amount of temperature control. In-floor heating also increases inhabitant comfort by providing a uniform temperature throughout the room. Because of the combination of energy efficient and IEQ benefits, we strongly support the inclusion of in-floor radiant heating into the proposed GES building.

Energy Saving Materials

There are many different materials that can be used in the ES/Greenhouse Space that can reduce the amount of energy used. The most significant materials are drywall, insulation, and glass. Detailed analyses of these three materials are provided in Section 2.2 B (p14).

Recommendations:

For energy saving materials, please see Section 3.3 (p52) of Materials and Resources building material recommendations..

Air Conditioning Systems

The greenhouse portion of the proposed GES building does not require an air conditioning system, but the environmental studies portion of the building does. Possible options include a compressed air system and a HANSA® system. A compressed air system connects to the compressed air heating system, and the environmental impacts and costs are the same as for heating (please see above for further discussion).

The second option is the HANSA® heating ventilation and air conditioning (HVAC) system, discussed in section 3.3, IEQ options analysis and section 2.4, energy and atmosphere baseline assessment.

Recommendations:

We recommend a HANSA® system for air conditioning in the environmental studies portion of the proposed GES building. Please see section 3.3 for further detail.

3.6 Water Efficiency

Collection Systems

Standard Rainwater Collection

The greenhouses currently water plants using drinking water from the Botany Wells. There is no rainwater collection system on campus. Therefore Wellesley College has ample opportunity to reduce water use by incorporating rainwater collection into the building design. A rainwater catchment system increases the water supply and reduces soil erosion due to runoff from impermeable surfaces. Additionally, it eliminates the need for complex and costly distribution systems. Because the annual rainfall for Wellesley is very high (45 inches, on average)³⁴¹ rainwater collection could eliminate the need for potable water in the greenhouses.³⁴² Rainwater catchment systems vary considerably, but all share three components: catchment areas, collection devices, and a conveyance system.

Rainwater Collection

Every inch of rain that falls on a catchment area of 1,000 ft² can bring in 600 gallons of rainwater.³⁴³ Rooftop catchments collect rainwater from gutters that are connected to downspouts that empty into a storage tank. As long as the roof is clear of debris, the water collected will have minimal contamination. A roof washer can also be installed to remove dirt, leaves, and debris from the roof periodically to ensure that the water is clean.³⁴⁴

Since the greenhouses apply whitewash to the roof of the display room each year, there is some concern that whitewash could adversely affect the water quality in a collection system. Whitewash fades over time, especially with the first snowfall, so water that came into contact with the wash would have some contamination. How trace amounts of whitewash would affect plants, however, is unknown. Whitewash is made of lime putty. Since lime is a natural buffer, its presence in the collection system could potentially neutralize the rainwater, which tends to be more acidic in New England than in other regions, thereby improving the water quality for plants. Thus the rainwater collected from the roof can still be used in the greenhouses, even if the greenhouses staff continue to whitewash the roof. Should whitewash or other chemicals prove a major concern, installing an activated carbon filter would likely be sufficient to remove any organic or health-threatening contaminants.

Water quality is also heavily dependent on the type of roofing materials used. The ideal roofing material is metal, such as aluminum, because pathogens cannot survive the heat. Slate is also suitable because of its smooth surface. Concrete tiles, however, are porous and can absorb as much as 10% of the flow due to its texture, inefficient flow, or evaporation.³⁴⁵

For the GES building, however, the majority of the roof will be made of glass. There is little research available on how glass functions as a roofing material for harvesting rainwater,

³⁴¹ Wellesley, Massachusetts, accessed 04/12/2007, at

<<http://www.citytowninfo.com/places/massachusetts/wellesley>>.

³⁴² Based on the current rooftop area of the greenhouses (8,416 ft²), a rainwater catchment system could collect as much as 241,330 gallons in one year. This well exceeds the estimated water usage of the greenhouses.

³⁴³ *Using Rain Barrels for Water Collection*, accessed 04/12/2007, at <<http://rainbarrelguide.com/>>.

³⁴⁴ *Roof Rainwater-Harvesting Questions Answered*, (Aug. 2006), Buildings, accessed 05/05/2007, at <<http://www.buildings.com/Articles/detail.asp?ArticleID=3233>>.

³⁴⁵ Texas Water Development Board, *The Texas Manual on Rainwater Harvesting*, (2005), accessed 04/14/2007, at <http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf>.

however. We can be certain glass does not decrease water quality, as it is a primary material used for sterilized lab procedures and food services. As a flat, smooth, non-absorbent surface, glass has many qualities that suggest it would be ideal for rainwater collection.

Gutters or downspouts collect water from the roof, but instead of releasing it to the ground, they funnel the rainwater into a storage tank. Gutters are commonly made of aluminum and galvanized steel, but aluminum is more costly to install.³⁴⁶ Alternatively, land surface catchments may have a greater surface area to harvest water but also have high rates of water loss due to infiltration into the ground and soil compaction. They also require extensive vegetation removal which, in turn, can induce soil erosion.³⁴⁷

A storage tank made of pine, cedar, or cypress wood has high aesthetic appeal. Because it is wrapped with steel tension cables and lined with plastic, it can be dismantled and reassembled for relocation. Although it can be lined with plastic to increase durability, wood has a relatively short life span compared to tanks made of other materials. Steel tanks are also lightweight and semi-mobile, but they are lined with PVC, a plastic which has health and safety risks associated with its production and disposal.³⁴⁸ Old or recycled steel tanks may contain lead and should be avoided. Brass and bronze fittings should not be connected directly to the tank because they will cause corrosion. Fiberglass tanks are light-weight, reasonably priced, and long lasting. Fiberglass has proven to be durable and easily repaired. The fittings on fiberglass tanks are an integral part of the tank, so there would be no need for leaking fittings. Although concrete tanks are not mobile, they can have the most versatile designs since they can either be poured in place or prefabricated and constructed above or below ground. Underground concrete tanks, however, are prone to cracks and leaks. It would be easy to repair leaks, but doing so may require draining the tank first.

Ferrocement tanks are made of low-cost, durable steel and concrete composite. These tanks use fewer materials in their construction and are thus less expensive than many other tanks, though they must be repaired immediately if there are leaks.

Below-ground tanks are usually made of polyethylene, which is a comparatively inexpensive, lightweight, and long-lasting recyclable material. They are more expensive than above-ground tanks because they require thicker walls and internal braces, in addition to excavation costs. Polyethylene tanks are lightweight and therefore are cheaper and easier to transport than concrete or metal. While these tanks can be located above or below-ground, underground tanks save space and do not disrupt the natural beauty of a location with their presence. A rain barrel requires the simplest installation but can only hold less than 1000 gallons of water.

Since there are so many kinds of rainwater storage and collection systems, we have presented only those we think reasonable for the proposed GES building in Table 19. Refer to the Materials Impact and Baseline Analysis for a comparison of various materials.

³⁴⁶ Texas Water Development Board,
<http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf>.

³⁴⁷ *An Introduction to Rainwater Harvesting*, accessed 04/14/2007, at
<<http://www.gdrc.org/uem/water/rainwater/introduction.html>>.

³⁴⁸ *PVC: Polyvinyl Chloride: Environmental Impact of PVC*, accessed 04/14/2007, at
<http://www.downbound.com/PVC_s/41.htm>.

Table 19a: Lifecycle costs and impacts compared to: Channeling Water to Storm Drains

		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$/gal)	●	■ 0	△		
	Human Health Risk	▽	● 0 ■	△		
	Habitat Degradation	●	△ 0 ▽ ■			
	Energy Consumption	● ▽	0 ■ △			
	Air and Atmosphere Quality	● ▽	0 ■ △			
	Waste Production		△ ● ■			
	Other Significant Impacts					
	Environmental Benefits	● ▽ ■	0 △			

Material	Symbol
Ferrocement	△
Steel	●
Fiberglass	▽
Concrete	■
Polyethylene	0

USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost	■ 0	△ ● ▽			
	Human Health Risk			△ ● ■		
	Habitat Degradation					△ ● ▽ ■
	Energy Consumption				△ ● ■	
	Air and Atmosphere Quality			△ ● ■		
	Waste Production		■ 0	△ ● ▽		
	Other Significant Impacts					
	Environmental Benefits				△ ● ■	

Table 19b: Feasibility of options compared to Channeling Water to Storm Drains

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility					△ ● ■
	Reduction of Cost (short run)				△ ● ■	
	Performance & Functionality				■ 0	△ ● ▽
	Overall Environmental Impact				△ ●	■ 0 ▽
	Local Availability	△ ● ▽	■			
	Educational Value					△ ● ■

Recommendations:

We recommend having an in-ground polyethylene tank with aluminum gutters to collect rainwater. Polyethylene tanks are lightweight, making transportation easier. They can also last for a long time and require little maintenance. With the Science Center and the Friends of Horticulture sandwiching the greenhouses in between, the main advantage of having the tank under the ground is to save space. Doing so means that the rainwater collection tank does not need to be fit in with the aesthetic appeal of the buildings around it either. Steel gutters are recommended over aluminum gutters namely because aluminum cannot stand corrosive environments. Additionally, steel is cost-effective, versatile, and durable and can be easily recycled.

Instead of supplying drinking water to some buildings or using it to irrigate landscapes, Wellesley currently uses water from Lake Waban. Wellesley can further these efforts by having a rainwater catchment system supply water for the greenhouses. Our estimates show that a rainwater catchment system could collect as much as 241,330 gallons in one year. This well exceeds the estimated water usage of the greenhouses. In conjunction with water-saving fixtures, the proposed GES building can potentially be self-sufficient with regard to water use by using only the rainwater collected throughout the year.

Reduced-flow Faucets

Standard Faucets

The campus currently uses Delta and Chicago low-flow faucets that meet the national standard of 2.2 gallons per minute (gpm) using aerating aerators.³⁴⁹ These aerators primarily add air to the water stream in order to make a small stream feel bulkier.

More Effective Aerators

Purchasing the same faucets and attaching to them more effective aerating aerators that go as low as 0.5 gpm would be the least expensive option. Wellesley also has the option of purchasing laminar flow aerators, which are non-aerating faucet aerators that produce multiple steam sprays in aerators. The multiple steam sprays widen for better rinsing, more spray velocity and better performance. These provide less heat loss, making aerators more energy and water efficient.³⁵⁰ Aerators in general, however, can harbor germs and pathogens.³⁵¹

Low-Flow Faucets

Low-flow faucets maintain an adequate flow rate for washing hands with a reduced flow rate of 0.5 - 2.2 gpm.³⁵² They would work the same way the faucets Wellesley currently has does.

³⁴⁹ 2005 ES 300 class, *Another Green Hall*, 81.

³⁵⁰ AM Conservation Group, Inc., *Swivel Laminar Flow Aerators*, accessed 05/05/2007, at <http://amconservationgroup.com/catalog.aspx?catid=248>.

³⁵¹ Building Green, Inc., *Showers, Faucets, and Drinking Fountains*, (May 2001), accessed 04/15/2007, at <http://www1.eere.energy.gov/femp/pdfs/29267-0.pdf>.

³⁵² James Piper, *Water Use: Slowing the Flow*, (Dec. 2003), accessed 04/15/2007, at <http://www.facilitiesnet.com/ms/article.asp?id=1969&keywords=>>.

Electronic Faucets

Electronic faucet controls offer improved sanitation and the convenience of hands-free operations, and are ideal for handicapped installations. Sensors are either mounted in the wall behind the sink or are integrated into the faucet, and they activate the faucet when IR or multispectrum sensors detect motion so that water is only running when it is needed.

Foot Pedal

The foot pedal can reduce germ transference by eliminating the need to touch the handle and also conserve water by ensuring that the faucet is only on when necessary. The foot pedal faucet controller acts as an on-and-off switch for the faucet when stepped on and requires no electricity. Foot pedals allow people to adjust water temperature with one foot pedal is for hot water and the other for cold (Figure 12). Foot pedals can either be wall-, ledge-, or floor-mounted.³⁵³ Foot pedals may be problematic for those with physical disabilities.



Figure 12: Hands-free wall-mounted foot pedal controller.³⁵⁴

Leaning Bar

The leaning bar is another common hands-free faucet controller (Figure 13). The user adjusts the temperature and flow rate using conventional handles, but water only flows when the user leans against a bar installed at the edge of the sink counter. The bar can also have a locking feature that enables the user to keep the faucet flowing. These would also be problematic for those with physical disabilities.



Figure 13: Hands-free faucet controller bar.³⁵⁵

³⁵³ 2005 ES 300 Class, *Another Green Hall*, 82.

³⁵⁴ Paragon Medical, *Scrub Sinks*, accessed 05/05/2007, at <<http://www.paragonmed.com/sinks.shtml>>.

Table 20a: Lifecycle costs and impacts compared to 2.5 gal/min faucet

		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)	■	● 0 ◇	△		
	Human Health Risk			△ ●		
	Habitat Degradation		0 ◇	△ ● ■		
	Energy Consumption		0 ◇	△ ● ■		
	Air and Atmosphere Quality		0 ◇	△ ● ■		
	Waste Production		0 ◇	△ ● ■		
	Other Significant Impacts					
	Environmental Benefits		0 ◇	△ ● ■		
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost		0 ◇ ■	△ ●		
	Human Health Risk			△ ●	0 ◇ ■	
	Habitat Degradation			●	△ 0	◇ ■
	Energy Consumption				△ ● ■	0 ◇
	Air and Atmosphere Quality			●	△ 0	◇ ■
	Waste Production			0 ◇ ■ ● △		
	Other Significant Impacts					
	Environmental Benefits			●	△ 0	◇ ■

Options	Symbol
More Effective Aerators	△
Low Flow Faucets	●
Electronic Faucets	■
Foot Pedal	0
Leaning Bar	◇

Figure 20b: Feasibility of options compared to 2.5 gal/min faucet

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility	0	◇	●		△ ■
	Reduction of Cost (short run)				△ ●	0 ◇ ■
	Performance & Functionality	0	◇			△ ● ■
	Overall Environmental Impact			● 0	△ ◇ ■	
	Local Availability		0 ◇	△ ● ■		
	Educational Value			△ ●	■ ◇	0

³⁵⁵ H2ouse, *Faucet Future Trends*, accessed 05/05/2007, at http://www.h2ouse.org/tour/details/element_action_contents.cfm?elementID=1D4BABB7-8E4C-4524-98836EECC5AEE08&actionID=A0D78D2C-69B7-4D4E-AC6C-9CFCE310A855.

Recommendations:

We recommend that the college install low-flow electronic faucets with more effective aerators. These are all easy to install and have immediate savings. Although a foot pedal or a leaning bar has more educational value because users have control over and must consciously decide how much water they are using, both would be problematic for those with physical disabilities.

Reduced-flow Showerheads

Standard Showerhead

The college purchases Chatham showerheads that meet minimum national standard with a low-flow rate of 2.5 gpm.³⁵⁶

Low-flow Showerheads

To conserve water, the college can install low-flow showerheads that use aerator technology as well as multiple flow settings. Using the air-water mixture under pressure to deliver a high velocity spray, these showerheads make it seem like more water is coming out than there actually is.³⁵⁷ Low-flow showerheads can have a low flow rate of 1.2 gpm and even a "pause" button that allows you to stop the water while soaping up or applying shampoo.³⁵⁸ Not only are low-flow showerheads relatively inexpensive, but they are also simple to install.

Thermostatic Mixing Valves

Thermostatic mixing valves ensure water is delivered within a set temperature range and pressure. Since there is no lag between the time water is turned on and when it reaches the preferred temperature, these valves can reduce the amount of water wasted. In addition, mixing valves ensure that temperature will remain within a safe range and thus prevent scalding.

Recommendations

We recommend low-flow showerheads and thermostatic mixing valves. Low-flow showerheads are simple to install, relatively inexpensive, and require no change in user behavior. Thermostatic mixing valves eliminate the need to leave the water on so that the water reaches a warm enough temperature for showering. Doing so helps to dispel the widespread notion that all showers require time to warm up.

Reduced-flow Toilets

Standard Low-flush Toilet

Wellesley College has installed low-flush Kohler brand toilets that meet the minimum federal regulations of 1.6 gallons per flush (gpf) in all construction projects since 1994. Although toilet brands vary around campus, a common model is the Kingston™ K-4330 which

³⁵⁶ 2005 ES 300 class, *Another Green Hall*, 79.

³⁵⁷ *Gaiam – Lowest Flow Showerhead*, accessed 04/15/2007, at <<http://www.gaiam.com/retail/product/46104>>.

³⁵⁸ Kelly Faloon, *The 'Greening' Of the Bathroom*, (March 2007), accessed 04/15/2007, at <http://www.pmmag.com/CDA/Articles/Cover_Story/BNP_GUID_9-5-2006_A_1000000000000062536>.

lists from \$175 to \$222.³⁵⁹ These toilets are one-piece, wall-mounted assemblages that meet the Americans with Disabilities Act (ADA) standards (17" to 19" from floor).³⁶⁰ While relatively easy to install and maintain, these toilets require regular checks to prevent leaks, especially in the piping system.

Currently water used to fill the toilet bowl is treated potable water pumped from the Botany Wells. Once flushed, the water enters the sewage system and is exported to the Deer Island Sewage Treatment Plant where it eventually is pumped into Boston Harbor. As mentioned in the Baseline Analysis, exporting water from the local area is a major concern since water exported cannot recharge the aquifer. Sewage transport and treatment is also an energy intensive process that results in greenhouse gas emissions.

Since toilet-flushing accounts for the majority (41%) of indoor water consumption in the average household,³⁶¹ any technology that reduces the gallons per flush would have a significant reduction in overall wastewater production.

Dual-flush

Dual-flush toilets were first designed in Australia in the 1980s, and though they have become popular outside the United States, they have yet to become common in the U.S..³⁶² Dual-flush toilets allow the user to select either a short flush (0.8 gallon) or long flush (1.6 gallons) depending on whether there are liquids or solids in the bowl.³⁶³ Studies done to test the performance of dual-flush technologies found that these installations successfully reduced the average flush volume from 1.6 gpf to 1.22 gpf for commercial uses.³⁶⁴ A study of 40 Seattle homes found that there was no significant increase in the flushing frequency after dual-flush toilet installations and that, on average, dual-flush systems could save 1,600 gallons per year compared to standard 1.6 gpf systems.³⁶⁵

In addition to reduced flow, many dual-flush toilets offer improved designs that make them more efficient at expelling waste and have less up-splash overall (Figure 14).³⁶⁶ Dual-flush toilets tend to be more expensive than standard toilet models, prices ranging from \$400 to \$900 depending on the brand.³⁶⁷ Based on the predicted ES 300 space and greenhouse use and Caroma product specifications, installing dual-flush toilets instead of standard 1.6 gpf toilets would save 33,800 gal/yr.³⁶⁸

³⁵⁹ Kohler®, Kingston™ wall-hung bowl with top spud, accessed on 04/14/2007, at <<http://search.us.kohler.com/?q=K-4330>>.

³⁶⁰ Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities (ADAAG), *Section 4.16.3 Height*, (Sept. 2002), accessed 04/14/2007, <<http://www.access-board.gov/adaag/html/adaag.htm#A4.16.3>>.

³⁶¹ 2005 ES 300, *Another Green Hall*, 73.

³⁶² Canada Mortgage and Housing Corporation (CMHC), *Research Highlights: Dual-flush Toilet Testing*, (2002), accessed 03/27/2007, at <<http://www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/02-124-e.html>>.

³⁶³ Caroma Innovation, accessed 04/14/2007, at <http://www.caromausa.com/innovate/idea_1.htm>.

³⁶⁴ John Koeller, *Dual-flush Toilet Fixtures—Field Studies and Water Savings*, (2002), accessed 04/14/2007 at <<http://www.caromausa.com/testimonial/Dual-Flush%20Fixture%20Studies.pdf>>.

³⁶⁵ John Koeller, <<http://www.caromausa.com/testimonial/Dual-Flush%20Fixture%20Studies.pdf>>.

³⁶⁶ Green Building Supply, *Dual Flush Water Saving Toilets Never Clog*, (2002), accessed 04/14/2007 at <<http://www.greenbuildingsupply.com/Public/EnergyWaterConservation/WatersavingToilets/CaromaDualFlushToilet/index.cfm>>.

³⁶⁷ Caroma Dual Flush Watersaving 270 ADA: \$400 (www.greenbuildingsupply.com) vs. Kohler Escal® K-19796: \$918 (www.us.kohler.com)

³⁶⁸ Calculations based on Caroma online worksheet: Caroma, *Water and Cost Savings for Caroma Dual-Flush Toilets – United States*, (Sept. 27, 2002), accessed 04/14/2007 at <<http://www.greenbuildingsupply.com/DocumentFiles/166.xls>>.

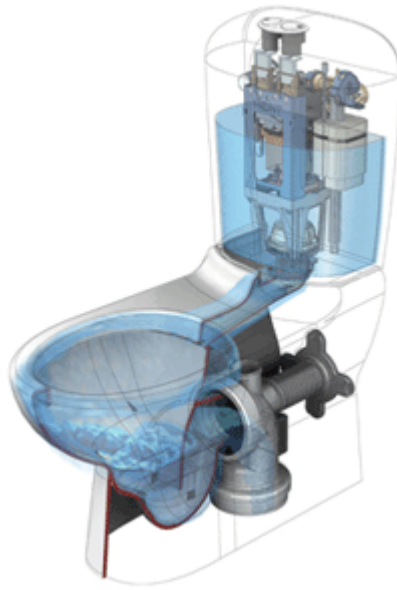


Figure 14: Dual-flush toilet design

369

Ultra-low Flush

There are many toilets on the market that out-perform the 1.6 gpf standard that are virtually indistinguishable in appearance and function from traditional toilets. These toilets can achieve up to 30% greater water efficiency either through pressure- or gravity-assisted suction.³⁷⁰

The benefits of these toilets are that they significantly reduce water consumption while also assuring that users will feel comfortable with the system. Because the plumbing is the same as that of standard toilets but the volume of water is reduced, these systems often create more noise than standard models and have increased likelihood of leaving unsightly rings in the bowl.

One specific example of a pressure-assisted model is the Kohler Highline™ (K-3519) which uses 1.1 gpf.³⁷¹ Ultra-low flush models tend to be at least double the price of a standard 1.6 gpf toilet.

Composting toilets

Composting toilets use biological processes to decompose human wastes on site under controlled conditions. Units can be completely dry or use a minimal amount of water (1 pint/flush) and they are classified either as “separate” or “self-contained”.³⁷²

Separate systems have toilets connected to a relatively large composting unit located nearby. If waterless, the bathroom is typically installed directly above the composting unit with

³⁶⁹ Caroma USE, Inc., *Australia's gift to a thirsty world*, accessed 04/14/2007, at <http://www.caromause.com/conserv/index.htm>.

³⁷⁰ Veritec Consulting Inc. and Koeller & Co., *Maximum Performance (MaP): Testing of Popular Toilet Models*, (March 2007, 9th Ed.), accessed 04/14/2007, at <http://www.cuwcc.org/uploads/product/MaP9thEdition07-03-30.pdf>.

³⁷¹ Kohler, *Highline™ Comfort Height™ elongated 1.1 gpf toilet*, accessed 04/15/2007, at <http://search.us.kohler.com/?q=K-3519>.

³⁷² Envirolet®, *Envirolet Composting Toilets*, accessed 04/14/2007, at <http://www.envirolet.com/models.html>.

a straight chute for connection. Foam/ultra-low-flush systems can be offset from the composting unit and connected to it using a standard pipe.³⁷³ These systems must be emptied every year for optimal performance, though at minimum, once every other year.

Self-contained systems are those where the toilet seat, receptacle, and composting tank are all a single unit. These are much smaller than separate systems and the compost must be removed multiple times each year.

Composting tanks are where decomposition takes place. As in nature, the rate of decomposition depends on environmental factors including temperature, moisture, pH, oxygen availability, and the ratio of carbon to nitrogen. Since human urine has high nitrogen content, an occasional addition of a carbon-rich substance such as sawdust or plant material may be necessary. In order to optimize chemical conditions, many systems are equipped with fans, heaters, and sensors to ensure proper functioning.³⁷⁴ As a result, most composting toilets rely on electrical energy which, based on Wellesley's energy sources, would contribute to greenhouse gas emissions.

Composting toilets are significantly more expensive than conventional toilets, with prices ranging from \$1,895 to \$2,095.³⁷⁵ Despite high system costs, the total cost with installation can be offset or even reduced for new installations since minimal piping is necessary, and the toilets are not connected to the sewer system. Additionally, waterless systems would save the complete cost of water-use, while foam or ultra-low-flush systems use only 19% of the water per flush of conventional toilets.

Since composting toilets accumulate compost from fecal waste, there is some potential for human pathogens to be present. For this reason the Massachusetts Department of Environmental Protection (DEP) requires that compost either be buried in a location and manner approved by the Board of Health, or that it be removed by a licensed septage hauler.³⁷⁶ Despite the special instructions required by state law, the human health risks associated with composting toilets are not significantly greater than those associated with standard systems.³⁷⁷ The pathogenic organisms that could be present are killed under aerobic conditions and have a life span of under 6 months, and so die naturally within the compost.³⁷⁸ The greatest risk associated with composting systems is that they will be abused by the user through the introduction of non-decomposable objects such as plastics that take up space in the composting unit.

As toilets go, composting toilets are not very popular. Often stigmatized as smelly and labor-intensive, many people are hesitant to use or adopt composting systems. These stereotypes might be true of poorly-managed systems, but improved technologies have made composting practical for commercial installations as diverse as a McDonald's/Mobile gas station and a law

³⁷³ Massachusetts Department of Environmental Protection (DEP), *Using Composting Toilets and Greywater Systems in Massachusetts*, (April 2005), accessed 04/14/2007, at <<http://www.mass.gov/dep/water/wastewater/comptoi.doc>>.

³⁷⁴ MA DEP, *Using Composting Toilets and Greywater Systems in Massachusetts*, (April 2005), accessed 04/14/2007, at <<http://www.mass.gov/dep/water/wastewater/comptoi.doc>>.

³⁷⁵ Prices from Envirolet® (www.envirolet.com), Sun-Mar® (www.sun-mar.com), and F.W.Horch (fwhorch.com)

³⁷⁶ MA DEP, 310 CMR 15.289(3), *Using Composting Toilets and Greywater Systems in Massachusetts*, (April 2005), accessed 04/14/2007, at <<http://www.mass.gov/dep/water/wastewater/comptoi.doc>>.

³⁷⁷ 2005 ES 300 class, *Another Green Hall*, 75.

³⁷⁸ David del Porto, personal communication, April 11, 2007.

school building the size of the Wellesley College Club.³⁷⁹ Foam-flow systems are often designed to look and function similarly to traditional toilets to minimize user discomfort.

Large systems can handle an average of 6 to 8 users per day (3 uses each), with occasional doubling of the system load (Figure 15). Whether the system capacity is appropriate for the ES Program and Greenhouses space depends on how many independent systems are installed. The space as designed now would likely need at least two composting tanks.

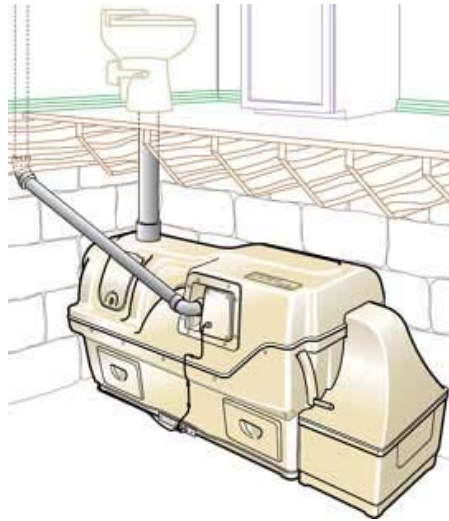


Figure 15: Sun-Mar Centrex 3000 separate composting unit and drum.³⁸⁰

³⁷⁹ Clivus, *Economic Solutions*, (2002), accessed 04/14/2007, at <http://www.clivusne.com/Vsm/templates/temp.asp?articleid=90&zoneid=33>.

³⁸⁰ Let's Go Green!, *Central Composting Toilet Systems Using only One Pint Flush Toilets*, accessed 05/07/2007 at: <http://www.letsogogreen.com/centrexwaterflush-desc.html>. Price listed as \$2,059 (US\$).

Table 21a: Lifecycle costs and impacts compared to Kohler 1.6 gal/flush toilet

		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)	■	● △			
	Human Health Risk			■ ● △		
	Habitat Degradation			■ ● △		
	Energy Consumption			■ ● △		
	Air and Atmosphere Quality			● △	■	
	Waste Production				● △	■
	Other Significant Impacts					
	Environmental Benefits				■	
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost		■	● △		
	Human Health Risk			■ ● △		
	Habitat Degradation				● △	■
	Energy Consumption				■ ● △	
	Air and Atmosphere Quality				■ ● △	
	Waste Production				■ ● △	
	Other Significant Impacts					
	Environmental Benefits					■

Options	Symbol
Dual Flush	△
Ultra-low flush	●
Composting	■

Table 21b: Lifecycle costs and impacts compared to Kohler 1.6 gal/flush toilet

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility		■	● △		
	Reduction of Cost (short run)		■ ● △			
	Performance & Functionality			■ ● △		
	Overall Environmental Impact				● △	■
	Local Availability			■ ● △		
	Educational Value			●	■	△

Recommendations:

We recommend the installation and use of dual-flush toilets in the proposed GES building. Unlike many of our recommendations, dual-flush toilets do not offer the greatest environmental benefits of the options we considered. We recommend them, however, in conjunction with other recommendations in the Water Efficiency sector—primarily the Living Machine. Dual-flush toilets would reduce water consumption from the standard 1.6 gallons per flush model while allowing for complete integration of all water systems within the proposed GES building. In contrast, composting toilets would be a separate entity, disconnected from the water system.

In addition to complete integration, dual-flush toilets invite the user to consider how much water they use by providing two flushing options. Although composting toilets are likely the best option for reducing overall environmental impact and also have potential educational value, dual-flush toilets require the user's awareness of water consumption. Water-saving devices only conserve when people conserve; in other words, a system cannot be more efficient than its users. Unless individuals become more aware of how they consume water, they will continue to use water unnecessarily and will not change their habits. Dual-flush toilets take one small step toward making users more cognitive of their water consumption. This little step could be responsible for the later changing of other water-use behaviors.

Our recommendation for toilets is largely dependent on the water reuse systems we also recommend. If a Living Machine or water reuse technology were not part of the building design, however, we recommend composting toilets for installation. Composting toilets are completely separate from the sewage disposal system, and thus eliminate a major source of wastewater export while also offering educational benefits.

Wellesley College does not currently have a water reuse system. Water from all sources—sinks, dishwaters, heating and cooling systems, showers, toilets—goes directly from the drain to the sewage pipes. The college and the proposed GES building, however, have great potential for water reuse because there are many sources of water consumption that do not require treated, potable water. Paramesium Pond, the heating and cooling systems, toilet bowls, and all campus irrigation are a few processes which could potentially use recycled water. Below are two ways that water could be reused in the proposed GES building.

Water Reuse Systems

A Living Machine

A Living Machine is a so-called 'wastewater' treatment system that mimics the ecological processes found in wetlands and other detritus-based foodwebs to purify water. The size and design of a Living Machine is specific to the needs and climate of the site, though systems can have flow volumes ranging from average daily household use to 220,000 gallons per day (gpd).³⁸¹ Several companies offer engineering consultation to custom design a site-appropriate system—Solar Aquatics Group,TM³⁸² Living Design Group, LLC,³⁸³ and Worrell

³⁸¹ Living Designs Group, *Representative Living Machine® Projects*, accessed 04/14/2007 at: <http://www.livingdesignsgroup.com/eng-project-master-list/>.

³⁸² Solar Aquatics GroupTM, www.ecological-engineering.com.

³⁸³ Living Design Group, LLC, www.livingdesignsgroup.com.

Water Technologies, LLC³⁸⁴ are a few that have completed projects in New England. Although each company has slightly different practices, the general steps for treatment are as follows (See also Figure 16):³⁸⁵

1. Open aerobic reactor

Bubbler ensures constant mixing and aeration of this tank

Function: oxygen kills many harmful pathogens, eliminates unpleasant odors, and promotes growth of *Nitrosomonas* spp. bacteria that convert ammonia (NH₃) & ammonium (NH₄⁺) into nitrate (NO₃⁻).

2. Covered aerobic reactor (with macrophytes)

Macrophytes and plants cover the surface of these tanks; their roots provide surface area for microorganism growth

Function: Primary and secondary treatment for the digestion of dissolved carbon compounds (reduce Biological Oxygen Demand (BOD)), persistent chemical compounds (halogens such as chloride or bromide), and solids (grease, oil, toilet paper).

3. Clarifying tank

Typically no activity in this tank; remaining solids are collected and moved to the compost tank. Some systems may recirculate water from this tank to earlier tanks to improve overall efficiency

Function: Remove potentially system-clogging solids; improve system efficiency

4. Solids compost

Sludge not digested is pumped to a composting tank.

Function: Allow residual solids to decompose more thoroughly

5. Anaerobic bed or tank

Influent is fed through a sand or gravel bed, often with plants growing at the surface. Anaerobic conditions promote the growth of denitrifying bacteria.

Function: Denitrification by anaerobic bacteria brings the water to tertiary standard

6. UV light radiation flow treatment

Water flows through UV light filter before directed to non-potable water uses or groundwater discharge

Function: UV radiation ensures that any remaining pathogens are exterminated

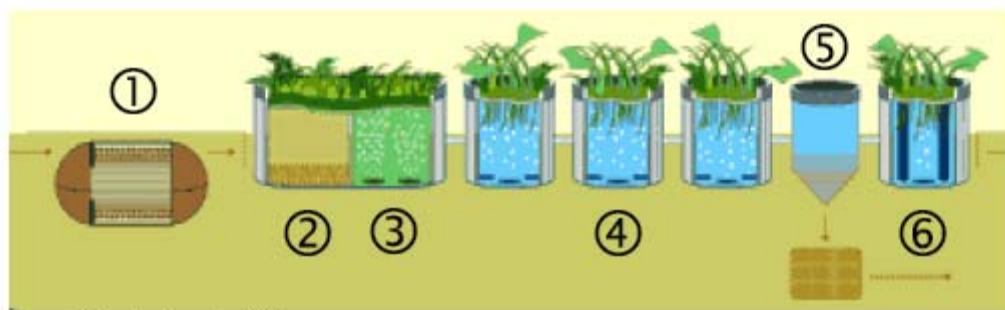
Unlike the majority of municipal treatment facilities, Living Machine systems are able to treat water to tertiary standards (or better) without producing any harmful byproducts such as

³⁸⁴ Worrell Water Technologies, LLC, <www.curoxin.com/about.cfm>.

³⁸⁵ Steps are based primarily from explanations given by David del Porto with Solar Aquatics Group™. David Del Porto, personal communication, April 11, 2007. Further information can be found with: U.S. EPA, *Wastewater Technology Fact Sheet: The Living Machine®* (Oct. 2002), Office of Water, EPA 832-F-02-025.

activated sludge, requiring the use of harmful chemicals such as chlorine, or negatively impacting the surrounding environment with greenhouse gas emissions or nutrient-rich effluent. These systems also have many added benefits. In addition to meeting or exceeding effluent standard goals for BOD, pathogen, and nitrogen removal, Living Machines can grow commercially valuable plants such as bamboo, palm oil, corn, or corkscrew willow. If a site has water quality concerns, such as high lead or arsenic concentrations, plants such as some fern species that are known to concentrate heavy metals can be used for phytoremediation.³⁸⁶

The most obvious benefit of Living Machines, however, is the human-friendly habitat they create. Living Machines are interesting because they transform “wastewater”—which is toxic and smelly, into a beautiful, lush, green space. Living Machines are ideal for greenhouses since the warm temperatures increase the rate of decomposition, though native evergreen plants can be selected for outdoor systems. Having a Living Machine inside the Wellesley Greenhouses would attract additional visitors and bring positive publicity to the college. The complex system of nutrients, microorganisms, plants, invertebrates, and even fish also provides an invaluable educational opportunity. Within one system there is the potential to learn, study, and experiment with nutrient cycling, ecological niches, trophic levels, resource partitioning, phytoremediation, while promoting good environmental stewardship practices.



Source: Living Machines Inc., 2001.

FIGURE 1 THE COMPONENTS OF THE LIVING MACHINE®: (1) ANAEROBIC REACTOR, (2) ANOXIC REACTOR, (3) CLOSED AEROBIC REACTOR, (4) OPEN AEROBIC REACTORS, (5) CLARIFIER, AND (6) “ECOLOGICAL FLUID BED”

Figure 16: An example of the various stages of a living machine system. Some systems have the anaerobic stage as the final step.

387

Living Machines greatly reduce environmental impact. They keep water local by either allowing for re-use in irrigation systems or for groundwater discharge. The energy cost associated with water treatment is minimal compared to the cost Wellesley currently incurs by exporting water to Deer Island. Only a few devices require an electricity source: a water pump, aerator device, and UV light flow machine.

Furthermore, Living Machines have low material costs and, depending on the installation, can be designed in a fashion that could be dismantled and relocated if necessary. The Solar Aquatics systems requires only plastic bag liners, mesh wire cylinders, metal piping between tanks, and a gravel field in addition to the electrical devices. Most of the costs for Living

³⁸⁶ David Del Porto, personal communication, April 11, 2007.

³⁸⁷ U.S. EPA, *Wastewater Technology Fact Sheet: The Living Machine®*, (Office of Water, EPA: Oct. 2002), 832-F-02-025.

Machines are up-front for the custom-design and installation, though prices are comparable to conventional treatment systems.³⁸⁸

Living Machines do require more maintenance than the standard sewage system. Since the system is alive, plants must be periodically (1-2 times per year) cut-back to maximize growth. The MA DEP also requires that systems be tested to ensure that water is meeting effluent standards, and to qualify for a groundwater discharge permit, the state requires that a certified wastewater treatment facility operator be present for at least 2 hours each day. This qualification could be obtained by current Wellesley Greenhouse staff, as the requirement can be met simply by passing a written exam about wastewater treatment facilities.³⁸⁹

A Living Machine system creates the opportunity to prevent wastewater production, use non-chlorinated water for greenhouse plants,³⁹⁰ reduce the impact of Wellesley's wastewater export, and integrate the green aspects of the ES Program/Greenhouse space in one aesthetically pleasing and educational system.

Greywater Primary Treatment Option

Greywater is used washwater from sink, shower, hose, and drinking fountain drains, as well as rain-water collection sources. Basically, any water that ordinarily goes into the sewer system that has not passed through a toilet (considered blackwater), fits the greywater category. Since greywater is often only slightly polluted, it can be safely re-used for non-potable sources after primary treatment. Ideal uses for greywater are for plant consumption—both in and outdoors—and to fill toilet bowls if a wet-septic system is used.

By using greywater, the overall wastewater export could be reduced by 50%³⁹¹ or more, especially since the greenhouses have ample use for non-potable water. In the event that greywater recycling and rainwater collection combined are not enough to satisfy the needs of the greenhouse plants, at minimum, greywater recycling would reduce the total water consumption of the ES Program and Greenhouse space.

There are many options available for filtering and treating greywater to the extent necessary for use. One option is to incorporate greywater into a Living Machine system, as described above. Commercial systems are also available. Commercial systems utilize the same environmental conditions as the living machine—a network of anaerobic, aerobic, and settling tanks ending with an UV light flow—however, the commercial systems are self-contained in plastic and can be placed entirely underground. For a diagram of a commercial greywater filtration system, see Figure 17.

³⁸⁸ U.S. EPA, *Wastewater Technology Fact Sheet: The Living Machine®*, Oct. 2002.

³⁸⁹ Commonwealth of Massachusetts, *Board of Certification of Wastewater Treatment Plant Operators* (2007), accessed 04/15/2007, at <<http://www.mwpca.org/s07examNotice.pdf>>. Exam fee is \$80.00. More information is available at <www.mwpca.org>.

³⁹⁰ Greenhouse staff indicated that they would prefer non-chlorinated water for plant care, personal communication March 2007.

³⁹¹ Equaris Corporation, *Greywater System*, accessed 04/14/2007, at <<http://www.equaris.com/default.asp?Page=Wastewater>>.

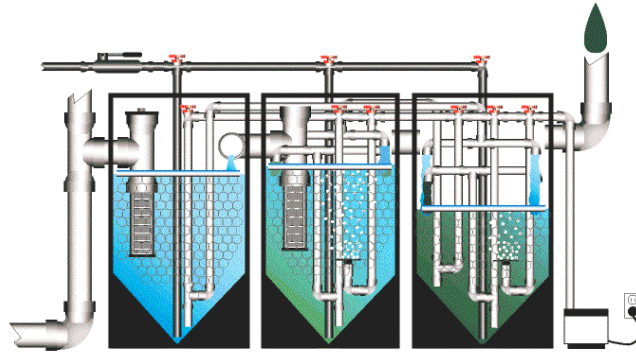


Figure 17: Equaris Greywater Treatment System. Water enters from the right and is purified as it moves (left) through the system.

392

Commercial systems such as the Equaris Greywater Treatment System require minimal maintenance after installation since they come equipped with sophisticated monitoring systems. They do require annual sludge removal since the microorganisms do not digest 100% of the grease and solids that might accumulate.³⁹³

These systems are capable of removing up to 99% of the nutrient load and BOD present in the effluent, and require minimal electricity (110 volts for a 67-watt air compressor). The efficiency comes at a high price, however. A system that treats 250 gpd costs \$5,000, and to add an additional composting system is \$10,000 more.³⁹⁴

³⁹² Equaris Corporation, <<http://www.equaris.com/default.asp?Page=Wastewater>>.

³⁹³ Equaris Corporation, <<http://www.equaris.com/default.asp?Page=Wastewater>>.

³⁹⁴ Equaris Corporation, *Price List*, available at <www.equaris.com>.

Table 22a: Lifecycle costs and impacts compared to wastewater export

		Worse		Same as Standard		Better
PRODUCTION	Initial Cost (\$)	●	△			
	Human Health Risk			●	△	
	Habitat Degradation			●		△
	Energy Consumption		●		△	
	Air and Atmosphere Quality			●	△	
	Waste Production			●	△	
	Other Significant Impacts					
	Environmental Benefits					△
USE (U) & DISPOSAL (D)	Maintenance & Disposal Cost		●			△
	Human Health Risk			●		△
	Habitat Degradation				●	△
	Energy Consumption				●	△
	Air and Atmosphere Quality				●	△
	Waste Production					● △
	Other Significant Impacts					△
	Environmental Benefits					△

Options	Symbol
Living Machine	△
Graywater Re-use	●

Table 22b: Feasibility of options compared to Wastewater Export

		Worse		Same as Standard		Better
FEASIBILITY	Feasibility		● △			
	Reduction of Cost (short run)	●	△			
	Performance & Functionality				●	△
	Overall Environmental Impact					● △
	Local Availability					● △
	Educational Value				●	△

Recommendations:

Before mentioning our specific recommendation for a water reuse system, it is worth reiterating that Wellesley does not currently have a water recovery system on campus. Any system that is implemented would be new to Wellesley and an improvement over the current 'sink to sewer' flow pattern. Furthermore, regardless of the type of system installed, whether it be a Living Machine or greywater recovery, there are decisions to be made about how to reuse the water.

Recycled water can be used for toilet bowls, indoor plants, and outdoor irrigation. Alternatively, treating water to tertiary standards and allowing it to percolate into soils on site allows the water to recharge the aquifer locally rather than contribute to the cost of water export to Deer Island. Due to public health concerns and regulatory complications, we recommend that recycled water be used for indoor and outdoor irrigation only. Rainwater collected requires only minimal treatment and poses virtually no health risk; therefore, to eliminate unnecessary potable water use, rainwater can be used for toilet bowls.

For the actual water-reuse system in the proposed GES building, we recommend a Living Machine, an ecological engineered wastewater treatment system. Without a doubt, any treatment system adopted would be more expensive than Wellesley's current practice of exporting all wastewater to Deer Island. After considering the environmental, ethical, and educational benefits of a Living Machine, however, we have determined that the benefits far outweigh the cost.

A Living Machine is ideal for the proposed GES building because it both physically and metaphorically integrates the greenhouses with the Environmental Studies space. Not only are these systems beautiful, displaying an array of flora that can be chosen for its aesthetic beauty or functionality, but they serve additionally as a beacon for visitors. The combined ingenuity and aesthetics of Living Machines attracts people of all ages who are curious to see waste fuel beauty. More valuable still than visitors to the greenhouses, however, is the educational merit of such a system. An ecosystem of its own, Living Machines offer virtually unlimited opportunities to study whole-system dynamics as well as species-specific adaptations. Living Machines also provide pure water that would be ideal for indoor and outdoor plants in the greenhouses.

Greywater recovery systems are improvements on the current lack of water reuse at Wellesley; they don't offer the same degree of ingenuity, beauty, or educational merit as do Living Machines, however. For that reason, we recommend a Living Machine as the ultimate investment towards environmental stewardship and education in the proposed GES building.

3.7 Crossover among Sections

Though we have divided our recommendations by sector, some sectors overlap, which impacts recommendations. One example of crossover arose when examining embodied energy during lifecycle analyses. There are specific impacts that result from using steel, but many more significant impacts occur during the manufacturing process. The production of steel requires large amounts of energy in order to reach the necessary smelting temperature, approximately 3000°F.³⁹⁵ This energy input must be considered even though it is not directly related to the use of steel as a building material.

³⁹⁵ Encyclopedia Britannica Online, *Steel*, (2007), accessed 05/08/2007, at <<http://0-search.eb.com.luna.wellesley.edu:80/eb/article-81370>>.

In the Water Efficiency options analysis, we recommend the inclusion of a Living Machine, rainwater collection system and dual-flush toilets in the proposed GES building because they complement one another. The Living Machine acts as a mechanism for water treatment, and both collected rainwater and greywater from the toilets can be filtered through the Living Machine to produce clean, potable water. Since the Living Machine also serves as a collection site for rainwater should the rainwater storage tank overflow, the combination of the Living Machine and a cistern controls storm water runoff from the building, an important aspect of Site Sustainability. Though we would have recommended composting toilets in place of dual-flush toilets if a Living Machine were not an option, the benefits of installing a Living Machine, rainwater collection system and dual-flush toilets in concert outweigh the benefits associated with composting toilets alone. The operation of a living machine results in zero waste production, building stormwater is handled and equal volumes of clean water enter and exit the system. Furthermore, implementation of these options would benefit students and the wider community educationally, because they provide the opportunity to learn about nutrient cycling, ecological niches, and environmental stewardship.

Our recommendation to install permeable pavers also affects both the Site Sustainability and the Water Efficiency sectors. Since permeable pavers allow water to seep into the ground, constructing a storm water management system for the pavement becomes unnecessary. Permeable pavers are beneficial because they create less site disturbance, but unfortunately the water that seeps through the permeable pavement cannot be collected later for greenhouse use. This water may, however, help to recharge the aquifer. Overall, we think permeable pavers are the best way to manage pavement and storm water runoff.

Indoors, our recommended in-floor heating system in the proposed GES Building also has implications across sectors. In addition to increasing energy efficiency, in floor radiant heat dramatically improves the IEQ of the building. As opposed to typical compressed air systems, in floor radiant heat does not cause pressure gradients across rooms, eliminating potential headaches and increasing building comfort. The lack of pressure gradients also increases air circulation and ventilation, both of which are essential to positive IEQ. Another important aspect of in floor heating is controllability. Each room can have individual temperature controls, allowing the heat setting to vary across rooms according to the inhabitants' needs, whether the occupants are plants or humans.

The recommended indoor lighting systems, while energy-efficient, do not necessarily optimize IEQ. Efficient lights would have motion sensors and timers to turn off the lights when not in use. ES space occupants may, however, need to work later than the timers have the lights on, or they may need to sit still for longer than the motion sensors would keep the lights on. For this reason, we recommend having override options for lighting so occupants can control the indoor lighting to suit their needs.

4. LEED Analysis



The U.S Green Building Council (USGBC) is an organization with goals to promote, develop and establish higher standards for engineered buildings. Leadership in Energy and Environmental Design (LEED) was created by the USGBC to provide a rating system that is voluntary, consensus-based, market-driven, and founded on accepted energy and environmental principles that strike a balance between established practices and emerging concepts.³⁹⁶

LEED certification is based on points awarded in six sectors: Sustainable Sites, Materials and Resources, Indoor Environmental Quality, Energy and Atmosphere, Water Efficiency, and Innovation and Design Process. The rating system grants points by examining each stage in a project's cycle: proximity of materials, a material's life, renewable energy, air quality, recycled content and much more. There are four levels of certification depending on the number of points acquired: Certified (26-32 points), Silver (33-38 points), Gold (39-51 points) and Platinum (52-69 points).³⁹⁷

While some green elements can be introduced over time, the most effective designs strive for this goal from the outset. LEED certification ensures that these considerations will be integrated into the entire building process.

LEED provides a framework for efficient and "green" initiatives that should be implemented regardless of whether Wellesley decides to seek LEED approval. People may ask, "Why involve an extra layer of bureaucracy and expense simply to label what we are already doing as green?" The danger of not using LEED, however, is that green elements that are part of an initial design may be cut from a project if decisions are left to sub-contractors or if a project risks going over budget, even if those elements would have provided long-term savings. If there is no designated individual to advocate for green measures and no reward for following through with the original plans for environmental consideration, green features of a building can be lost.

Education is the fastest growing sector in green design.³⁹⁸ Many elite colleges and universities have begun to build to LEED standards. For example, Harvard currently has twenty-one LEED certified buildings³⁹⁹, and Mt. Holyoke has two with one underway.⁴⁰⁰ MIT has

³⁹⁶ U.S. Green Building Council, *LEED-NC: Green Building Rating System For New Construction & Major Renovations, Version 2.2*, (10/2005), accessed 05/11/2007 at

<https://www.usgbc.org/FileHandling/show_general_file.asp?DocumentID=1095>.

³⁹⁷ U.S. Green Buildings Council,

<https://www.usgbc.org/FileHandling/show_general_file.asp?DocumentID=1095>.

³⁹⁸ U.S. Green Building Council, *Press Releases*, accessed 05/10/07 at

<<http://www.usgbc.org/News/PressReleaseDetails.aspx?ID=2889>>.

³⁹⁹ Harvard Gazette, 2006: *Harvard registers its 16th LEED building project*. 2007: *Harvard registers its 21st LEED building project*, Green Milestones, accessed 05/10/07 at

<<http://www.news.harvard.edu/gazette/2007/04.19/01-greentimeline.html>>.

adopted a policy for all new constructions to achieve Silver LEED certification.⁴⁰¹ Given that Wellesley has already implemented many innovative green elements around campus, LEED certification would give recognition to the college's commitment to sustainable practices.

We evaluated LEED guidelines by the six sectors into which LEED is divided. For each point we considered LEED requirements in terms of what Wellesley currently does or is capable of doing for the proposed GES building, describing each credit in detail while also discussing ways that Wellesley could achieve each. Finally, we ranked points based on how difficult they would be to obtain.

Our ranking system has five categories: standard, easy, moderate, hard, and impossible. "Standard" refers to building practices that are already common at Wellesley, while "impossible" denotes practices or qualifications that are not possible due to the nature of our site or building program. For example, the credit for building within one half-mile of public transportation is "standard" at Wellesley due to the college's bus service to Boston and location near the commuter rail, whereas it is "impossible" for Wellesley to remediate a Brownfield because there are no Brownfields at Wellesley.

For credits that do not fall into these two categories (and most do not), we based our designations on the degree of deviation from standard practices and costs. Points are deemed "easy" if they did not require a significant change from standard practices or an increase in cost. "Moderate" points are those that incur significant additional costs, but which do not necessitate a complete overhaul of current practices. For example, it would be easy to include amenities for cyclists in the proposed GES project since this would involve incorporating features that are regularly part of building projects (bike rack and shower), but it would be of "moderate" difficulty to reduce building water consumption by 30% or more since doing so would require measures beyond simply installing low-flow devices. "Hard" is reserved for those credits that are both significantly more expensive and which also require considerable deviation from standard practice. For example, achieving a point for having at least 35% of energy be produced by renewable resources would be "hard" for our proposed GES building since Wellesley produces its own power and has no need for additional energy contracts.

4.2 Sustainable Sites

Site sustainability addresses how the construction of a building, the grounds surrounding a building and a building's exterior impact the environment. Our analysis shows that eleven of the fourteen LEED points for this sector would be earned with at most moderate efforts to make the building greener. Striving to meet these goals would help the College earn recognition for sustainable practices already in place, such as providing Exchange Bus and Senate Bus transportation shuttles into Boston. Earning Site Sustainability credits would also benefit people who would prefer to bike to work, the surrounding ecological community and the campus grounds.

SS Prerequisite 1: Construction Activity Pollution Prevention

This prerequisite to obtaining LEED certification requires that a sediment and erosion control plan be implemented in accordance with local standards and codes, the EPA's best

⁴⁰⁰ Mount Holyoke, College Street Journal, *Two MHC Buildings Garner LEED Award for Green Design*, accessed 05/10/07 at <<http://www.mtholyoke.edu/offices/comm/csj/091004/green.shtml>>.

⁴⁰¹ MIT Department of Facilities, *Environmental Initiatives*, accessed 05/10/07 at <<http://web.mit.edu/facilities/environmental/leed-buildings.html>>.

management practices (BMPs) for storm water management for construction or according to recommendations by the Minnesota Pollution Control Agency. As Wellesley College has shown great commitment to controlling stormwater runoff in other building projects, such as Alumnae Valley, we believe complying with this prerequisite is standard for Wellesley College.

SS 1: Site Selection

To earn this credit, a building may not be constructed in areas prohibited by LEED, including farmland, floodplains, wetlands, and public parkland. As the GES building site would be where the current greenhouses now stand, our site does not conflict with the LEED requirements for this credit, and we therefore consider meeting it to be standard.

SS 2: Development, Density and Community Connectivity

The goal of this credit is to channel development into existing infrastructure while also preserving habitat and natural resources. To achieve the point, a project must renovate a previously developed site that is located within ½ mile of both a residential area with an average density of 10 units per acre and at least 10 “Basic Services”. Basic Services include (but are not limited to): 1) Fire station; 2) Beauty; 3) Laundry; 4) Library; 5) Medical/Dental; 6) Park; 7) Post Office; 8) Theater; 9) Community Center; 10) Fitness Center; 11) Museum. By nature of being a college campus, itself a residential area that meets the minimum density requirements while providing well over 10 Basic Services that are readily accessible to pedestrians, we consider this credit standard for our site.

SS 3: Brownfield Redevelopment

The GES building site is not a part of a brownfield, and is therefore not eligible for this credit. Brownfields consist of land previously used for industrial or certain commercial uses that may be contaminated by low concentrations of hazardous waste or pollution but may be reused once cleaned up.

SS 4.1: Alternative Transportation: Public Transportation Access

This credit requires that the project be located within ½ mile of an existing or planned commuter rail or subway station or within ¼ mile of public or campus bus lines. Our site is located within ½ mile of a commuter rail (Figure 18). Additionally, the College provides two bus lines into Cambridge and Boston – the weekday Exchange Bus and the weekend Senate Bus. Both the proximity to a commuter rail and the Wellesley College bus services would earn the GES building this LEED point without further effort on the part of the college, making it standard practice.



Figure 18: From Google Maps, the Wellesley College greenhouses site (left arrow) and the Wellesley Square Commuter Rail stop (right Arrow).⁴⁰²

SS 4.2: Alternative Transportation: Bicycle Storage & Changing Rooms

To help commuters reduce pollution from automobile use, this LEED credit requires a building to provide a bicycle rack and a shower to building users. Bicycle racks are heavily utilized throughout campus and are already part of building design for many projects. And both bike racks and showers are inexpensive, easy to install and do not require much room. A shower could also be helpful to the greenhouses staff who have a messy job at times. Although showers are not necessarily part of academic building projects at Wellesley, including one in the building design as we have proposed is an easy endeavor. Since the requirements for this credit are fairly common Wellesley practices that are inexpensive and practical, the GES building could easily earn this Site Sustainability point.

SS 4.3: Alternative Transportation: Low Emitting & Fuel and Vehicles

This credit requires preferred parking for low-emitting and fuel-efficient vehicles or the provision of such vehicles for a percentage of building occupants. Since the GES building would provide neither parking nor vehicles nor refueling stations, the building would be ineligible for this credit, which we count as impossible.

SS 4.4: Alternative Transportation: Parking Capacity

This credit concerns parking sizes and preference for carpools. No new parking will be provided by constructing the GES building, which makes the building ineligible for this credit.

⁴⁰² Google™ Maps, Wellesley, MA (02481), accessed 05/05/2007, at <www.google.com>.

SS 5.1: Site Development: Protect or Restore Habitat

To earn a LEED point for protecting habitat, a previously developed site must protect 50% of the surrounding native or adapted vegetation. As long as no plans are made to disturb the native and adapted vegetation to the south of the GES building site, this point will be easy to acquire.

SS 5.2: Site Development: Maximize Open Space

This credit may be earned by maintaining a vegetated space adjacent to the GES building that is equal in area to the building's footprint. The vegetated slope south of the current greenhouses exceeds the area of the proposed blueprint, so the easy act of protecting the vegetation on the slope, which in turn will slow stormwater runoff, would earn this credit.

SS 6.1: Stormwater Design: Quantity Control

This credit requires the implementation of a stormwater management plan that increases on-site infiltration (water seepage into the ground), reducing or eliminating pollution for stormwater runoff, and eliminating contaminants. Our recommended stormwater runoff collection system would not only set aside rainwater for greenhouse use, but it would also help prevent surface runoff and therefore minimize erosion. Such a system would be moderately difficult to design and install. Additionally, we could protect stormwater from causing erosion by installing permeable pavement for walkways. Such pavement would promote the infiltration of stormwater into the ground rather than over the surface, where erosion occurs. This LEED credit could be achievable with the implementation of the proposed runoff collection system or permeable pavement at the site, both of which would require moderate effort.

SS 6.2: Stormwater Design: Quality Control

This credit is similar to the previous in that it requires a stormwater management plan that reduces impervious cover and promotes infiltration. It also requires that 90% of stormwater runoff be captured and treated. The stormwater collection system mentioned above (SS 6.1) would capture stormwater runoff, and either a Living Machine or the existing system for campus stormwater treatment would control the quality of whatever water the greenhouses did not use. Stormwater treatment via Living Machine would be moderately difficult to implement, but the educational value would be great.

SS 7.1: Heat Island Effect: Non-roof

In order to prevent heat islands from developing on walkways, as this LEED credit requires, Wellesley College could easily pave walkways with light-colored concrete or permeable pavers.

SS 7.2: Heat Island Effect: Roof

This credit requires the use of roofing materials that either have a high Solar Reflectance Index (SRI) (a measure of a surface's ability to reflect solar heat) or vegetation covering 50% or more of the roof area. As designed, the proposed GES project must have a glass roof since the second story of the building is a greenhouse that would need solar radiation. Since no other roofing material would be possible, this credit cannot be achieved using our proposed design.

SS 8: Light Pollution Reduction

This credit requires that the amount of light being emitted from the building at night be minimized. Greenhouse plants would prevent nighttime artificial lights used inside the building from illuminating the outdoors. For areas in which there would not be enough foliage to block indoor light, automatic timed shades could be installed with moderate effort. The proximity of this building to the observatory suggests that blocking the light would be a priority for reasons other than LEED certification or environmental impact as well.

Table 23: LEED Sustainable Sites Credit Evaluation					
LEED Credits	Sustainable Sites	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
SS PreReq1	Construction Activity Pollution Prevention				
	Design a site, sediment and erosion control plan than conforms to best management practices in the EPA's Storm Water Management for Construction Activities, EPA Document No. EPA-832-R-92-005, Chapter 3, OR as outlined in "Protecting Water Quality in Urban Areas: Best Management Practices for Minnesota," Minnesota Pollution Control Agency, OR local Erosion and Sedimentation Control standards and codes, whichever is more stringent	Required	Standard	Yes	Wellesley already meets required federal and local storm water regulations for construction sites.
SS: 1	Site Selection				
	Do not develop buildings on portions of sites that include farmland, threatened or endangered species, parkland or wetlands.	1	Standard	Yes	The site under consideration does not violate any of the prohibited criteria.
SS: 2	Development, Density and Community Connectivity				
	Construct on a previously developed site within ½ mile of a residential zone or neighborhood with an average density of 10 units per acre net and within ½ mile of at least 10 Basic Services and with pedestrian access between the building and the services.	1	Standard	Yes	Faculty apartment complexes and residence halls that meet the density requirements are within 1/2 mile of the site, as are at least 10 of the basic services listed.
SS: 3	Brownfield Redevelopment				
	Develop on a site classified as a Brownfield and provide remediation as required for EPA's Sustainable Redevelopment of Brownfields Program requirements and that support Minnesota's Community-Based Planning Act.	1	Impossible	No	There are no Brownfields at Wellesley.

LEED Credits	Sustainable Sites	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
SS: 4.1	Alternative Transportation: Public Transportation Access				
	Locate building within 1/2 mile of a commuter rail, light rail or subway station or 1/4 mile of 2 or more bus lines.	1	Standard	Yes	The site is already within 1/2 mile of the commuter rail, Senate and Exchange Busses
SS: 4.2	Alternative Transportation: Bicycle Storage & Changing Rooms				
	Provide suitable means for securing bicycles, with convenient changing/shower facilities for use by cyclists, for 5% or more of building occupants	1	Easy	Yes	Include a bike rack and shower in the building design
SS: 4.3	Alternative Transportation: Low Emitting & Fuel Efficient Vehicles				
	Install alternative-fuel refueling station(s) for 3% of the total vehicle parking capacity of the site in addition to providing preferred parking to these vehicles.	1	Impossible	No	There is no parking available (or needed) at the greenhouses site.
SS: 4.4	Alternative Transportation: Parking Capacity				
	Size parking capacity not to exceed minimum local zoning requirements AND provide preferred parking for carpools or van pools capable of serving 5% of the building occupants, OR , total parking capacity must be less than 5% of the non-residential FTE occupancy AND preferred parking must be provided for carpools or van pools for 5% of the building occupants, OR , no new parking is provided.	1	Standard	Yes	No new parking spaces will be built for the GES building.
SS: 5.1	Site Development: Protect or Restore Habitat				
	On greenfield sites, limit site disturbance including earthwork and clearing of vegetation to 40 feet beyond the building perimeter, 5 feet beyond primary roadway curbs, walkways, and main utility branch trenches, and 25 feet beyond pervious paving areas that require additional staging areas in order to limit compaction in the paved area; OR , on previously developed sites, restore or protect a minimum of 50% of the remaining open area with native or adapted vegetation.	1	Easy	Yes	Do not disturb vegetation to the south of the GES building site.

LEED Credits	Sustainable Sites	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
SS: 5.2	Site Development: Maximize Open Space				
	Reduce the development footprint (total area of the building footprint, hardscape, access roads and parking) and/or provide vegetated open space within the project boundary to exceed the local zoning's open space requirement for the site by 25% , OR , for areas with no local zoning requirements (e.g., some university campuses, military bases), provide vegetated open space area adjacent to the building that is equal to the building footprint, OR , where a zoning ordinance exists, but there is no requirement for open space (zero), provide vegetated open space equal to 20% of the project's site area.	1	Easy	Yes	Do not disturb the vegetated space adjacent to the site that already exceeds the proposed building footprint.
SS: 6.1	Stormwater Design: Quantity Control				
	Implement a stormwater management plan that: Prevents the post-development peak discharge rate and quantity from exceeding the pre-development peak discharge rate and quantity for the one- and two-year 24-hour design storms, OR , implements a stormwater management plan that protects receiving stream channels from excessive erosion by implementing a stream channel protection strategy and quantity control strategies.	1	Moderate	No	Install a rainwater collection to prevent runoff from the building surfaces. Permeable or block pavers to increase infiltration
SS: 6.2	Stormwater Design: Quality Control				
	Implement a stormwater management plan that: Reduce impervious cover, promotes infiltration, and captures and treats the stormwater runoff from 90% of the average annual rainfall using acceptable best management practices (BMPs). BMPs used to treat runoff must be capable of removing 80% of the average annual post development total suspended solids (TSS) load based on existing monitoring reports.	1	Moderate	Yes	Install rainwater collection in conjunction with greywater filtration Use only permeable or block paving where pavement is necessary Ensure grease-trap filters are in place in all storm drains

LEED Credits	Sustainable Sites	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
SS: 7.1	Heat Island Effect: Non-Roof				
	Provide shade (within 5 years of occupancy) on at least 50% of non-roof impervious surface on the site, including parking lots, walkways, plazas, etc., OR , use light-colored/high-albedo materials (Solar Reflectance Index (SRI) of at least 29) for 50% of the site's non-roof impervious surfaces, OR use an open-grid pavement for 50% of the site hardscape.	1	Easy	Yes	Install open-grid or permeable paving on site.
SS: 7.2	Heat Island Effect: Roof				
	Use roofing materials having a SRI equal to or greater than given LEED values for a minimum of 75% of the roof surface, OR, install a vegetated roof for at least 50% of the roof area, OR , Install high albedo and vegetated roof surfaces that, in combination, meet the following criteria: $(Area\ of\ SRI\ Roof / 0.75) + (Area\ of\ vegetated\ roof / 0.5) > Total\ Roof\ Area$	1	Impossible	No	Greenhouses cannot afford to lose sunlight to reflective or vegetated roofs.
SS: 8	Light Pollution Reduction				
	Do not exceed Illuminating Engineering Society of North America (IESNA) footcandle level requirements as stated in the Recommended Practice Manual: Lighting for Exterior Environments, AND design interior and exterior lighting such that zero direct-beam illumination leaves the building site.	1	Moderate	No	Minimize outdoor lighting at night Install automated shades to cover window surfaces of the building and greenhouses at night (also provides increase insulation). Install motion-sensor and timers for non-safety/security lights
Total:		14	Standard: 4 Easy: 4 Moderate: 3 Hard: 0 Impossible: 3		

4.3 Materials and Resources

LEED provides a framework to regulate the acquisition, use and disposal of building materials since the planning, design and construction processes of any new building are often decentralized. The LEED materials and resources requirements are intended to reduce and divert waste from landfills, conserve and recycle materials and natural resources, mitigate the environmental impacts of resource extraction, processing and transport and encourage sustainable natural resource use and management. The results of our LEED analysis for our proposed GES building show that 10 of the 13 possible LEED points in this sector may be obtained with easy to moderate effort.

MR Prerequisite 1: Storage and Collection of Recyclables

In order to receive any Materials and Resources LEED points, a building must first fulfill the prerequisite for storage and collection of recyclables. The new building has to provide an easily accessible area that serves the entire building and is dedicated to collection and storage of non-hazardous materials for recycling, including paper, corrugated cardboard, glass, plastics and metals. Wellesley has a student-run recycling program in place in the residence halls, but a full-scale, consistent recycling program does not exist in any other campus buildings. Staff members currently carry out paper and cardboard recycling. Additionally, some small-scale glass and aluminum recycling occurs in select administrative buildings on campus, but a comprehensive, institutionalized recycling program has not yet been implemented. To fulfill this prerequisite, the GES plan must include space for recycling, preferably on each floor. Coordination with both the physical plant administration and students is necessary to ensure that collection of recyclables occurs. While institutionalizing recycling on a campus-wide basis remains extremely challenging, creating a recycling program for the GES would be relatively easy.

MR Credit 1.1: Building Reuse: Maintain 75% of Existing Walls, Floors & Roof

In the interest of extending the life of existing building stock, conserving resources and reducing waste, LEED has created three Building Reuse credits. MR Credit 1.1 requires that a new building maintain at least 75%, based on surface area, of the existing building structure including structural floor and roof decking and envelope which includes exterior skin and framing, excluding window assemblies and non-structural roofing material. Hazardous materials that are remediated as a part of the project scope are excluded from the calculation of the percentage maintained.

While Wellesley conserved existing building shells during the Science Center extension project around Sage Hall and its 1999 renovation of Stone-Davis Hall, it would be impossible to meet Building Reuse credits for the proposed GES building. A large portion of the building does not yet exist, namely the Environmental Studies classrooms and offices. Our proposed plans for the GES building would require too much demolition and redesign of the existing greenhouses to make achieving this point possible.

MR Credit 1.2: Building Reuse: Maintain 95% of Existing Walls, Floors & Roof

To obtain a supplementary MR credit, a new building must maintain an additional 20% (95% total, based on surface area) of existing building structure (including structural floor and roof decking) and envelope (exterior skin and framing, excluding window assemblies and non-structural roofing material)—see MR Credit 1.1 for additional stipulations. The proposed GES building could not obtain this credit for the reasons outlined above.

MR Credit 1.3: Building Reuse: Maintain 50% of Interior Non-Structural Elements

This credit calls for the use of existing non-structural elements, such as interior walls, doors, floor coverings and ceiling systems in at least 50 % of the completed building. If the project includes an

addition to the existing building, this credit is not applicable if added area more than doubles the size of the existing building.

The non-structural elements of the current greenhouses are sparse: the interior walls and ceiling of the building consist of glass, the floor of cement, and most of the greenhouses contain only doorways, not doors. These elements are not suitable for the Environmental Studies portion of the proposed GES building, and since many of them are structurally unsound (i.e., the glass is cracked), they would be undesirable for reuse in the research greenhouses. Furthermore, the proposed GES project would nearly double the size of the current greenhouses. These considerations in mind, this point is impossible to obtain for the proposed GES building.

MR Credit 2.1: Construction Waste Management: Divert 50% from Disposal

LEED construction waste management credits require recycling of substantial amounts of non-hazardous construction and demolition debris. To earn MR Credit 1.1, contractors for a new building must recycle and/or salvage at least 50% of non-hazardous construction and demolition debris. They must develop and implement a construction waste management plan that, at minimum, identifies the materials to be diverted from disposal and whether the materials will be sorted on-site or co-mingled. Excavated soil and land-clearing debris do not contribute to this credit. Calculations can be done by weight or volume but must be consistent throughout.

All contractors are required by law to sort construction waste onsite so that some materials may be recycled and diverted from the waste stream. There are also financial incentives in place that encourage contractors to recycle. According to Adel Rida, former Director of the Physical Plant, Wellesley typically recycles 60% of unused new materials from projects.⁴⁰³ To develop a construction waste management plan and ensure that 50 to 75% of materials are actually recycled, however, would still require a moderate amount of time and effort.

MR Credit 2.2: Construction Waste Management: Divert 75% from Disposal

A project may earn an additional construction waste management credit if contractors recycle and/or salvage an additional 25% of non-hazardous construction and demolition debris beyond MR Credit 2.1 (75% total). Excavated soil and land-clearing debris do not contribute to this credit. Like Credit 2.1., recycling 75% of construction and demolition debris would require moderate time and effort.

MR Credit 3.1: Materials Reuse 5%

The proposed GES building would be eligible for this point if salvaged, refurbished or reused materials were incorporated into the building such that the total cost of these materials accounted for at least 5% of the total material value. Only materials permanently installed are considered in this calculation. Mechanical, electrical and plumbing components and specialty items such as elevators are excluded from the overall material calculation, though furniture may also be counted, providing that it is done so consistently in MR Credits 3-7.

Wellesley saves and sometimes acquires used materials like carpeting, workstations, doors, and refrigeration units, which are included in new projects and renovations. No building on campus, however, currently meets the 5% standard.⁴⁰⁴ Although the college could easily reuse bricks, other salvaged materials such as flooring, beams, doors, and furniture would need to be acquired from specialty vendors. Due to the time and cost involved, obtaining this credit is of moderate difficulty.

⁴⁰³ 2005 ES 300 class, *Another Green Hall*, 109.

⁴⁰⁴ 2005 ES 300 class, *Another Green Hall*, 113.

MR Credit 3.2: Materials Reuse

To achieve an additional materials reuse credit, the proposed GES building would have to use salvaged, refurbished or reused materials for an additional 5% beyond MR Credit 3.1 (10 % total, based on cost)—see MR Credit 3.1 for additional stipulations. The GES building could achieve this point with moderate effort.

MR Credit 4.1: Recycled Content: 10% (post-consumer + ½ pre-consumer)

This credit can be earned by using materials with recycled content such that the sum of post- and one-half the pre-consumer content constitutes at least 10% (based on cost) of the total value of the materials in the project.⁴⁰⁵ Recycled content is determined by weight, and the recycled fraction of the assembly is then multiplied by the cost of assembly to determine the recycled content value. The same restriction that applied to MR Credit 3.1 and 3.2 about which materials are included in total cost calculations apply here as well. Recycled content is defined in accordance with the International Organization for Standardization document, *ISO 14021—Environmental labels and declarations—Self-declared environmental claims (Type II environmental labeling)*.

The proposed GES building could easily earn Credit 4.1. by requiring that the contractor choose materials with high recycled content. Many common building materials are available that meet these requirements such as many forms of steel and aluminum and, increasingly, concrete, brick and drywall as well (See Section 2.2 B p13).

MR Credit 4.2: Recycled Content: 20% (post-consumer + ½ pre-consumer)

This credit is more challenging to fulfill because it requires that materials contain an additional 10% recycled content as in MR Credit 4.1 (20% total). The proposed GES project could earn this credit with moderate effort.

MR Credit 5.1: Regional Materials: 10% Extracted, Processed & Manufactured Regionally

LEED defines regional materials as those extracted, harvested or recovered and also manufactured within 500 miles of the project site. To be eligible for this credit the building must incorporate regional materials for a minimum of 10%, based on cost, of the total value of materials. If only a fraction of a product or material is extracted, harvested, recovered and manufactured locally, then only that percentage, by weight, can contribute to the regional value. As with previous MR credits, only materials permanently installed in the project are included in calculations and the same exclusions apply as before.

Wellesley's original campus buildings, constructed around 100 years ago, likely contain local materials due to the concentration of industrialization in the Northeast and limitations on transportation at the time. While building materials are now obtained from a more diverse range of geographic areas, the college continues to incorporate regional materials into building projects. Pre-cast concrete obtained from Pittsfield, MA composes more than 50 percent of the recently-constructed Davis Parking Facility. LEED's requirement for including 10% (based on cost) building materials from regional sources could easily be met by a building plan specifying that stonework (i.e., granite from NH, slate from VT, and concrete from western MA), wood, and steel (from Pittsburgh, PA if willing to pay a premium) should be obtained from regional vendors when available.

⁴⁰⁵ According to *LEED for New Construction Version 2.2* (October 2005), Post-consumer material is defined as waste material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose. Pre-consumer material is defined as material diverted from the waste stream during the manufacturing process. Excluded is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.

MR Credit 5.2: Regional Materials: 20% Extracted, Processed & Manufactured Regionally

This credit requires that the building use regional materials for an additional 10% beyond MR Credit 5.1 (total of 20%, based on cost). If only a fraction of a product or material is extracted, harvested, recovered and manufactured locally, then only that percentage, by weight, will contribute to the regional value. It would require moderate effort to ensure that 20% of the materials used in the proposed GES building were obtained locally.

MR Credit 6: Rapidly Renewable Materials

This credit requires that a project include rapidly renewable building materials and products for 2.5% of the total value of all building materials and products (based on cost). Such materials are made from plants that are typically harvested within a ten-year or less cycle. One example is bamboo, which the College has already incorporated as interior finishes in the Wang Campus Center, although not in high enough quantities to meet LEED standards.⁴⁰⁶ Linoleum is another low-cost material that satisfies the rapidly renewable materials credit. With some moderate planning, the proposed GES building could meet this requirement.

MR 7: Certified Wood

To earn a LEED point for use of certified wood a building must contain a minimum of 50% wood-based materials and products that have been certified in accordance with the Forest Stewardship Council's (FSC) principles and criteria for wood building components. These components include, but are not limited to, structural framing and general dimensional framing, flooring, sub-flooring, doors, and finishes. This credit only includes materials permanently installed in the project. Furniture may be included, provided it is included consistently in MR Credits 3-7.

Wellesley could easily ensure use of FSC wood in the proposed GES building, as FSC woods are readily available on the domestic market and can be purchased from stores such as Home Depot and Lowe's Home Improvement Center.⁴⁰⁷ The college incorporated FSC certified Brazilian Cherry into the Wang Campus Center, although it does not meet the LEED requirement of 50%.⁴⁰⁸

⁴⁰⁶ 2005 ES 300 class, 110.

⁴⁰⁷ Forest Stewardship Council, *Where Can I Find FSC-certified Products?*, accessed 05/04/2007, at <http://www.fscus.org/faqs/fsc_products.php?link=2>.

⁴⁰⁸ 2005 ES 300 Class, 110.

Table 24: LEED Materials and Resources Credit Evaluation					
LEED Credits	Materials and Resources	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
MR PreR 1	Storage and Collection of Recyclables				
	Provide an easily accessible area that serves the entire building and is dedicated to the collection and storage of non-hazardous materials for recycling, including (at a minimum) paper, corrugated cardboard, glass, plastics, and metals.	Required	Easy	No Recycling is not consistent in all buildings	Create central and floor locations for separation of recyclables from trash. Ensure adequate removal of recyclables on regular basis.
MR 1.1	Building Reuse: Maintain 75% of Existing Walls, Floors & Roof				
	Maintain at least 75% (based on surface area) of existing building structure (including structural floor and decking) and envelope (exterior skin and framing, excluding window assemblies and non-structural roofing material).	1	Impossible	Yes	Not possible in construction of new building. However, should be kept in mind when considering future renovations.
MR 1.2	Building Reuse: Maintain 95% of Existing Walls, Floors & Roof				
	Maintain an additional 20% (95% total) , based on surface area) of existing building structure (including structural floor and decking) and envelope (exterior skin and framing, excluding window assemblies and non-structural roofing material).	1	Impossible	No	See Above
MR 1.3	Building Reuse: Maintain 50% of Interior Non-Structural Elements				
	Use existing interior non-structural elements (interior walls, doors, floor coverings and ceiling systems) in at least 50% (by area) of the completed building (including additions).	1	Impossible	No	See Above
MR: 2.1	Construction Waste Management: Divert 50% From Disposal				
	Recycle and/or salvage at least 50% (by weight or volume, but must be consistent throughout) of non-hazardous construction and demolition debris. Develop and implement a construction waste management plan that, at minimum, identifies the materials to be diverted from disposal and whether the materials will be sorted on-site or co-mingled.	1	Moderate	No	Specify waste sorting for recycling before construction begins. Delineate areas for specific materials to be recycled. Educate laborers on the necessity of sorting waste for recycling. Incorporate associated higher labor costs into budget.

LEED Credits	Materials and Resources	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
MR: 2.2	Construction Waste Management: Divert 75% From Disposal				
	Recycle and/or salvage an additional 25% beyond Credit 2.1 (75% total) of non-hazardous construction and demolition debris	1	Moderate	No	See Above
MR: 3.1	Materials Reuse: 5%				
	Use salvaged, refurbished or reused materials such that the sum of these materials constitutes at least 5% , based on cost, of the total value of materials on the project. Mechanical, electrical and plumbing components and specialty items such as elevators and equipment shall not be included in this calculation.	1	Moderate	No	Reuse building materials such as brick and glass. Acquire previously used materials from specialty vendors. Keep in mind resource reuse when purchasing furniture as well.
MR: 3.2	Materials Reuse: 10%				
	Use salvaged, refurbished or reused materials for an additional 5% beyond MR Credit 3.1 (10% total, based on cost).	1	Moderate	No	See Above
MR: 4.1	Recycled Content: 10% (post-consumer + ½ pre-consumer)				
	Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% (based on cost) of the total volume of the materials in the project. The recycled content value of a material assembly shall be determined by weight. The recycled fraction of the assembly is then multiplied by the cost of the assembly to determine the recycled content value.	1	Easy	No	Incorporate materials with high recycled content such as recycled/synthetic gypsum, steel, aluminum, and concrete with fly ash content.
MR: 4.2	Recycled Content: 20% (post-consumer + ½ pre-consumer)				
	Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the pre-consumer content constitutes an additional 10% beyond MR Credit 4.1 (total of 20% , based on cost) of the total value of the materials in the project.	1	Moderate	No	See Above

LEED Credits	Materials and Resources	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
MR: 5.1	Stormwater Design: Quantity Control				
	Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the project site for a minimum of 10% (based on cost) of the total materials value. If only a fraction of a product or material is extracted/harvested/recovered and manufactured locally, then only that percentage (by weight) shall contribute to the regional value.	1	Easy	Yes	Continue to obtain brick, stone (slate), and concrete from local sources. Could acquire steel from local source (Pittsburgh, PA) if willing to pay a premium.
MR: 5.2	Stormwater Design: Quality Control				
	Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the project site for an additional 10% beyond MR Credit 5.1 (total 20% , based on cost) of the total materials value. If only a fraction of a product or material is extracted/harvested/recovered and manufactured locally, then only that percentage (by weight) shall contribute to the regional value. * Manufacturing refers to the final assembly of components into the building product that is furnished and installed by the tradesmen. For example, if the hardware comes from Dallas, Texas, the lumber from Vancouver, British Columbia and the joist is assembled in Kent, Washington; then the location of the final assembly is Kent, Washington.	1	Moderate	Yes	See Above
MR: 6	Rapidly Renewable Materials				
	Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 2.5% of the total value of all building materials and products used in the project, based on cost.	1	Moderate	No	Incorporate rapidly renewable materials such as bamboo and/or linoleum flooring.

LEED Credits	Materials and Resources	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
MR: 7	Certified Wood				
	Use a minimum of 50% of wood-based materials and products, which are certified in accordance with the Forest Stewardship Council (FSC) Principles and Criteria, for wood building components. These components include, but are not limited to, structural framing and general dimensional framing, flooring, sub-flooring, wood doors and finishes.	1	Easy	No	Specify use of FSC certified wood to architect, builder and contractors before construction begins. Will pay a premium. Even better if wood source is local.
Total:		13	Standard: 0 Easy: 3 Moderate: 7 Hard: 0 Impossible: 3		

4.4 Indoor Environmental Quality

The Indoor Environmental Quality (IEQ) sector has the potential to provide Wellesley with many easily achievable LEED points. The temperature control and air management systems already in place are advanced and, with some slight modifications to other existing systems, Wellesley can easily improve indoor environmental quality while fulfilling many LEED points as well.

There are two prerequisites that must be met in order to receive any credits within the IEQ sector. Wellesley would not have to change its regular construction or operation policies to fulfill these prerequisites, however, and thus they are easy to achieve.

EQ Prerequisite 1: Minimum indoor air quality

This prerequisite requires that the ventilation system installed in the building meet the minimum requirements of sections 4-7 of the American Society of Heating, Refrigerating, and Air-conditioning Engineers standard ASHRAE 62.1-2004. The system must also be designed using the strictest of the following: Ventilation Rate Procedure in ASHRAE 62.1-2004 or the applicable local codes. Wellesley College already installs state of the art HANSA system in all new campus buildings which exceeds the standards listed above.⁴⁰⁹ Therefore, Wellesley would achieve this prerequisite with its standard activities.

EQ Prerequisite 2: Environmental Tobacco Smoke

This prerequisite requires that smoking be prohibited in buildings and that exterior smoking areas be located at least 25 feet from entries, air intakes, and operable windows. Smoking in buildings is already prohibited due to a Wellesley town ordinance. Additionally,

⁴⁰⁹ Dennis Clancy, personal communication, April 25, 2007.

Wellesley College has a policy of allowing smoking no closer than 20 feet from buildings.⁴¹⁰ The only change in current policy needed to fill this credit is to extend the non-smoking area around the perimeter of the building by 5 feet. This policy change could easily be done.

EQ 1: Outdoor Air Delivery Monitoring

This credit requires that the carbon dioxide concentrations in densely occupied spaces of the building be monitored and that the direct outdoor air flow be measured in all non-densely occupied spaces. The HANSA systems that are used on campus are pre equipped to monitor these elements.⁴¹¹ The only additional implementation that is needed is to place the carbon dioxide monitors between three and six feet from the floor in each space. This placement is easy to accomplish when planned from the beginning of the building's design.

EQ 2: Ventilation Effectiveness

This credit requires that outdoor air ventilation rates be set at least 30% above the minimum rates set by ASHRAE Standard 62.1-2004. The HANSA systems are capable of this air handling rate, as long as the air ducts are initially designed to handle the higher rates of air flow.⁴¹² This credit should be easy to achieve.

EQ 3.1: Construction IAQ Management during Construction

The goal of EQ Credit 3.1 is to reduce and prevent air quality problems that could affect the well-being of construction workers and building occupants. To meet this credit, the college would need to develop an Indoor Air Quality (IAQ) Management Plan for during construction and prior to occupancy. This plan should have three components. First, the control measures of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines for Occupied Buildings under Construction (1995) must be met or exceeded. Second, all on-site or installed absorptive materials must be protected from moisture damage. Finally, if permanent air handlers are used during construction, each intake air grille filtration media with a Minimum Efficiency Reporting Value (MERV) of 8 should be used according to the ASHRAE 52.2-1999 standard. All filtration media must be replaced prior to occupancy.

The college probably already meets these requirements, especially for the protection against moisture damage; Wellesley does not, however, have a plan for how to dictate them. Incorporating an IAQ management plan from the beginning stages of a project design is an easy action for the college to take, and one that would ensure that potential health problems were not overlooked.

EQ 3.2: Construction IAQ Management Plan: Before Occupancy

Similar to EQ Credit 3.1, the goal of this point is to sustain indoor environmental quality for building users prior and into occupancy. As in EQ 3.1, this credit requires the development and implementation of an IAQ Management Plan, but there are several options for what that plan can entail.

One option is called a "flush-out" where, after construction end but prior to occupancy, the building is flushed-out with 14,000 cubic feet of outdoor air per square foot of floor.

⁴¹⁰ Diana Chapman Walsh. *Memo: Report for implementation of smoke-free residence hall policy*, (May 26, 1999), accessed at: <<http://www.wellesley.edu/PublicAffairs/President/LocalOnly/smoking.html>>.

⁴¹¹ Dennis Clancy, personal communication, April 25, 2007.

⁴¹² Dennis Clancy, personal communication, April 25, 2007.

Alternatively, should Wellesley prefer utilize the space prior a flush-out, the flush-out could be performed over a series of days so long as the space is ventilated with a minimum of 3,500 ft³ air/ft² floor 3 hours prior to occupancy.

The second option calls for extensive air testing, where after construction but prior to occupancy, the college would perform a baseline IAQ test according to the standard protocol outlined by the U.S. EPA Compendium of Methods for the Determination of Air Pollutants in Indoor Air. These options are equally viable methods for obtaining this point and improving environmental quality, though given Wellesley's history of spending little time between the finished construction and move-in, Wellesley would most likely opt for air testing or the extended flush-out. So long as the college budgets the time and efforts required to carry out this IAQ Management Plan well in advance of project completion, this would be an easy credit to obtain.

EQ 4.1: Low-Emitting Materials: Adhesives & Sealants

This credit requires compliance with the following reference standards: Adhesives, Sealant and Sealant Primers must comply with the South Coast Air Quality Management District (SCAQMD) Rule #1168. Aerosol Adhesives must comply with the Green Seal Standard for Commercial Adhesives CS-36 requirements in effect on October 19, 2000. This credit could be moderate or hard depending on the availability and cost of approved adhesives that meet the needs for building construction.

EQ 4.2: Low Emitting Materials: Paints & Coatings

This credit is intended to improve air quality by reducing the quantity of materials used that produce odorous, irritating and (or) harmful contaminants. To fulfill this credit, the paints, coatings, and primers applied to interior walls and ceilings would have to meet specific criteria for volatile organic compound (VOC) content. The LEED guidelines establish threshold limits for VOCs based on the specific kind of material considered and the availability of low-emitting products. For example, paints applied to walls and ceilings have lower VOC limits than floor sealants, presumably because fewer low-VOC alternatives exist for floor coatings. This credit should be fairly easy for Wellesley to achieve so long as materials are selected with VOC-content in mind.

EQ 4.3: Low-Emitting Materials: Carpet Systems

The purpose of EQ 4.3 is identical to EQ 4.2, though this credit applies to carpets. To obtain this point, all carpets installed in the building interior must meet the testing and product requirements of the Carpet and Rug Institute's Green Label standard and plus program. Carpet adhesives must also meet the requirements of EQ Credit 4.1. The college does not currently purchase low-emitting carpets that are labeled by the Carpet and Rug Institute, though doing so would not require a significant change from standard material purchasing.

Low-emitting carpets reduce the amount of VOCs released such as 4-phenylcyclohexene (4-PC) which is a contributor to "new carpet smell".⁴¹³ The purchase of "Green Label" carpets would meet this point with only a slight cost increase compared to the standard carpeting that Wellesley currently installs. The process of airing carpets prior to installation can significantly reduce the VOCs new carpets emit. The ES space will likely have minimal carpeting while the

⁴¹³ 2005 ES 300 class, 131.

greenhouses will have none. As proposed, Wellesley could easily this credit for the GES building since there is so little carpeting used.

EQ 4.4: Low-Emitting Materials: Composite Wood & Agrifiber Products

Some composite wood and agrifiber products such as fiberboard and plywood contain urea-formaldehyde resins that are harmful and irritating. In order to avoid air contaminants from these sources, this credit specifies that all composite wood and agrifiber products be free of these harmful resins. From our baseline assessment, we found that Pendleton East contained very little composite wood. Since there are few areas for utilizing composite wood products in our proposed GES building, Wellesley could easily avoid products with urea-formaldehyde resins without significant financial burden. Thus, this point would be easy to achieve.

EQ 5: Indoor Chemical & Pollutant Source Control

In order to gain this point, a building must have a mechanism to control and minimize pollution entry into interior spaces. LEED recommends pollution control by utilizing grates, grilles, or slotted systems (minimum length: 6 feet) to trap dirt in the entryway of a building. Roll-out mats are only acceptable when maintained on a weekly basis by a contracted organization. Additionally, this point requires ventilation for all spaces that may contain hazardous chemicals or fumes—such as photocopy rooms or janitor closets.

Wellesley currently employs permanent door mats and, in some buildings such as the Wang Campus Center and Pendleton, double door entryways to minimize the amount of dirt and pollutants (and heat loss) from buildings. Since pollution control is already a standard practice at Wellesley, including a grille that would match the specific LEED guidelines would be easy for the college to do, and it would not incur significant costs.

In contrast, the only spaces at Wellesley that have specific air filtration systems are the Science Center labs. Copy rooms and janitor closets are not ventilated in any special way, and certainly not to the standard required by LEED: rooms with potentially hazardous fumes must have negative pressure in respect to adjacent spaces and filtration media must provide a MERV (Minimum Efficiency Reporting Value) of 13 or higher. Meeting this aspect of EQ Credit 5 could be moderately difficult or even hard to implement—depending on the engineering and construction of the ventilation systems.

Considered together—the pollution control and the ventilation systems would likely be of moderate difficulty for Wellesley to implement in the GES building. Since we are unable to assess the engineering challenge ventilating our proposed design would present, however, we cannot say for sure how much effort would be required to achieve this point.

EQ 6.1: Controllability of Systems: Lighting

This point requires that a minimum of 90% of the building occupants are provided with individual lighting controls to enable adjustments to suit their individual task needs and preferences. Additionally, multi-occupant spaces needed to be provided with lighting system controls to enable lighting adjustments that meet group needs and preferences. These controls are found in almost all buildings on campus. Bathrooms, classrooms, offices, and common spaces have adjustable lights. Achieving this point would not require any modification of standard planning.

EQ 6.2: Controllability of Systems: Thermal Comfort

This point requires that individual comfort controls are incorporated for a minimum of 50% of building occupants to enable adjustments to suit individual needs. Operable windows can be used in lieu of comfort controls for occupants of areas that are 20 feet inside of, and 10 feet to either side of, the operable part of the window. Additionally, comfort system controls must be incorporated into all shared multi-occupant spaces to enable adjustments to suit group needs. The areas of operable windows must meet the requirements of ASHRAE 62.1-2004 paragraph 5.1 for Natural Ventilation. These thermal controls include the factors of air temperature, radiant temperature, air speed and humidity but for the purposes of this credit, occupant control over at least one of these factors is sufficient. Similar to the previous point, these controls are found in almost all buildings on campus and would require no modification of standard planning.

EQ 7.1: Thermal Comfort: Design

HVAC systems and the building envelope must be designed to meet the requirements of ASHRAE Standard 55-2004, Thermal Comfort Conditions for Human Occupancy. Thermal monitoring systems can already be found on campus in buildings like the Davis Museum, which must maintain specific humidity levels for the preservation of the artwork.⁴¹⁴ The GES building will also need specific controls for the different humidity levels of the rooms. By using a HANSA unit, already standard practice on Wellesley's campus, the specific ASHRAE 55-2004 standard would be met and exceeded. The HANSA system meets European standards which are stricter on occupational health in buildings.

EQ 7.2: Thermal Comfort: Verification

This credit provides for the assessment of the building's thermal comfort over time by implanting a thermal comfort survey of occupants within 6-18 months after occupancy. If more than 20% of occupants are dissatisfied with thermal comfort in the building then a plan must be developed for corrective action. This credit would be very easy to achieve, and could be incorporated into the coursework of an environmental studies class, offering students an opportunity to learn about the components of indoor environmental quality that are applicable to them.

EQ 8.1: Daylight & Views: Daylight for 75% of Spaces

This point requires the strategic placing of windows to ensure that interior daylighting is provided for at least 75% of all regularly occupied space. Installing more windows in the building could increase initial costs, but costs may be recovered by minimizing the need for electrical lighting. Although glass is not a good insulator, Energy Star® windows with low-e coating would minimize heat loss even with additional windows. Furthermore, daylight increases in productivity and well-being of occupants by establishing a connection to outdoor spaces. Given that the location of the proposed building is adjacent to the Science Center, which blocks much natural light, this credit would be of moderate difficulty to attain.

EQ 8.2: Daylight & Views: Views for 90% of Spaces

Similar to EQ 8.1, the goal of this credit is to maximize occupants' connection to the outdoors with natural lighting and views into regularly occupied spaces in the building. To

⁴¹⁴ 2005 ES 300 class, 130.

achieve this credit, there must be a direct line-of-sight to the outdoors between 2.5 and 7.5 feet in height for 90% of all occupied spaces. Whether or not a design meets this point depends on the total square foot area of occupied space and whether or not a direct sight line can be drawn from any given location to perimeter vision glazing and back based on section and plan views.

Some strategies to achieve this point include lowering partition heights and using interior shading devices to reduce glare from the sun, including large windows and open areas in building design, and installing automatic light-level controls. Without actually performing the calculations of occupied spaces and line-of-sights for our proposed GES building, we cannot say whether our design fulfills this credit or not. Nonetheless, by nature of being a greenhouse and because our design includes ample window views and open spaces, this point should be easy to achieve.

Table 25: LEED Indoor Environmental Quality Credit Evaluation					
LEED Credits	Indoor Environmental Quality	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
EQ PrER 1	Minimum IAQ Performance				
	Meet the minimum requirements of Sections 4-7 of ASHRAE 62.1-2004, Ventilation for Acceptable Indoor Air Quality.	Required	Standard	Yes	Install state of the art HANSA systems in all new buildings
EQ PrER 2	Environmental Tobacco Smoke (ETS) Control				
	Minimize exposure to non-smokers to ETS by prohibiting smoking in the building and locating any exterior designated smoking areas at least 25 feet away from entries and operable windows.	Required	Easy	Yes	Adopt a policy that prohibits smoking within 25 feet of buildings.
EQ: 1	Outdoor Air Delivery Monitoring				
	Install permanent monitoring systems that provide feedback on ventilation system performance to ensure that ventilation systems maintain design minimum ventilation requirements. Configure all monitoring equipment to generate an alarm when the conditions vary by 10% or more from set point, via either a building automation system alarm to the building operator or via a visual or audible alert to the building occupants.	1	Easy	Yes	Installs permanent monitoring systems in all new buildings that include CO ₂ concentration monitors
EQ: 2	Increased Ventilation				
	For mechanically ventilated buildings, Increase breathing zone outdoor air ventilation rates to all occupied spaces by at least 30% above the minimum rates required by ASHRAE Standard 62.1-2004 as determined by EQ Prerequisite 1.	1	Easy	Yes	Ensure all new systems conform to ASHRAE Standards.

LEED Credits	Indoor Environmental Quality	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
EQ: 3.1	Construction IAQ Management Plan: During Construction				
	Develop and implement an Indoor Air Quality (IAQ) Management for the construction and pre-occupancy phases of the building as follows: <ul style="list-style-type: none"> • During construction meet or exceed the recommended Control Measures • Protect stored on-site or installed absorptive materials from moisture damage. • If permanently installed air handlers are used during construction, filtration media with a Minimum Efficiency Reporting Value (MERV) of 8 shall be used at each return air grille • Replace all filtration media immediately prior to occupancy. 	1	Easy	No	Create an IAQ Management Plan prior to the construction phase.
EQ: 3.2	Construction IAQ Management Plan: Before Occupancy				
	Develop and implement an Indoor Air Quality (IAQ) Management Plan for the pre-occupancy phase: either Flush-Out or Air Testing	1	Easy	No	Create an IAQ Management Plan prior to the occupancy phase the coordinate either air testing or flush-out procedures.
EQ: 4.1	Low-Emitting Materials: Adhesives & Sealants				
	All adhesives and sealants used on the interior of the building (defined as inside of the weatherproofing system and applied on-site) shall comply with the following reference standards: Adhesives, Sealants and Sealant Primers: South Coast Air Quality Management District (SCAQMD) Rule #1168. VOC limits are listed in the table below and correspond to an effective date of July 1, 2005 and rule amendment date of January 7, 2005. Aerosol Adhesives: Green Seal Standard for Commercial Adhesives GS-36 requirements in effect on October 19, 2000.	1	Moderate	No	Use hook and loop fasteners instead of adhesives. Use low-emitting adhesives and sealants

LEED Credits	Indoor Environmental Quality	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
EQ: 4.2	Low-Emitting Materials: Paints and Coatings				
	<p>Paints and coatings used on the interior of the building (defined as inside of the weatherproofing system and applied on-site) shall comply with the following criteria:</p> <ul style="list-style-type: none"> • Architectural paints, coatings and primers applied to interior walls and ceilings: Do not exceed the VOC content limits established in Green Seal Standard GS-11, Paints, First Edition, May 20, 1993. • Anti-corrosive and anti-rust paints applied to interior ferrous metal substrates: Do not exceed the VOC content limit of 250 g/L established in Green Seal Standard GC-03, Anti-Corrosive Paints, Second Edition, January 7, 1997. • Clear wood finishes, floor coatings, stains, and shellacs applied to interior elements: Do not exceed the VOC content limits established in South Coast Air Quality Management District (SCAQMD) Rule 1113, Architectural Coatings, rules in effect on January 1, 2004. 	1	Easy	No	Use organic or low-emitting paints
EQ: 4.3	Low Emitting Materials: Carpet Systems				
	<p>All carpet installed in the building interior shall meet the testing and product requirements of the Carpet and Rug Institute's Green Label Plus program.</p> <p>All carpet adhesive shall meet the requirements of EQ Credit 4.1: VOC limit of 50 g/L.</p>	1	Easy	No	<p>Substitute linoleum or wood for carpet.</p> <p>Air out carpet before installation.</p>
EQ: 4.4	Low Emitting Materials: Composite Wood & Agrifiber				
	<p>Composite wood and agrifiber products must contain no added urea-formaldehyde resins.</p>	1	Easy	No	Use wood and agrifiber products with no added urea-formaldehyde resins

LEED Credits	Indoor Environmental Quality	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
EQ: 5	Indoor Chemical & Pollutant Source Control				
	Design to minimize pollutant cross-contamination of regularly occupied areas: <ul style="list-style-type: none"> • Employ permanent entryway systems (grills, grates, etc.) to capture dirt, particulates, etc. from entering the building at all high volume entryways. • Where chemical use occurs (including housekeeping areas and copying/printing rooms), provide segregated areas with deck to deck partitions with separate outside exhaust at a rate of at least 0.50 cubic feet per minute per square foot, no air re-circulation and maintaining a negative pressure of at least 7 PA (0.03 inches of water gauge). • Provide drains plumbed for appropriate disposal of liquid waste in spaces where water and chemical concentrate mixing occurs 	1	Moderate	No	Install grills or grates in entryways and Install ventilation systems with negative pressure for janitorial closets and photocopy rooms Install drains for liquid wastes
EQ: 6.1	Controllability of Systems: Lighting				
	Provide at least an average of one operable window and one lighting control zone per 200 square feet for all regularly occupied areas within 15 feet of the perimeter wall.	1	Easy	Yes	Include lighting controls and task lighting for occupant use.
EQ: 6.2	Controllability of Systems: Thermal Comfort				
	Provide controls for each individual for airflow, temperature and lighting for at least 50% of the occupants in non-perimeter, regularly occupied areas.	1	Easy	Yes	Design systems with comfort controls.
EQ: 7.1	Thermal Comfort: Design				
	<ul style="list-style-type: none"> • Comply with ASHRAE Standard 55-2004, Thermal Comfort Conditions for Human Occupancy. • Design building envelope and systems with the capability to deliver performance to the comfort criteria under expected environmental and use conditions. • Evaluate air temperature, radiant temperature, air speed, and relative humidity in an integrated fashion and coordinate these criteria with EQ Prerequisite 1, Credit 1, and Credit 2. 	1	Easy	No	Install a more innovative natural air system within each room (not just halls and the bathrooms)

LEED Credits	Indoor Environmental Quality	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
EQ: 7.2	Thermal Comfort: Permanent Monitoring System				
	Install a permanent temperature and humidity monitoring system configured to provide operators control over thermal comfort performance and the effectiveness of humidification and/or dehumidification systems in the building.	1	Easy	No	Implement a monitoring system.
EQ:8.1	Daylight and Views: Views for 75% of Spaces				
	Achieve a minimum Daylight Factor of 2% (excluding all direct sunlight penetration) in 75% of all space occupied for critical visual tasks. Spaces excluded from this requirement include copy rooms, storage areas, mechanical plant rooms, laundry and other low occupancy support areas. Other exceptions for spaces where tasks would be hindered by the use of daylight will be considered on their merits.	1	Moderate	Yes	Include numerous windows in building design Position windows, skylights, and/or skytubes to maximize daylighting
EQ: 8.2	Daylight and Views: Views for 90% of Spaces				
	Achieve a direct line of sight to vision glazing for building occupants in 90% of all regularly occupied spaces. Examples of exceptions include copy rooms, storage areas, mechanical, laundry and other low occupancy support areas. Other exceptions will be considered on their merits.	1	Easy	Yes	Same as above
Total:		15	Standard: 0 Easy: 12 Moderate: 3 Hard: 0 Impossible: 0		

4.5 Energy and Atmosphere

Wellesley relies entirely on fossil fuels for its energy production. Although the college saves energy through efficiency gains and a local production with its co-generation facility, the rising costs and the increased awareness of the consequences of fuel consumption make reducing current energy demand beneficial to the college both financially and sustainably. Since buildings are major energy consumers, those that incorporate energy-efficient design, infrastructure, and fixtures can help reduce fossil fuel consumption and its associated environmental impacts.

Producing energy on-site is more cost effective than purchasing it from a renewable source; thus, it does not make sense for Wellesley to pursue some LEED points in this sector based on a simple cost-benefit analysis. Moreover, the environmental benefits that would be gained from doing so may be better realized for less cost in other sectors. Wellesley can,

however, obtain points by improving current practices through planning, optimizing, and tracking energy performance.

Before Wellesley can earn any Energy and Atmosphere LEED points, three prerequisites must be satisfied. Currently Wellesley satisfies one (optimize energy performance), but it can meet the other two as well. Wellesley cannot obtain any points in the Energy sector without fulfilling the prerequisites, therefore these are the most important measures to implement.

EA Prerequisite 1: Fundamental Commissioning of the Building Energy Systems

This prerequisite requires that the project owner designate a commissioning team and also an individual to serve as a Commissioning Authority (CxA). These people act independently of the design and construction processes to verify that the building's planned energy related systems are installed, calibrated, and perform according to the project requirements. The CxA is also responsible for documentation, reports, and recommendations to the project owner.

By standardizing the energy systems for all building construction, a commissioning team could benefit Wellesley by reducing energy use, lowering operating costs, improving occupant productivity, as well as verifying that the systems perform as they were intended. Commissioning building energy systems can have high upfront costs associated with contracting a third party but typically result in 10% to 30% in annual energy savings.⁴¹⁵ In this way, commissioning teams more than pay back their initial cost within no more than 10 years.

Since Wellesley has not yet attempted LEED certification, designating a commissioning team and CxA would be a new procedure. There are committees at Wellesley that could be modified to fill the commissioning team role, however, such as the Buildings and Grounds or the Sustainability Advisory Committee. For the actual CxA, Prerequisite 1 requires that the individual have at least two-years of prior building experience and be independent of the design and construction processes. Wellesley could either designate a current staff member who meets these requirements as the CxA or hire an unaffiliated individual. Since in both cases designating a CxA would require a change in standard Wellesley practice with the possibility of additional cost, this prerequisite is of somewhat moderate difficulty, though it is well within reasonable means. Furthermore, being a prerequisite for all points in the Energy sector, this designation is top priority for the project.

EA Prerequisite 2: Optimize Energy Performance

Buildings constructed before 1992 on Wellesley's campus do not meet building energy efficiency and performance standards as required by ASHRAE/IESNA Standard 90.1-2004. Under the Energy Policy Act of 1992, however, new commercial buildings in the country must meet ASHRAE 90.1 standards. These efficiency standards target heating and air-conditioning equipment and water heaters. Additionally, ASHRAE 90.1 is Massachusetts' statewide standard for energy building code. Thus, both national and state laws require Wellesley to fulfill the prerequisite to optimize energy performance.

To meet ASHRAE 90.1, a building must implement all available energy efficient technologies.⁴¹⁶ To this effect, Wellesley has standardized the purchase of some Energy

⁴¹⁵ Frank A. Mauro, *Commissioning Basics for Owners*, (May 4, 2005), accessed 05/04/2007, at <http://www.peci.org/ncbc/proceedings/2005/BF_01_Mauro_NCBC2005.pdf>.

⁴¹⁶ American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. et al., *Energy Standard for Buildings except Low-Rise Residential Buildings: Standard 90.1-2004*.

Star®⁴¹⁷ appliances, the installation of HANSA energy-efficient heating, ventilation, and air conditioning (HVAC) systems for new projects, and the replacement of burnt-out bulbs with compact fluorescent lights. There is also an initiative to phase in motion-sensor lights in some spaces on campus.⁴¹⁸ Though Wellesley satisfies this prerequisite through these standard practices, the proposed GES building could easily improve on these standards by incorporating daylighting into building design and installing efficient heating and smart lighting systems. These investments offer major financial savings in the future.

EA Prerequisite 3: Fundamental Refrigerant Management

This credit calls for zero use of CFC-based refrigerants in HVAC systems. The new CFC-free HANSA system used in the Lulu Chow Wang Center has the most innovative HVAC technology of its time⁴¹⁹ and can serve as the standard for subsequent buildings. The chillers in the Science Center, however, still use CFC-based refrigerants. And though the cooling system is not connected to the greenhouses, the heating system is.⁴²⁰ Because redesigning energy distribution is extremely costly, the connection between these systems would most likely remain. Wellesley can, however, easily bypass this prerequisite by having a third party audit. The audit must show that replacing the chillers or converting to another system is not economically feasible.

These measures would not be necessary if the GES building were to have its own cooling system. Installing a system separate from the Science Center would comply with this prerequisite since no new HVAC technologies use CFCs. The additional costs of a separate system could be offset by the energy efficiency gains and the improved indoor environmental quality. Complying with this prerequisite is of easy to moderate difficulty, depending on the extent and nature of an audit, or the costs of installing a new HANSA system. Neither of these actions, however, would require deviation from standard Wellesley practices.

EA 1.1 to 1.10: Optimizing Energy Performance

There are 10 points available depending on the percentage of energy cost savings following ASHRAE 90.1 standards. EA Credit 1.1 requires an overall energy savings of 10%, and each subsequent point requires an additional 3.5% energy-use reduction. A maximum of 10 points requires a 42% or more overall savings (Table 26). Determining the actual magnitude of energy savings would require a computer simulation to confirm the baseline energy-use and project predicted energy consumption by the proposed design. In general, however, the greater energy savings, the more difficult points are to obtain. We have ranked the first two credits as standard for Wellesley, as many of the systems and technologies (e.g. lights, ventilation) that the college employs are significant improvements from what the greenhouses currently use. Increasing energy savings to 17.5% we believe would be easy since great savings come through efficient insulation and heating systems, both of which would be easy to install in the proposed GES building. Subsequent points we have ranked as moderate or hard since further energy savings might require significant upfront costs or modifications to current practices.

⁴¹⁷ Created by the Department of Energy and the Environmental Protection Agency, the Energy Star® label identifies energy efficient products. All Energy Star labeled products must operate significantly more efficiently than its counterparts, while maintaining or improving performance.

⁴¹⁸ Tom Kane, personal communication, February 28, 2007.

⁴¹⁹ 2005 ES300 class, 116.

⁴²⁰ Peter Zuraw, personal communication, February 28, 2007.

There are many ways to optimize energy performance. Wellesley can easily make small-scale technological improvements that can add up to significant long-term saving, such as by using Energy Star® appliances and compact fluorescent bulbs. Further savings can be achieved by installing occupancy sensors with a 30-minute delay and light sensors to dim lights when there is optimum natural light available. Energy-efficient design and fixtures of this kind would be easy for Wellesley to implement as many are already part of standard practice. Without a simulated model, however, it is difficult to predict how many points these energy-saving measures could achieve.

Table 26: Points available for each increment of demonstrated energy-use reduction from standards required by ASHRAE 90.1

Energy-use Reduction	Points available
10.5%	1
14%	2
17.5%	3
21%	4
24.5%	5
28%	6
31.5%	7
35%	8
38.5%	9
42%	10

Of only moderate difficulty would be taking additional steps to minimize heat transfer out of or within the building. Buildings consume large amounts of energy as heat transfers across poorly insulated surfaces. There are many ways to improve insulation, however. Glazing for glass surfaces, shades to cover windows at night, and various materials for walls (e.g. cellulose, fiberglass) all work to prevent heat loss from a building.

In addition to insulation, efficient heating and cooling systems reduce building energy requirements. For example, newer buildings on campus send water instead of steam through radiators to allow for better control over room temperature. The GES project need not use the same heating and cooling systems as other buildings on campus. In-floor radiant heating, for example, could provide even greater energy savings. These measures would be of easy to moderate difficulty because some of these materials such as glazed glass have higher initial costs than the standard currently used. When incorporated into building design from the beginning, however, the added short term costs of more efficient and durable materials is a worthwhile investment.

Energy costs could also be recovered by renewable energy sources. Although we do not suggests doing so due to the limitations of the site and characteristics of the proposed building, technologies such as solar panels could augment electrical power. Renewable energy sources would be hard to implement for the proposed GES building.

EA 2.1 to 2.2: Renewable Energy (2.5% to 12.5%)

On-site renewable energy systems that could offset building costs would be difficult for Wellesley to use since the college has its own co-generation plant. All energy production from this facility relies on the use of fossil fuels, oil and natural gas. Adding the use of renewable energy increases the building costs and requires additional infrastructure and maintenance. The GES building's site location also has space limitations. Even if one could invest in solar panels, for example, there would be little available space to capture light. Solar panels are traditionally installed on rooftops, but since greenhouses, by their nature, require unrestricted light penetration through the roof, solar panels are not feasible for most of the building. Only one-third of the second floor in the proposed GES design has any space for a solar panel, but even then the Science Center to the west and the tall trees to the southeast make this space a poor location for capturing solar energy. Other technologies such as geo-thermal energy would be theoretically possible, though the site would have to be assessed for ultimate feasibility. The technology and even the assessment, however, may be prohibitively costly. Thus the space limitations, building

needs, and high costs make onsite-renewable energy a hard point for the proposed GES building to achieve.

EA 3: Additional Commissioning

The purpose of additional commissioning is to award a point to commissioning teams that exceed the minimum requirements established by EA Prerequisite 1. Assuming that Wellesley designated a commissioning team, this would be an easy and beneficial credit to earn.

In order to achieve this point, the Commissioning Authority (CxA) has to be more involved with the initial design and follow-through of system monitoring than is otherwise required. For example, for this point the CxA must review and comment on the design documents prior to the mid-construction phase as well as review all subsequent design submissions. In addition, the CxA and commissioning team must develop a systems manual that provides future operating staff information about how to optimize the use of commissioned systems and verify that all potential operators of the systems are adequately trained.

Assigning a CxA and commissioning team to perform these extra tasks would benefit the college by verifying that systems are operated optimally and that they perform to their intended standards. .

EA 4: Fundamental Refrigerant Management

Obtaining this point requires either that a building utilize systems without refrigerants or that only use refrigerants which contain minimal or no ozone-depleting compounds such as CFCs (chlorofluorocarbons) and halons. The LEED guidelines specify a maximum threshold permitted for refrigerant emissions through a series of formulas that determine the extent to which a refrigerant contributes to ozone-depletion and global warming. Unlike Prerequisite 3 which prohibits the use of CFCs or else requires their use to have a plan to phase out of use, this credit applies to all refrigerants and new systems.

Assuming that the proposed GES building would have its own cooling system, this point is easy to achieve. Wellesley has adopted the energy-efficient HANSA system as the standard for air conditioning and ventilation. As Wellesley's standard policy has already eliminated the use of CFCs, no change in policy or practice would be needed to fulfill this credit.

EA 5: Measurement and Verification

This credit requires that there be a plan to measure and verify energy usage in a building for at least one year after construction. Wellesley recently installed meters for the residence and academic clusters in order to monitor electrical energy use. These meters are useful, but they don't distinguish the electrical power consumed by individual buildings, nor do they account for heating costs since heat is conveyed through the steam tunnels and is not metered at all.⁴²¹ The college does keep detailed record of fuels consumed, however.⁴²²

In order to gain this point, Wellesley can easily install energy meters for both electricity and heating in the GES building. In doing so, it may be necessary to separate the energy used by the Friends of Horticulture building from the GES building since the greenhouses are currently heated using the same piping systems. Nevertheless, this use of meters would be useful on a larger scale as Wellesley is trying hard to keep track of energy consumption. Although meters

⁴²¹ Peter Zuraw, personal communication, March 1, 2007.

⁴²² 2005 ES 300 class, 116.

can easily be installed at any time, it would also be easier and less expensive to budget and implement a meter as the building is built rather than retroactively.

EA 6: Green Power

Green power is available in our region and therefore a technically viable option, but earning this point requires that the college engage in a two year contract to purchase green energy.⁴²³ Because Wellesley cost-effectively produces all of its own power, the added cost of purchasing green energy is not practical. Green power might one day be economically feasible should oil and gas prices continue to rise, and purchasing green energy would uphold Wellesley's sustainability statement. At present, however, green power is costly and should not be a main focus for this project.

Table 27: LEED Energy and Atmosphere Credit Evaluation					
LEED Credits	Energy and Atmosphere	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
EA PreR 1	Fundamental Commissioning of the Building Energy Systems				
	Implement fundamental commissioning of the building energy systems by engaging a commissioning authority, reviewing design intent and basis of design documentation, including commissioning requirements in the construction documents, developing and utilize a commissioning plan, verifying installation, functional performance, training and documentation, and completing a commissioning report.	Required	Easy	No	Reorganize a Wellesley-based committee into a LEED commissioning group or designate a qualified employee to lead the commissioning process. Hire an unaffiliated organization to serve as the commissioning team and Authority
EA PreR 2	Minimum Energy Performance				
	Comply with the mandatory provisions (Sections 5.4, 6.4, 7.4, 8.4, 9.4 and 10.4) and the prescriptive requirements (Sections 5.5, 6.5, 7.5 and 9.5) or performance requirements (Section 11) of ASHRAE/IESNA Standard 90.1-2004 (without amendments).	Required	Standard	Yes For modern buildings	Future buildings must meet ASHRAE 90.1-2004 standards. Install efficient heating system, smart systems with automated responses to building reduced unnecessarily wasted energy, incorporate daylighting into building design, install energy-saving light fixtures, or a combination of the aforementioned.

⁴²³ Connecticut College, *CC Joins Energy Co-Op, First College in Nation to Make Commitment*, (May 18, 2001), accessed 04/12/2007, at <https://aspen.conncoll.edu/camelweb/index.cfm?action=none&circuit=none&function=none&fuse=none&fuseaction=ccnews&id=485&id2=0&printerlogo=yes&solution=none&uid=0&printer=no>.

LEED Credits	Energy and Atmosphere	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
EA PreR 3	Fundamental Refrigerant Management				
	Zero use of CFC-based refrigerants in new base building HVAC&R systems. When reusing existing base building HVAC equipment, complete a comprehensive CFC phase-out conversion prior to project completion. Phase-out plans extending beyond the project completion date will be considered on their merits.	Required	Easy	No	Contract a third party to perform an audit to show that system replacement or conversion is not economically feasible.
EA: 1.1	Optimize Energy Performance: 10.5%				
	Demonstrate a percentage improvement in the proposed building performance rating compared to the baseline building performance rating per ASHRAE/IESNA Standard 90.1-2004 (without amendments) by a whole building project simulation using the Building Performance Rating Method. The minimum energy cost savings percentage must be 10.5% .	1	Standard	Yes	Design the building envelope and systems to maximize energy performance. Assess energy performance to identify the most cost-effective energy efficiency measures, and quantify energy performance as compared to a baseline building.
EA: 1.2	Optimize Energy Performance: 14%				
	The minimum energy cost savings percentage must be 14% .	2	Standard	Yes	
EA: 1.3	Optimize Energy Performance: 17.5%				
	The minimum energy cost savings percentage must be 17.5% .	3	Easy	No	
EA: 1.4	Optimize Energy Performance: 21%				
	The minimum energy cost savings percentage must be 21% .	4	Moderate	No	
EA: 1.5	Optimize Energy Performance: 24.5%				
	The minimum energy cost savings percentage must be 24.5% .	5	Moderate	No	
EA: 1.6	Optimize Energy Performance: 28%				
	The minimum energy cost savings percentage must be 28% .	6	Moderate	No	

LEED Credits	Energy and Atmosphere	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
EA: 1.7	Optimize Energy Performance: 31.5%				
	The minimum energy cost savings percentage must be 31.5% .	7	Moderate	No	
EA: 1.8	Optimize Energy Performance: 35%				
	The minimum energy cost savings percentage must be 35% .	8	Hard	No	
EA: 1.9	Optimize Energy Performance: 38.5%				
	The minimum energy cost savings percentage must be 38.5% .	9	Hard	No	
EA: 1.10	Optimize Energy Performance: 42%				
	The minimum energy cost savings percentage must be 42% .	10	Hard	No	
EA: 2.1	On-Site Renewable Energy: 2.5%				
	Use on-site renewable energy systems to offset building energy cost. Calculate project performance by expressing the energy produced by the renewable systems as a percentage of the building annual energy cost calculated in EA credit 1. The minimum to offset building energy cost by renewable energy is 2.5% .	1	Hard	No	Assess the project for non-polluting and renewable energy potential including solar, wind, geothermal, low-impact hydro, biomass and bio-gas strategies
EA: 2.2	On-Site Renewable Energy: 7.5%				
	The minimum to offset building energy cost by renewable energy is 7.5% .	1	Hard	No	See Above
EA: 2.3	On-Site Renewable Energy: 12.5%				
	The minimum to offset building energy cost by renewable energy is 12.5% .	1	Impossible	No	Unfeasible for Wellesley at this time

LEED Credits	Energy and Atmosphere	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
EA: 3	Enhanced Commissioning				
	Implement fundamental commissioning of the building energy systems by engaging a commissioning authority, reviewing design intent and basis of design documentation, including commissioning requirements in the construction documents, developing and utilize a commissioning plan, verifying installation, functional performance, training and documentation, and completing a commissioning report.	1	Easy	No	<p>Include the Commissioning Authority and team early in the design process.</p> <p>Create an instruction manual and training program for all operators of energy-related systems.</p> <p>Take measures to ensure that the Commissioning Authority makes comments on the design and construction processes throughout the project.</p>
EA: 4	Enhanced Refrigerant Management				
	Do not use refrigerants or select refrigerants and HVAC&R that minimize or eliminate the emission of compounds that contribute to ozone depletion and global warming.	1	Standard	No CFCs remain in the Science Center	Install a HANSA system for HVAC.
EA: 5	Measurement & Verification				
	Develop and implement a Measurement & Verification (M&V) Plan consistent with Calibrated Simulation (Savings Estimation Method 2), or Energy Conservation Measure Isolation, as specified in the <i>International Performance Measurement & Verification Protocol (IPMVP) Volume III: Concepts and Options for Determining Energy Savings in New Construction, April, 2003</i> . The M&V period shall cover a period of no less than one year of post-construction occupancy.	1	Easy	No	<p>Develop an M&V Plan to evaluate building and/or energy system performance.</p> <p>Install metering equipment to measure energy use</p> <p>Evaluate energy efficiency by comparing actual performance to baseline performance.</p>
EA: 6	Green Power				
	Provide at least 35% of the building's electricity from renewable sources by engaging in at least a two-year renewable energy contract. Renewable sources are as defined by the Center for Resource Solutions (CRS) Green-e products certification requirements	1	Hard	No	Investigate opportunities to engage in a green power contract.
Total:		17	Standard: 3 Easy: 3 Moderate: 4 Hard: 6 Impossible: 1		

4.6 Water Efficiency

The Water Efficiency section has 5 points, most of which would be easy for Wellesley to obtain for the GES project. The points are based around two factors: reducing overall water use and using non-potable water sources. Wellesley has already made efforts to improve water efficiency around campus. For example, the athletic fields, Alumnae Valley, the Lulu Chow Wang Campus Center, parking garage, and Tower Hill landscapes all operate on a non-potable irrigation system supplied by Lake Waban.⁴²⁴ The college is also proactive about replacing inefficient systems and repairing leaks, thereby reducing overall water use. Thus, points in the Water Efficiency section are already in keeping with current Wellesley practices. The only difference is a matter of pursuing water efficiency standards beginning with construction rather than making improvements retroactively.

Three of the five points have been listed as easy since none of the changes would incur significant costs, require extensive maintenance, or cause Wellesley to deviate radically from standard operational norms.

WE 1.1: Landscaping: Reduce by 50%

The requirements for this credit are to reduce overall water use for outdoor irrigation by at least 50% based on a mid-summer baseline. Currently the only outdoor irrigation is for the Cameron Garden between the Friends of Horticulture building and the easternmost portion of the greenhouses. The Cameron Garden was designed by a landscape architect, and the species composition, while flexible, is not likely to change significantly. As it is now, the plants are a combination of native and exotic species, all of which are reasonably well-suited for their location.

This garden already employs a highly efficient watering system; the way it is used, however, is not ideal. The garden is watered through a soaker hose, using 49,680 gallons per year by our calculations, or 12,420 gallons per month if we assume irrigation is restricted to the four hottest months of the year. Although the garden is kept well-watered during dry months, the greenhouses staff have indicated that the garden as it is now could be maintained with significantly less water—watering only once a month during the dry season.⁴²⁵ The reason so much water is that the soaker hose for the garden is set up in a place where it is easily forgotten, and the irrigation is occasionally left on for days at a time—to no detriment to the plants, but unnecessarily.

Meeting this LEED credit would be easy because it would only require a change in practice, rather than a change in design. The greenhouses staff, by making a conscious effort to water this garden less frequently, could reduce the irrigation to less than half of what it is currently. There are many electronic timers that could easily be affixed to the faucet to automate watering on a schedule that would ensure that the hose is activated only for as long as necessary.⁴²⁶ The garden is kept well-mulched, and this added ground cover helps retain soil moisture. If some plants in the garden do not adjust to a reduced-watering schedule, however, they could be replaced with hardier species to further reduce the need for irrigation.

WE 1.2: Landscaping: No potable water use or no irrigation

⁴²⁴ Patrick Willoughby, personal communication, April 6, 2007.

⁴²⁵ Patricia Diggins and Dave Sommers, personal communication, May 4, 2007.

⁴²⁶ These timers cost an average of \$25. Examples of timers can be found at Kelly's Lawn & Irrigation Supply: <http://www.sprinklersupplies4less.com/productsservices/category.nhtml?catid=10114>.

In addition to reducing water use by 50% for irrigation, this credit requires that either only non-potable water be used or that there be no outdoor irrigation at all. The simplest way to achieve this point would be to eliminate the need for irrigation completely. As most landscape around the greenhouses is not irrigated, taking this step would require, at most, a few adjustments in the Cameron Garden. The garden was designed with its current plant species composition in mind, however, so making these changes is of moderate difficulty because of the historical value and desire of many to maintain the garden as it was originally created. The argument for allowing species composition to change is that there are educational and practical benefits to selecting native flowering plants suited to the garden's environment.⁴²⁷

If irrigation remains necessary, however, there are many options available for non-potable water sources. These include rainwater collection systems, greywater reuse, and Living Machine effluent. All of these water sources could be used both in and out of the greenhouses, thus eliminating the use of potable water for all plants. Of these systems, the simplest to implement and install is rainwater collection, though these systems can also be used in tandem.

Again, obtaining this credit by adopting a non-potable supply system is of moderate difficulty because there are significant installation costs. Wellesley uses non-potable water for many irrigation systems on campus, however, so the idea behind such a system is already part of Wellesley's current practices, and the benefits of a water capturing or reuse systems extend well beyond improving water efficiency.

WE 2: Innovative Wastewater Technologies

There are two options for this point: either to reduce wastewater by 50% through use of water-conserving fixtures or (and) non-potable water reuse, or to treat 50% of all wastewater on-site to tertiary standards. This option is of moderate difficulty because of the initial cost associated with installing water re-use or treatment systems, though water-saving fixtures are of comparable price to their standard counterparts.

It may be possible to reduce wastewater flow by half using water-conserving devices such as low-flow or composting toilets and aerated faucets, though this depends largely on which technologies are adopted. For instance, aerated faucets all reduce water flow, but the actual amount of reduction varies from 0.5 to 2.2 gallons per minute. By our calculations, to achieve a 50% wastewater reduction, faucets would need to have a maximum flow of 1.2 gallons/minute and toilets 0.8 gallons/flush (51% reduction).

The greenhouses offer a practical way to reuse greywater or even to treat wastewater on site. This point could be met by installing a greywater filtration system that would collect and purify water from the sinks, shower, and water fountain for re-use in the greenhouses, outdoor irrigation, or simply groundwater infiltration. If used in combination with ultra low-flow toilets, this could reduce wastewater by 50% or more.

Building a Living Machine is a way to treat all water used on site to tertiary standards and even have some available for re-use in the greenhouses. A Living Machine would meet and exceed this LEED credit, as well as qualify the GES project for additional points in the Innovation and Design category.

WE 3.1: Water use reduction: 20% reduction

This credit requires that a building use 20% less water overall after complying with the 1992 Energy Policy Act. Irrigation is not included in the water consumption for this calculation,

⁴²⁷ Patricia Diggins, personal communication, May 4, 2007.

and only water from toilets, sink faucets, and showers is considered. Installing low flow fixtures (1.5 gal/min faucets, 1.2 gal/flush toilets) would reduce our estimate for the GES project water usage by 28%. Since these devices cost little or no more than standard fixtures, this credit could be fulfilled with little effort or expense.

WE 3.2: Water use reduction: 30% reduction

To obtain an additional point for water reduction, overall water use must be reduced by 30%. The same restrictions about irrigation and the water-use sources apply to this point as in Credit 3.1. This point is of moderate difficulty to achieve because, as in Credit 2, there are significant initial costs associated with constructing new systems. Although not easy, these systems are not inherently more complicated than the sewage pipes that would be installed for any new building.

Systems that could reduce overall water use by 30% or more include greywater filtration and re-use systems or a Living Machine. Water from either of these systems could be re-used for toilet water (total water savings: 34%) as well as for watering plants within the greenhouses.

Table 28: LEED Water Efficiency Credit Evaluation

LEED Credits	Water Efficiency	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
WE: 1.1	Water Efficient Landscaping: Reduce by 50%				
	Reduce potable water consumption for irrigation by 50% from a calculated mid-summer baseline case.	1	Easy	No	<p>Install high-efficiency irrigation systems, such as underground soaker-hoses, which reduce the need for watering.</p> <p>Use non-potable water sources for some (or all) of irrigation (see below).</p>
WE: 1.2	Water Efficient Landscaping: No Potable Water Use or No Irrigation				
	<p>Achieve WE Credit 1.1 and use only non-potable water sources for outdoor irrigation, OR install landscaping that does not require permanent irrigation systems.</p> <p>Temporary irrigation systems for plant establishment are allowed only if removed within one year of installation.</p>	1	Moderate	No	<p>Plant low-maintenance plants around the greenhouses to eliminate the need for outdoor irrigation.</p> <p>Use non-potable water sources, such as from rainwater collection, greywater re-use, or a Living Machine for outdoor irrigation.</p>
WE: 2	Innovative Wastewater Technologies				
	<p>OPTION 1: Reduce potable water use for building sewage conveyance by 50% through use of water-conserving fixtures or non-potable water.</p> <p>OPTION 2: Treat 50% of wastewater on-site to tertiary standards. Treated water must be infiltrated or used on-site.</p>	1	Moderate	No	<p>Install a greywater recycling system for water greenhouse plants, outdoor irrigation and/or toilet bowls.</p> <p>Build a Living Machine to treat all black and greywater on site. Use excess for greenhouse plants.</p> <p>Install ultra-low-flow devices and composting toilets to reduce water consumption.</p>

LEED Credits	Water Efficiency	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
WE: 3.1	Water Use Reduction: 20% Reduction				
	Employ strategies that in aggregate use 20% less water than the water use baseline calculated for the building (not including irrigation) after meeting Energy Policy Act of 1992 fixture performance requirements.	1	Easy	No	Install ultra-low-flow faucets and composting toilets. Install rainwater collection to water greenhouse plants. Install a graywater re-use system or Living Machine to water greenhouse plants.
WE: 3.2	Water Use Reduction: 30% Reduction				
	Achieve WE Credit 3.1 and exceed it by at least 10% for an overall 30% water use reduction.	1	Moderate	No	Use a combination of the methods listed above (WE: 3.1).
Total: 5			Standard: 0 Easy: 2 Moderate: 3 Hard: 0 Impossible: 0		

4.7 Innovation and Design Process

The five points offered by LEED in the innovation and design (ID) category provide recognition for exceeding LEED requirements in the other five sections. LEED awards these points to buildings with “exceptional performance above the requirements set by the LEED-NC Green Building Rating System”⁴²⁸ as well as to innovations not listed within the rating system.

LEED divides the five points for innovation and design into two sections. The first four points are for excellent performance in meeting LEED regulations. LEED standards are not revised on the same timescales that sustainable building techniques and methods improve; these four points encourage builders to use the best practices even when they exceed current standards. Suggested strategies to accomplish these four points include exceeding LEED requirements for energy performance and water efficiency or providing quantifiable environmental and/or health benefits.⁴²⁹ The goal of the fifth ID point is to certify one team member as a LEED Accredited Professional in order to streamline the certification and application process.

Currently, Wellesley College is not eligible for any of these five points as the college presently has no green buildings and does not staff a LEED Accredited Professional. With the advent of a new green building, such as the GES Building, the college can obtain these points through easy and moderate courses of action.

⁴²⁸ U.S. Green Buildings Council, *LEED for New Construction*, Version 2.2, (November 2005), 80.

⁴²⁹ U.S. Green Buildings council, 80.

ID 1.1 to 1.4: Innovation in Design

For each credit, ID 1.1 to 1.4, is worth one point. Credits ID 1.1 and 1.2 are deemed easy because only two exceptional performances or innovations are required. Additional credits become more difficult to meet, as more innovations are required. Therefore, credits ID 1.3 and 1.4 are listed as moderate in difficulty.

There are multiple ways for Wellesley College to meet these credits. The college and the greenhouses, in particular, are strongly invested in community outreach and development. For example, the Friends of Horticulture sponsor a Plant FBI program in the greenhouses for local school children each year. Continuing the demonstrated commitment to community outreach, our proposed GES building could be the start of future programs.

As an institute of higher learning, Wellesley College is deeply committed to enhancing the knowledge of its students. The proposed GES building would provide educational opportunity unparalleled on campus, and through tours, displays, and student research, there is even greater potential for substantial benefits. The additional educational components of the GES building could earn the building an additional ID point.

The two final proposed options for LEED credits ID Credit 1.3 and 1.4 entail exceeding LEED requirements under the water efficiency guidelines. Both of these credits would be moderately difficult for Wellesley to obtain. ID Credit 1.3 could be reached by installing a rainwater collection system. The water harvested from rainwater collection would replace the potable water currently used for landscaping with reclaimed water, effectively eliminating treated well-water from the greenhouses irrigation. ID Credit 1.4 could be earned by engineering a Living Machine in the GES building. Instead of reducing wastewater by 50% or re-using 50% of wastewater, Living Machines allows 100% of wastewater to be filtered and then reused. The Living Machine clearly goes beyond the LEED requirements for innovative wastewater technology.

ID 1.5: Innovation in Design

There are three different ways for Wellesley College to gain ID Credit 1.5. The first option is for the college to hire an Accredited Professional (AP) to advise the accreditation. Many contractors or architects who work on green buildings on a regular basis have already been accredited. There are many LEED APs in Boston and one individual in the town of Wellesley.⁴³⁰

The second and third options are for either a student involved with the design process or a faculty or staff member of Wellesley College to become accredited. The exam does not require professional knowledge of green building, only familiarity with LEED resources and documentation, knowledge of LEED credits and requirements, and experience with life cycle and cost-benefit analyses.⁴³¹ LEED accreditation exams are available for new construction and major renovations, commercial interiors, and existing buildings. Although the proposed GES building would fall under the category of new construction and major renovations, the LEED AP is qualified if that person has passed any of the LEED exams.

⁴³⁰ U.S. Green Building Council, "Accredited Professionals," 2007, accessed 02/28/2007, at <http://www.usgbc.org/LEED/AP/ViewAll.aspx?CategoryID=1306&CMSPageID=1585>.

⁴³¹ U.S. Green Building Council, *Become a LEED AP*," 2007, accessed 02/28/2007, at <http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1563&>.

The cost to sit the LEED accreditation exam is \$250 for U.S. Green Building Council members and \$350 for non-members.⁴³² That a Wellesley College student with no background in green buildings and only minimal studying was able to come close to passing suggests that certification is indeed possible for a “civilian.”

Table 29: LEED Innovation and Design Credit Evaluation					
LEED Credits	Innovation and Design	LEED Point(s)	Level of Difficulty	Currently met by Wellesley?	How can a new building meet LEED standards?
ID: 1.1	Innovation in Design				
	In writing, using the LEED Credit Equivalence process, identify the intent of the proposed innovation credit, the proposed requirement for compliance, the proposed submittals to demonstrate compliance, and the design approach Used to meet the required elements, innovation or design aspect.	1	Easy	No	Community development with the town of Wellesley through the establishment of a green building—for example, educational programs about green building and the proposed GES project.
ID: 1.2	Innovation in Design				
	Meet Credit 1.1 and additional innovation or design aspect.	1	Easy	No	Educational value reached through classes, tours, displays, and research on how green architecture functions.
ID: 1.3	Innovation in Design				
	Meet Credit 1.2 and additional innovation or design aspect	1	Moderate	No	Exceed the landscaping water efficiency LEED performance credit through rainwater collection.
ID: 1.4	Innovation in Design				
	Meet Credit 1.3 and additional innovation or design aspect.	1	Moderate	No	Exceed the innovative wastewater technology LEED performance credit through the installation of a living machine.
ID: 2	LEED Accredited Professional				
	At least one principal participant of the project team that has successfully completed the LEED Accredited Professional exam.	1	Easy	No.	Hire an accredited professional from outside. Have someone already hired by Wellesley pass the LEED accreditation exam.
Total:		5	Standard: 0 Easy: 3 Moderate: 2 Hard: 0 Impossible: 0		

⁴³² U.S. Green Buildings Council, *Frequently Asked Questions: LEED AP* (2007), accessed 05/05/2007, at <<http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1638&>>.

Table 30: LEED Credit Evaluation Summary					
CONCLUSION: LEED POINTS	Standard	Easy	Moderate	Hard	Impossible
Sustainable Sites	4	4	3	0	3
Materials & Resources	0	3	7	0	3
Indoor Environmental Quality	0	12	3	0	0
Energy & Atmosphere	3	3	4	6	1
Water Efficiency	0	2	3	0	0
Innovation & Design Process	0	3	2	0	0
Total	7	27	22	6	7
Project Total (cumulative)	7	34	56	62	69

4.8 LEED Conclusions

Throughout the accreditation process, LEED serves not only as a rating system but as a guide to systematically approach the many aspects involved in building and design. Wellesley can attain certification with a minimum of 26 points and we have determined that Wellesley could easily gain 34, and with moderate effort up to 56, which qualifies for LEED Gold status.

LEED certification is more than a rating system. It sends a strong message to students and to the greater academic world that Wellesley is committed to the health and comfort of its students and staff as well as to improving efficiency and reducing environmental impacts.

To achieve LEED standards Wellesley would need to consider new methodologies and materials, as well as renewable energy and lighting. Wellesley has already put into effect many of the practices that LEED encourages and is on its way towards meeting LEED expectations. We strongly recommend that Wellesley combine the practices that can already be found on the campus, and apply the many innovative concepts of green design into one building. The designation of the proposed GES as a LEED certified building would be an achievement for the college and would demonstrate its commitment to sustainable practices. By making this commitment, Wellesley College can further enhance its reputation as a leader in service and educational excellence.

5. Conclusion

Construction of the proposed GES building would benefit Wellesley College, its students and academic programs and the wider community. As an institution of higher learning concerned with social responsibility, Wellesley has recently published its own sustainability statement, which asserts that "[m]embers of the Wellesley community have individual and collective responsibility for environmental stewardship."⁴³³ This obligation to environmental sustainability includes a responsibility to demonstrate environmental stewardship in the college's daily operations and planning. Ensuring that all new construction on campus meets green standards is the next logical manifestation of Wellesley's recent commitment. If the College were to make the effort to build green, it would achieve recognition for its actions to promote sustainability, and would also reduce operating costs and minimize Wellesley's overall environmental footprint. Members of the Wellesley College community express support for environmental responsibility, but unless they understand the far-reaching impacts of their current practices, they have little reason to act. Only by engaging the entire college—administration, trustees, all offices and departments, students—in decisions such as whether to build green can we ensure sustainable policies at Wellesley.

The proposed GES building would not, however, be only a symbol of Wellesley's environmental commitment. The proposed GES building creates a space in which sustainability is a way of thinking, learning, and doing. By demonstrating how our everyday activities affect the local and global environment, the proposed building can inspire students to incorporate sustainability principles into their own daily activities and learning. It could also help attract prospective students who seek a school with demonstrated commitment to environmental responsibility. Furthermore, the building would provide ES students with a community area in which to congregate, and—because of its excellent IEQ—would increase the well-being and mental health of students who chose to work or study there.

The building would also provide the space needed for the ES program to grow and flourish. As a program that integrates diverse systems of knowledge (science, history, sociology, justice, politics, economics), ES needs a space of its own to better concentrate ideas and experience in a way that is more valuable and meaningful to students, faculty and the community at large. ES is an increasingly popular academic field, and a strong ES program will help Wellesley stay competitive with its peer institutions. New ES space would help in the development of a sense of community for those within the major, and the building can also provide a centralized location for faculty, who come from a broad range of disciplines, to meet.

Finally, the proposed GES building could provide inspiration to encourage more green building in the Town of Wellesley and surrounding area. What better place to set an example for green design than at the greenhouses, which connect the college to the greater community through programs for elementary school children, Friends of Horticulture programs, and general visitation by the public.

⁴³³ Wellesley College Sustainability Statement, April 2007.

APPENDICES

Appendix I: Energy Baseline Calculation Data

****Note:** All actual calculations were done using metric units. Data are presented here in English units since the targeted audience is American. Not all units or conversions presented here are necessarily as precise as those used for calculations, however.

Top-down Calculations

Table A.1: Total area for Wellesley College academic buildings⁴³⁴

Building Name	Area (ft ²)
Founders Hall	64,200
Green Hall	99,300
Jewett Art Center	86,600
Library	204,100
Margaret Ferguson Greenhouses	7,235
Observatory	8,300
Pendleton Hall East	49,600
Pendleton Hall West	41,300
Science Center	289,300
Total: 849,935	
Total Campus Building Area:	2,267,550

Table A.2: Fuel consumption in the Physical Plant for 2006 (January to December)⁴³⁵

Boilers	Oil (gal/yr)	Oil (Btu/yr)	Gas (ft ³ /yr)	Gas (Btu/yr)	Total (Btu/yr)
	270,261	40,539,150,000	190,520,000	190,520,000,000	231,059,150,000
Generators			Gas (ft ³ /yr)	Gas (Btu/yr)	
			324,760,000	324,760,000,000	328,403,056,678
Overall					
		7%		93%	555,819,150,000

⁴³⁴ Traci Robie, personal communication, April 2007.

⁴³⁵ George Hagg, personal communication, April 2007.

Bottom-up Calculations

The following data were used to calculate the energy required to heat the volume of air contained within the greenhouses (GH) as well as the energy needed to compensate for the rate of heat loss.

Data apply to the following equations:

(Eqn. 2.4-3)

$$EnergyLoss[Btu/yr] = \sum \left\{ (GlassSurfaceArea)(U_{value}) \left(1.02 \frac{Btu}{(hr)(ft^2)(^{\circ}F)} \right) (\Delta MonthlyTemp)(NumHrs / Month) \right\}$$

(Eqn. 2.4-4)

$$EnergyLost[Btu/yr] = (GreenhouseRoomVolume)(1.129 Btu)(NumAirChanges)(\Delta Temp)$$

Table A.3: Constants used for bottom-up energy calculations

Constant	Value	Units
U-value	1.02	Btu/hr*ft ² *F
Air density	0.081	lb/ft ³
Energy to heat 1 ft ³ by 1°F	0.36	watts
	1.129	Btus

Table A.4: Average monthly temperature difference from winter greenhouses temperatures⁴³⁶

Month	Avg High (°F)	Avg Low (°F)	Avg. Hi/Lo (°F)	Diff from Avg GH Temp (69°F)
January	36	16	26	43
February	37	19	28	41
March	46	28	37	32
April	57	37	47	22
May	70	48	59	10
June	79	57	68	1
July	84	63	73	-4
August	82	61	72	-3
September	73	52	63	6
October	63	39	51	18
November	52	34	43	26
December	39	21	30	39

⁴³⁶ The Weather Channel, *Monthly Averages for Wellesley Hills, MA (02481)*, accessed 04/10/2007, at www.weather.com.

Table A.5: Greenhouse data by room

Room Name	Temp (°F)*	Area (ft ²)	Total Vol (ft ³)	Wall Glass SA (ft ²)	Roof Glass SA (ft ²)	Tot. Glass SA (ft ²)	Number Lights	Number Fans	kWh/mo from appliances
Student A	70	419	3560	175	488	663	2	2	176
Student B	70	408	3472	171	476	647	2	2	176
Seasonal A	70	434	3686	181	505	687	4	2	186
Desert	67	484	6438	265	516	781	2	0	10
Seasonal B	65	678	9013	371	722	1094	4	1	103
Tropical	72	1308	24968	995	1554	2549	12	0	60
Warm Temp	61	678	9013	371	722	1094	4	0	20
Hydrophyte	70	484	6438	265	516	781	2	0	370
Mabal A. Stone	70	434	3686	181	505	687	2	2	176
Begonia	70	412	3500	172	480	652	2	2	176
Fern Propagation	70	417	3546	175	486	661	2	2	176
Collections Support	70	412	3500	172	480	652	2	2	176
Research A	70	417	3546	175	486	661	2	2	176
Research B	70	412	3500	172	480	652	2	2	176
TOTAL:		7398	87867	3843	8416	12259	44	19	2155

Temp = Temperature

Vol = volume

kWh = Kilowatt Hours

SA = Surface area

mo = month

The ground floor coverage that we measured for the greenhouses came to a total of 7,398 square feet, though the value we obtained from the Director of the Botanical Gardens was 7,235 ft². For the purposes of determining the average greenhouse temperature, total volume, and glass surface area, we used our measured value (7,398 ft²). For determining the energy use per square foot of building and for all other calculations, however, we used 7,235 ft². We used the measured values for some calculations so that our data would be take into account the individual measurements of each room , thus allowing us to do a weighted average for the temperature, use individual room measurements for surface area (SA) and volume (vol) data, etc.

Although ideally we would have used the same number for all calculations, there was only a 2% difference between the values, and thus the difference had little effect the final data.

Table A.6: Energy consumption per appliance⁴³⁷

Energy Use	Watts	Est Hrs of Use/month	Watt hrs
Portable fan	115	720	82,800
6 ft fluorescent	70	72	5,040
Water pump	500	720	360,000

⁴³⁷ City of Ames, Iowa. "Common Household Appliance Energy Use." Available online at <http://www.city.ames.ia.us/ElectricWeb/energyguy/appliances.htm>.

Appendix II: Bottom-up Water Calculations

Water used inside for plants⁴³⁸:

$$\left(300 \frac{\text{gal}}{\text{day}}\right) \left(365 \frac{\text{day}}{\text{yr}}\right) = 109,500 \frac{\text{gal}}{\text{yr}} \quad (\text{Eqn. II-1})$$

Water used outside for plants:

$$\left(5 \frac{\text{gal}}{\text{min}}\right) \left(60 \frac{\text{min}}{\text{hr}}\right) \left(6 \frac{\text{hr}}{\text{day}}\right) (0.3) \left(92 \frac{\text{day}}{\text{yr}}\right) = 49,680 \frac{\text{gal}}{\text{yr}} \quad (\text{Eqn. II-2})^{439}$$

Amount of water used by greenhouse misters⁴⁴⁰:

To calculate the number of seconds the misters could theoretically be on during the summer and winter:

$$\text{TimeSummer} = \left(9 \frac{\text{hr}}{\text{day}}\right) \left(60 \frac{\text{min}}{\text{hr}}\right) \left(60 \frac{\text{sec}}{\text{min}}\right) = \left(32,400 \frac{\text{sec}}{\text{day}}\right) (183 \text{days}) = 5,929,200 \text{sec}$$

$$\text{TimeWinter} = \left(5 \frac{\text{hr}}{\text{day}}\right) \left(60 \frac{\text{min}}{\text{hr}}\right) \left(60 \frac{\text{sec}}{\text{min}}\right) = \left(18,000 \frac{\text{sec}}{\text{day}}\right) (182 \text{days}) = 3,276,000 \text{sec}$$

To calculate the number of times the misters come on during the summer and winter, where x_{summer} and x_{winter} equal the number of times the misters are on. $x_{\text{summer,prop}}$ and $x_{\text{winter,prop}}$ include 15 seconds when the misters are on and 180 seconds when the misters are off. $x_{\text{summer,ceil}}$ and $x_{\text{winter,ceil}}$ include 15 seconds when the misters are on and 600 seconds when the misters are off. Solve for x:

For propagation misters:

$$(15 \text{sec})x_{\text{summer,prop}} + (180 \text{sec})x_{\text{summer,prop}} = 5,929,200 \text{sec}$$

$$\Rightarrow x_{\text{summer,prop}} = 30,406 \text{times}$$

$$(15 \text{sec})x_{\text{winter,prop}} + (180 \text{sec})x_{\text{winter,prop}} = 3,276,000 \text{sec}$$

$$\Rightarrow x_{\text{winter,prop}} = 16,800 \text{times}$$

For ceiling misters:

$$(15 \text{sec})x_{\text{summer,ceil}} + (600 \text{sec})x_{\text{summer,ceil}} = 5,929,200 \text{sec}$$

$$\Rightarrow x_{\text{summer,ceil}} = 9,640 \text{times}$$

$$(15 \text{sec})x_{\text{winter,ceil}} + (600 \text{sec})x_{\text{winter,ceil}} = 3,276,000 \text{sec}$$

$$\Rightarrow x_{\text{winter,ceil}} = 5,326 \text{times}$$

Water used by propagation misters:

⁴³⁸ Estimated daily usage to account for usage year-round reported to a regulatory organization; the amount of time to water the plants ranges from 0-3 hours; the hose pumps about 5 gallons of water per minute, so the greenhouse uses 0-900 gallons in a day; Anthony Antonucci, personal communication, March 30, 2007.

⁴³⁹ 0.3 is the probability of extremely dry days, when watering is necessary, between June and August. There are 92 days between June and August.

⁴⁴⁰ Mist every 3-6 minutes for 3-15 seconds for propagation; sprinklers mist the same amount but with longer intervals in between estimated at 10 min.

$$\left(11 \frac{\text{mistert}}{\text{time}}\right) \left(\frac{1}{4} \frac{\text{cup}}{\text{mister}}\right) \left(\frac{1\text{gal}}{16\text{cup}}\right) \left((30,406 + 16,800) \frac{\text{time}}{\text{yr}}\right) = 8,113.5 \frac{\text{gal}}{\text{yr}}$$

Water used by ceiling misters:

$$\left(8 \frac{\text{mistert}}{\text{time}}\right) \left(\frac{1}{4} \frac{\text{cup}}{\text{mister}}\right) \left(\frac{1\text{gal}}{16\text{cup}}\right) \left((9,640 + 5,326) \frac{\text{time}}{\text{yr}}\right) = 1,870.75 \frac{\text{gal}}{\text{yr}}$$

Total water used by misters:

$$\left(8,113.5 \frac{\text{gal}}{\text{yr}}\right) + \left(1,870.75 \frac{\text{gal}}{\text{yr}}\right) = 9,984.25 \frac{\text{gal}}{\text{yr}} \quad (\text{Eqn. II-3})$$

Water used when for pond⁴⁴¹:

$$\text{pondwater} = \left(1000 \frac{\text{gal}}{\text{fill}}\right) \left(3 \frac{\text{fills}}{\text{yr}}\right) = 3000 \frac{\text{gal}}{\text{yr}} \quad (\text{Eqn. II-4})$$

Amount of water used for whitewash:

During Application:

$$\left(\frac{1}{3} \frac{\text{cup}}{\text{yr}}\right) \left(\frac{1\text{gal}}{16\text{cup}}\right) = 0.02 \frac{\text{gal}}{\text{yr}}$$

During Removal:

$$\left(5 \frac{\text{gal}}{\text{min}}\right) \left(\frac{60\text{min}}{\text{hr}}\right) \left(\frac{5\text{hr}}{\text{day}}\right) \left(\frac{2\text{day}}{\text{yr}}\right) = 1500 \frac{\text{gal}}{\text{yr}}$$

Total water used for whitewash:

$$\left(0.02 \frac{\text{gal}}{\text{yr}}\right) + \left(1500 \frac{\text{gal}}{\text{yr}}\right) = 1500.2 \frac{\text{gal}}{\text{yr}} \quad (\text{Eqn. II-5})$$

Table A.7: Greenhouse total water consumption per year

Use	Water Consumption (gal/yr)
Water inside plants	109,500
Water outside plants	49,680
Misters	9,984
Changing water in pond	3,000
Whitewash	1,500
Total	173,664

⁴⁴¹ David Sommers, personal communication, March 30, 2007.