Clean, Green Athletics Machine

A Sustainable Renovation of the Wellesley College Sports Center

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Environmental Studies 300
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ABBREVIATIONS AND DEFINITIONS

AC - Air Conditioner
Albedo – measures the ability of a surface to reflect the sun's light
CdTe – Cadmium Telluride
CFC - Chlorofluorocarbon
CFL - Compact Fluorescent Light bulb
CIGS - Copper Indium Gallium Selenide
CO_2 - Carbon Dioxide
CRT – Cathode Ray Tube
Cistern - a receptacle for holding water
DC - Direct Current
EIFS - Exterior Insulation and Finish System
Emittance - the energy radiated by the surface of a building (measured /sec/area)
EPA - Environmental Protection Agency
ES - Environmental Studies
ft. - Feet
GHP - Geothermal Heat Pump
GLOW - Wellesley College Circus Organization
HCFC - Hydrocholorofluorocarbon
HID - Human Interface Device
HVAC – Heating, Ventilation, and Air Conditioning
Insulation - material that prevents the heat or sound waves from passing through walls
KSC - Keohane Sports Center
LCA - Life Cycle Assessment
LCD - Liquid Crystal Display
LCW - Lulu Chow Wang Campus Center
LEAP - Lifetime Empowerment and Awareness Program
LED - Light Emitting Diode
LEED - Leadership in Energy and Environmental Design
Lumen - a measure of perceived power of light
LWC - Lake Water Cooling
MIT - Massachusetts Institute of Technology
MMBtu - 10 Million British Thermal Units
mph - Miles per Hour
MP3 - MPEG Audio-Layer 3
NCAA - National Collegiate Athletics Association
p-Si, mc-Si, a-Si, c-Si - units of measurement of solar cell efficiency
PVC - Photovoltaic cell
PIR - Passive Infrared
PSI - Pound per Square Inch
PE - Physical Education
PERA - Physical Education, Recreation, and Athletics
Reflectivity - the fraction of incident radiation reflected by a surface
SEER - Seasonal Energy Efficiency Ratio
tCO_2eq - equivalent tonne of carbon dioxide

Title IX - Education Amendments of 1972, which prevented an institution from excluding women from any educational activity
US - United States
USGBC - United States Green Building Council
UV - Ultraviolet
VOCs - Volatile Organic Compounds
WASAC - Wellesley Association for South Asian Cultures
kW - Kilowatts
kWh - Kilowatt Hours
kWh/a - Kilowatt Hours per Annum
mW - Megawatt
W - Watt
1G - first generation
2G - second generation
°F - Degrees Fahrenheit

EXECUTIVE SUMMARY

Each spring, the students in ES 300, the capstone course for the Environmental Studies major at Wellesley College, act as consultants to the College on specific environmental issues on campus. This year, our charge was to provide recommendations for the renovation of the Keohane Sports Center (KSC) in order to make it more environmentally sustainable and to better serve its various users.

The current structure of the Keohane Sports Center dates to 1985, and includes a 25m pool, a 200m indoor track, dance studios, recreational fitness equipment, office space, and playing and practice space for sports. Renovations are needed to deal with a small number of pressing structural repairs and to adapt the building to better meet the needs of current users, with the goal of involving more students in fitness programs. A green renovation in particular may inspire students to develop healthy lifestyles that include both regular exercise and green living, and it will continue the campus push towards environmental sustainability. A green renovation of the KSC will also provide the College with an opportunity to gain knowledge of environmentally sustainable renovations that can be applied to other areas of campus in the future.

We defined the scope of this project after consultation with senior staff of the KSC and the Facilities Department, and we have chosen to consider ten aspects of environmental design in the sports center. In this report, we examine several alternative ways to lessen environmental impacts and increase user benefits in each of these categories. Our evaluations of alternatives are based on the costs and benefits of each alternative for the College including environmental, educational, social, financial, and logistical concerns. We also examined the alternatives' lifetime environmental impacts. In the short-term, we recommend improving the energy efficiency of the KSC's lighting, heating systems, and equipment; installing water-efficient appliances; cooling the building with passive techniques; installing green roofs and cool roofs; and adding signage, student art, and lounge amenities to increase user comfort. In the long-term, we recommend reorganizing the physical space in the KSC to better meet the needs of current users; installing a combination of technologies for alternative energy generation; incorporating more natural lighting into the building's structure; and limiting indoor air pollution through an improved ventilation system. We also urge the College to consider the life cycle environmental impacts of all materials bought or discarded in the renovation process.

Each of the recommendations we make promises repayment to the College either directly, by reducing the cost of energy production, or indirectly, through increasing community awareness of its environmental impacts, which could lead to further reductions in energy use. Incorporating a combination of these recommendations into the KSC renovation could also provide certification through the Leadership in Energy and Environmental Design (LEED) program. While LEED certification is an expensive process, we recommend pursuing it as a symbol of Wellesley's commitment to environmental sustainability that is recognizable to alumnae and potential applicants.

With the recommendations in this report, we seek to demonstrate the many elements that can contribute to a green renovation of the KSC. If these recommendations are implemented, the KSC will attract more users and reduce its environmental impact. More broadly, a cleaner, greener athletics machine will provide an example for future renovations on campus.

I. INTRODUCTION

Project Background

Environmental Decisionmaking (ES 300) is the capstone course for the Environmental Studies (ES) major. The purpose of this course is to bring together junior and senior ES majors to comprehensively analyze and address a specific environmental project on the Wellesley College campus.

The spring 2009 ES 300 project was to formulate renovation ideas for the Keohane Sports Center (KSC) that would significantly decrease the building's environmental footprint. By making the Sports Center more energy efficient, the building will serve as a testament to Wellesley College's environmental mission. In addition to strengthening the College's environmental reputation, the recommendations throughout this report are aimed at making the Sports Center a healthier place for all of its visitors, a more appealing place to encourage exercise on campus, and a more responsible user of the planet's environmental resources.

History of the KSC

The construction of the Keohane Sports Center in 1985 followed a succession of gymnasium building additions made to accommodate the changing needs of Wellesley College's physical education and recreation requirements. The original Recreation Building, constructed in the 1930s, had suffered a long period of neglect. The administration partially attributed a drop in applications to the dilapidated state of the gymnasium.[1]

The KSC was built to remediate this problem and to meet the growing need for more space. A rise in women's athletics was followed the Title IX legislation of 1972, which made it illegal for any federally funded program to exclude or discriminate on the basis of sex.[2] To accommodate these needs the College tore down the 1909 gym and built an addition to the 1938 gymnasium, making it the largest building on campus at that time.[3]

In 1993 the building was renamed The Nannerl O. Keohane Sports Center after the College's 13th president who led a campaign to raise $16 million for the renovation. President Keohane strongly advocated for a new facility in keeping with the College's established athletic tradition and in adherence to the cultural movement towards larger, more modern exercise facilities.[4] The new facility totaled 140,000 square feet in an L-shaped configuration, including a new field house on the west end with a 200-meter running track and courts for indoor sports including tennis, racquetball, basketball, and volleyball.[5] The new entryway connected the main building with the pool house and eight-lane, 25 meter pool, and diving area in the location of the former 1909 gymnasium. These new additions allowed for the expansion of the College's physical education curriculum and provided an exercise facility for the growing varsity, intramural, and club sports as well as the recreational activities of the community.

PERA Philosophy

The Department of Physical Education, Recreation, and Athletics (PERA) is responsible for planning and executing the physical education, intramural, and varsity sports programs offered by the College. These programs continue the health philosophy of Wellesley's founder, Henry Fowle Durant, who promoted a "sound mind and body" through regular physical activity.[6] Durant advised the students "to make the blood

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[1] Peter Fergusson, James F. O'Gorman, and John Rhodes, *The Landscape & Architecture of Wellesley College*. (Wellesley: Wellesley College, 2000), 244.
[2] United States Department of Labor. Office of the Assistant Secretary for Administration and Management "Title IX, Education Amendments of 1972. http://www.dol.gov/oasam/regs/statutes/titleIX.htm Date Accessed April 29, 2009.
[3] Peter Fergusson, James F. O'Gorman, and John Rhodes, *The Landscape & Architecture of Wellesley College*. (Wellesley: Wellesley College, 2000), 261.
[4] Peter Fergusson, James F. O'Gorman, and John Rhodes, *The Landscape & Architecture of Wellesley College*. (Wellesley: Wellesley College, 2000), 245.
[5] Deborah K. Dietsch. Architectural Record. "Working Out." August 1987. p. 91.
[6] Wellesley College. "The History of Wellesley College Athletics." Friends of Wellesley College Athletics. http://www.wellesley.edu/Athletics/athletics/FriendsFolder/History/history.html Date Accessed April 27, 2009.

bound through your veins; that will stimulate the mind and help to make you good students."[7] The contemporary sentiment of this exercise philosophy is articulated in PERA's mission statement as the "catalyst for all students to learn, play, compete, and achieve an active balanced lifestyle."[8] The Keohane Sports Center serves indoor recreation, physical education classes, and varsity and intramural sports.

PERA welcomes all who wish to participate to enjoy the sports programs and facilities at Wellesley. All are encouraged to engage in daily physical activity and incorporate a healthy lifestyle to balance the rigorous academic demands of the College. A redesigned facility will help PERA fulfill its goals, one of which is to increase participation in athletics by students, faculty, staff, and the larger Wellesley community. Participation in athletics fosters good health, personal growth, and valuable life skills such as leadership and teamwork. Improved lighting, air quality, temperature, space, and exercise equipment creates a healthy and supportive work and exercise space where everyone can be more comfortable. A welcoming and aesthetically pleasing facility can help all users achieve a sound body and mind, both of which strengthen the goals of PERA and the liberal arts foundation at Wellesley College.

Healthy Bodies, Healthy Planet

The ideas presented in this report illustrate a keen awareness of the importance of the health and performance of all the users and staff. Most notable are the health benefits of improved air quality and energy system recommendations. Climate-controlled exercise and work spaces are healthier for employees and users who suffer from allergies and asthma. With increased air flow, improved temperature control, and cleaner air, those who may have avoided using the facility may now be able to participate in sports activities. Proper flooring in the dance studios and field house will also ensure the safety and performance of athletes and recreational users to prevent falls and other injuries—a current liability with the worn out flooring.

Our recommendations include improving the aesthetics of the facility with the addition of art and technology. Newer more efficient energy systems, including human power, add an educational component as well. PERA can incorporate environmental awareness about energy and water conservation. Other academic departments may use the facility for courses that study the environmental innovations. Wayfinding signage can highlight the energy and water saving technologies and techniques so that students can carry this knowledge to their residence halls. Physical education classes present a unique opportunity to use human powered cardio equipment to create and recapture energy and increase awareness about energy consumption on campus and advance the college's sustainability goals.

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[7] Wellesley College. "The History of Wellesley College Athletics." Friends of Wellesley College Athletics. http://www.wellesley.edu/Athletics/athletics/FriendsFolder/History/history.html Date Accessed April 27, 2009.
[8] Wellesley College. "The Wellesley College Physical Education, Education, and Recreation." http://www.wellesley.edu/Athletics/main.html Date Accessed April 28, 2009.

Project Goals

Due to a few necessary replacements in the KSC's near future, this project provided an opportunity to gather research on more energy- and water-efficient technologies, new opportunities in roofing, alternative energy generation, and the overall structure and use of the building. We gathered data for the Facilities Department so that it might implement these changes when the time is right. These changes can either be implemented all at one time, possibly garnering a LEED certification, or they can be installed sequentially as needed and as funding is available.

For each recommendation, we pare down our alternatives to include only the most cost-effective, feasible options, making sure that each device or system minimally affects its surrounding environment in terms of toxicity and greenhouse gas emission. Accordingly, we prioritize products manufactured in close proximity to Wellesley, MA so that their transportation would emit fewer greenhouse gases. We also prioritize products that are recycled easily and inexpensively, and those that require minimal maintenance.

Our goal for the overall building design encourages KSC visitors to think about energy usage, their relationship to the environment, and how they can minimize their own environmental footprints. This objective is cost-effective: the more people turn off their lights and computers when they go to their dorms, the less fossil fuel the community will consume. Implementing all of the following recommendations will be initially expensive but we have prioritize the most cost-effective options.

Economic Context

In the light of the current economic crisis one might wonder whether pursuing an environmentally-friendly renovation of the KSC is feasible. Yet there are several compelling reasons to pursue a green building project during the current economic crisis: (i) green renovations will save money over time through improved efficiency, (ii) construction and labor will be less expensive due to lower market prices, (iii) such projects stimulate the weakened economy by creating jobs, and (iv) this project will re-affirm Wellesley's commitment to sustainability no matter the economic challenges.

One of the strongest arguments for green building projects is that they save money in the long run through lower operational and maintenance costs.[9] The USGBC and the Energy Star Program have calculated that green buildings use 30% less energy than conventional buildings.[10] As the KSC's annual energy usage is estimated to be around 5.9 million kWh, a 30% reduction could save just over 1.7 million kWh per year, adding up to substantial savings. Construction materials and labor will cost less now than in the future. The price of building materials have declined recently due to the economic crisis, making construction less expensive now than it would have been two years ago.[11] Implementing this project now will create jobs, an important consideration given that 5.1 million jobs have been lost since the recession began in

[9] Sarah Gale, March 9, 2009, "Green Power Forecast: Partly Cloudy – For the Short Term", GreenBiz.com, [http://www.greenbiz.com/feature/2009/03/09/green-power-forecast-partly-cloudy]. Date Accessed: April 20, 2009.
[10] United States Green Building Council, www.usgbc.org. Date Accessed: April 20, 2009.
[11] Starner, Ron, January 2009, "Build Here, Build Now, Pay Less" Site Selection Magazine, http://www.siteselection.com/features/2009/jan/Building-Materials/. Date Accessed: April 20, 2009.

December of 2007.[12] While renovating the KSC may not make a big impact on regional or national unemployment rates, every job contributes to economic recovery.

Finally, greening the KSC will demonstrate Wellesley College's commitment to sustainability. Investing in a green building project now shows that we are not simply following recent popular trends—we are serious about reducing our environmental impact. Colleges and universities, particularly ones like Wellesley College, have been the source of some fundamental changes in American society over the past couple centuries. Another such opportunity is being presented, and demonstrating our commitment to sustainability and the environment now (in spite of the economic crisis) could have important symbolic value.

Approaches

Consulting Faculty, Staff and Students

In order to better understand both the space requirements of the KSC and the desires of the Wellesley College community regarding a renovation of the facility, we consulted several relevant constituencies. These included: the Physical Education, Recreation and Athletics (PERA) staff, members of the Student Athletics Advisory Committee (SAAC), varsity coaches, intramural and club sports team captains, students at large, and some high level athletics and facilities administrators. We requested information about the space needs of teams and clubs, the rental histories of equipment from the front desk, varsity team year-round schedule, and broader suggestions for improving and "greening" the Sports Center.

In late February and early March of 2009, we questioned these constituencies using two different methods; we sent short e-mail surveys to all staff, student athletes, student organization presidents, and club captains, tailored specifically to their relationship with the KSC. We also initiated a discussion on Community and put a survey box in the Science Center to generate ideas for an ideal sports center. It was easy to gather concrete data like equipment rentals and team schedules, but survey response rates were disappointingly low. The survey and Community responses we received nevertheless provided consistent ideas that supported what we learned from relevant individuals about the needs for the KSC.

Cost Estimation

The numbers presented in this report are rough estimates. Prices, output, material costs, and savings were obtained through research and calls to manufacturers. Information regarding pricing was also taken from comparable projects completed elsewhere. Contractors requested site visits and more detailed specifications prior to providing estimates. To move forward with this project, the College must contact local contractors to formalize design plans for competitive pricing.

[12] United States Department of Labor, Bureau of Labor Statistics, March 2009, Employment Situation Summary – March 2009, http://www.bls.gov/news.release/empsit.nr0.htm. Date Accessed: April 20, 2009.

Life Cycle Analysis

In creating this report, we researched the environmental impacts that could be caused by the extraction, production, transportation, installation, maintenance, and disposal of each of the materials researched and recommended. Most often we applied this process in considering various types of alternative energy. This process is called a Life-cycle Analysis, or Assessment (LCA), which aims to account for all the variables, regarding the creation, use, and disposal of a product, service or process during its viable "life-time."[13] LCA involves incorporating all aspects of the life of a specific good including the amount of energy required to manufacture, package, ship, use, and recycle it.

LCA is flexible in that it during this project we examined which aspects we cared the most about in our products (e.g. environmental impact, cost, amount of energy produced or saved), enabling us to frame decisions according to our preferences. Other benefits include being able to make systematic comparisons across different alternatives, and making information accessible for others outside of the industry to understand.

LCA is a valuable tool in planning for the environmental as well as the economic costs of a product that is being considered in a renovation or construction project. These projects often consider only the operation costs of a product, and not the product's manufacture, transportation, installation, maintenance, or disposal. When these impacts are not accounted for up front they can have many harmful effects in the aftermath. LCA helps to avoid these negative impacts.

[13] K.S. Rosselot and D.T. Allen, "Life-Cycle Concepts, Product Stewardship and Green Engineering," in David T. Allen and David R. Shonnard, *Green Engineering* (Upper Saddle River, NJ: Prentice Hall, 2002), p. 419

II. PHYSICAL SPACE

Summary

Wellesley College is home to varsity, intramural, and club sports as well as a physical education program and many causal users. The layout and design of the Keohane Sports Center do not adequately provide for these current users. To alleviate these space concerns, we recommend several changes including: a cantilevered running track, permanent basketball and volleyball courts, new flooring, a multipurpose center, and a larger fitness center. These changes are intentionally separable so that they can be implemented according to the funding available. Most importantly, they are compatible with PERA's goals of increased participation at all levels of recreation at Wellesley College.

Introduction

The Keohane Sports Center accommodates a variety of athletes and recreational users, but the community's needs are not fully met by the physical space as is. The KSC is home to an eight-lane 25-yard pool, a 200-meter indoor track in the field house, six squash courts, three racquetball courts, two weight rooms, two dance studios, an auxiliary gymnasium, an athletic trainers facility, one classroom, and administrative offices.

We surveyed the Wellesley student body, student organizations, Keohane administrative staff, and varsity coaches to ascertain the major concerns about the Sports Center. These multi-perspective survey responses provided helpful insight to inform the priorities about changes to the physical space. Several common themes emerged regarding major modifications to the design, sustainability, and modernization of the fitness center. Based on responses from these students, faculty and staff, we formulated several priorities for modifying the physical space of the KSC including (i) to provide adequate and appropriate space for all users, (ii) to sustainably upgrade the flooring of the KSC, and (iii) to expand and modernize weight-lifting and fitness facilities.

By implementing these design and modification recommendations to the KSC, Wellesley College will join the ranks of many other colleges in prioritizing the physical, social, and environmental health of all students. A well-planned, sustainable, state-of-the-art fitness center will better serve Wellesley's 13 varsity teams, numerous club programs, and recreational users, and it will fulfill many of PERA's goals regarding student athletic involvement.

Space Needs

The Wellesley College PERA program endeavors to support all students who participate on varsity teams, club sports, and recreation programs by providing adequate facility hours, fitness space, and sports equipment. Varsity sports and student organizations are vital facets of student life at Wellesley and are directly correlated to students' mental and physical health.[14] These extracurricular programs are valuable to many people and provide means of expression, exercise, art, entertainment and stress reduction. Renovations to the Sports Center to accommodate these shared values will increase participation in sports and extracurricular activities and would help to further develop the goals of PERA.

Limited space in the Keohane Sports Center creates conflicts between the varsity teams and many student organizations that require specific facilities for practice and events. Student organizations must compete for time and space and consequently, many organizations are forced into marginal areas at undesirable times. For example, some groups find the only time they can hold practices is from 10:00 to 11:00 at night.

[14] See, for example Daniel M. Landers, "The Influence of Exercise on Mental Health." Available through the US Department of Health and Human Services. Available at http://www.fitness.gov/mentalhealth.htm Accessed May 2, 2009.

Student Organizations

To better assess their needs, we gathered information about the space needs of the various student organizations on campus, as illustrated below.

Figure 1. Student Organization Space Needs

Organization	Frequency	Space
Freestyle	8-15 hrs/week	Dance Studio
Dance Collective	4-5 hrs/week	Dance Studio
Ultimate Frisbee	2 hrs/week	Field House
Cielito Lindo	2-7 hrs/week	Dance Studio
Martial Arts Club	1-2 practices/week	Dance Studio
Ballroom Dance Team	1 practice/week	Dance Studio
Badminton	2 hrs/week	Multi-Purpose Gym
Belly Dancing Society	2 hrs/week	Flexible
GLOW	2 hrs/week	Racquetball Courts
Rugby	Seasonal - 6 hrs/week	Multi-Purpose Gym, Weight Room
Ethos	Occasional	Field House
Belly Dancing Society	2 hrs/week	Dance Studio
Ice Hockey	4 times/year	Flexible
WASAC	Seasonal	Dance Studio
LEAP	2 days/week	Flexible

As an example of space and time conflicts, the dance group Freestyle requires 8-15 hours a week in the dance studios, but has been seen practicing late at night in the lower level of the parking garage in lieu of studio space. Many of Wellesley's student organizations require dance space, but the two dance studios in the KSC have antiquated flooring and do not provide enough space for all users. It is notable that many non-dance organizations use the dance studios because there is no other multipurpose space available, putting a strain on groups that specifically require dance space with mirrors and appropriate flooring.

Recreational and PE Users

The KSC provides sports equipment for rent at the front desk to recreational users and physical education students. The equipment rental data collected from January through March 2009 is displayed below. Students borrow a variety of equipment from the front desk, and the most popular during this time period were basketball, racquetball, and tennis accoutrements. These were due in part to racquetball and tennis P.E. classes during this term.

Figure 2. Visitor Equipment Use

Equipment	Use Rate
Badminton	75
Basketball	166
Dodgeball	21
Jump Rope	9
Pool Table	5
Racquetball	209
Rugby	1
Sleeping Bag	1
Soccer Ball	41
Squash	54
Stopwatch	9
Tennis	307
Volleyball	9

Varsity Athletics

Wellesley is home to thirteen varsity sports. Many seasons overlap, and during the winter months many teams vie for indoor space to run, throw, and do other conditioning. A temporary court is installed during basketball season, costing the College time and resources. The volleyball team practices on the second floor multipurpose gym which has antiquated wood flooring. Both teams suffer a lack of spectator seating and inappropriate flooring, preventing them from hosting NCAA tournaments.

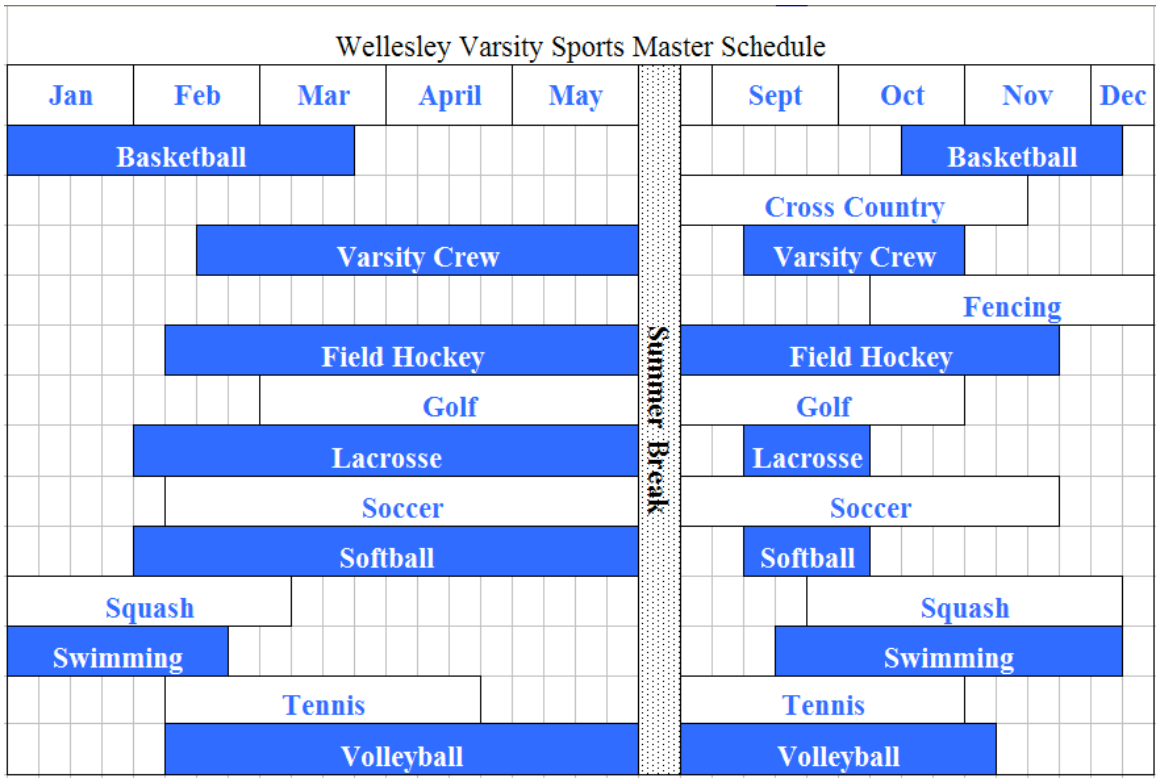

Figure 3. Wellesley Varsity Seasons Master Schedule

Recommendations

Field House

Although the field house is a large space, its inefficient design detracts from its usability. Our main goal in renovating the field house is to create access to as much of the floor space as possible. Currently, the 200-meter indoor track takes up much of the area, limiting the space for tennis, basketball, and volleyball courts, as well as indoor practice space for many varsity teams. As mentioned, a temporary basketball court is put down for the season, which is both expensive and inefficient. Fifteen to twenty cardio machines are housed in the northeast corner, creating a cramped workout space. Physical education classes also currently use the field house, but in our recommendations alternate space will be allocated for them on the second floor.

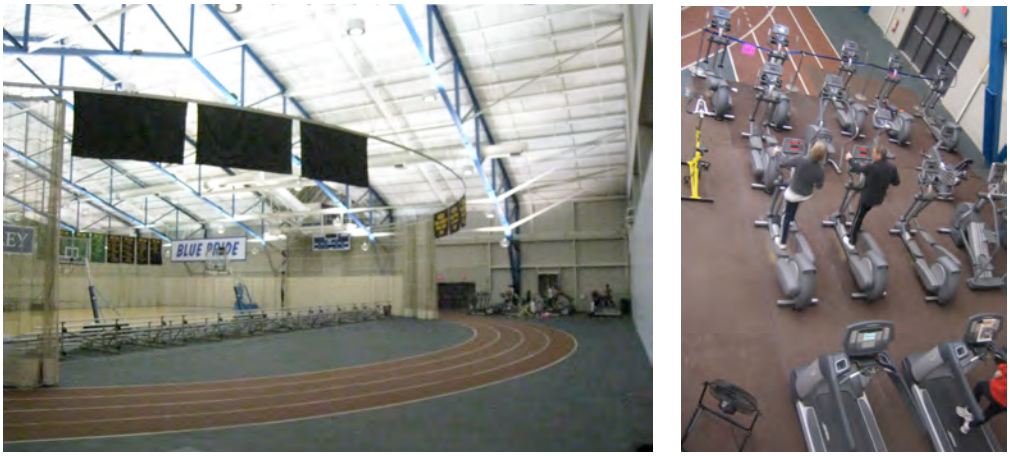

Figure 4. KSC Field House and Cardio Machines

The installation of a 200 meter cantilevered elevated track would leave the entire square footage (49,995 ft^2) of the field house for varsity teams. At the west end permanent basketball and volleyball courts can be installed in the new space, as well as a significant number of permanent bleachers. In our proposal the adjoining area consists of a space for team benches. In the east half of the field house, multipurpose flooring should be installed that would provide the other varsity sports with indoor practice space. This area would be particularly useful to sports teams, PE classes and recreational users that require a large space in which to practice.

Figure 5. Babson College Indoor 200 meter cantilevered track

The Sport Court® company[15] offers many different types of flooring suitable for multi-purpose use as well as for team-specific use.[16] The entire field house could be floored with their "Response" flooring, as it is NCAA certified for volleyball courts, and recommended for basketball and tennis courts.

[15] "Sport Court: Basketball indoor courts": http://www.sportcourt.com/find_by_sport-basketball-indoor.php. Accessed May 2, 2009.
[16] This flooring system was recommended by Martha Dietrick via personal communication on February 11, 2009

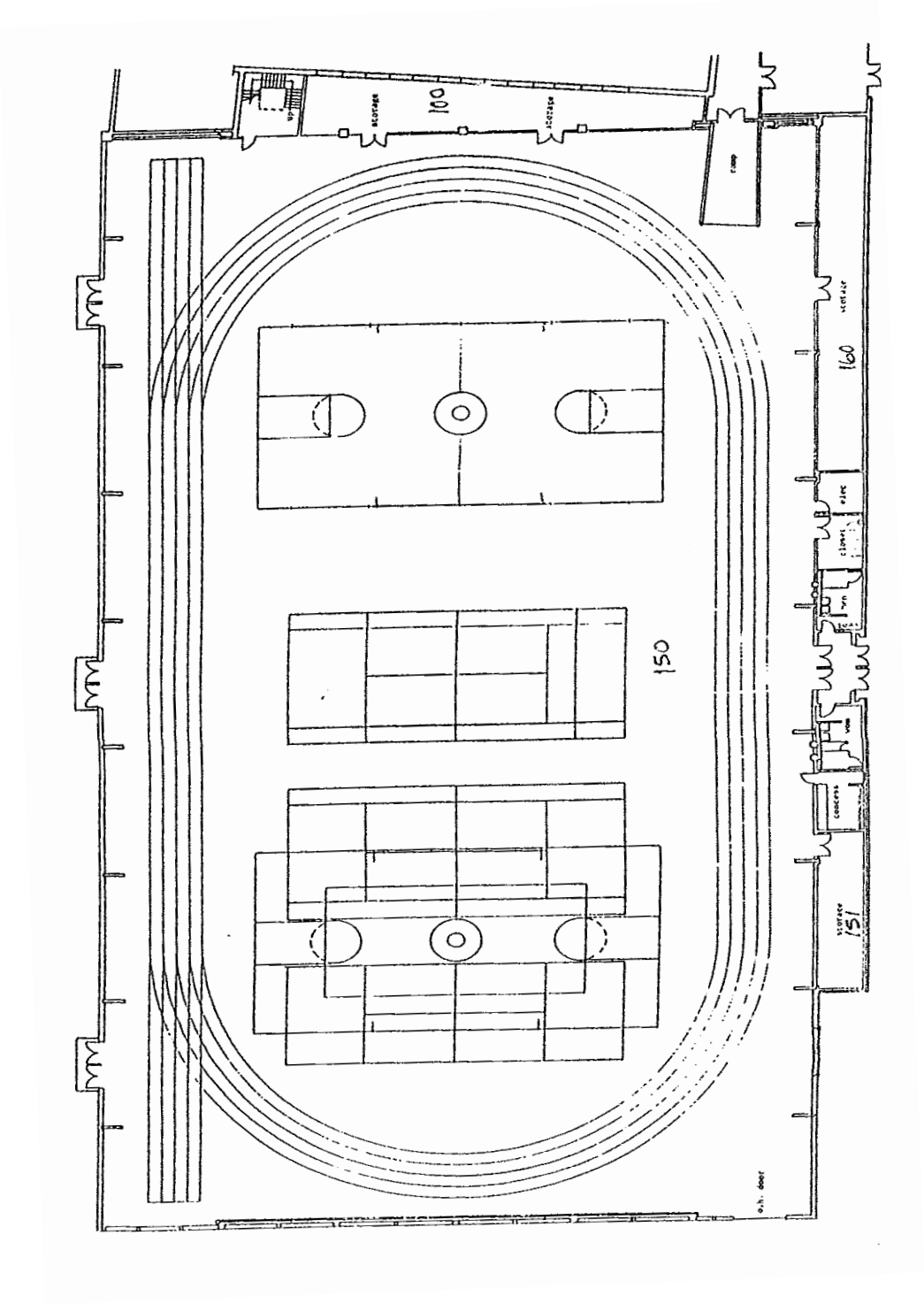

Figure 6. Current KSC Field House

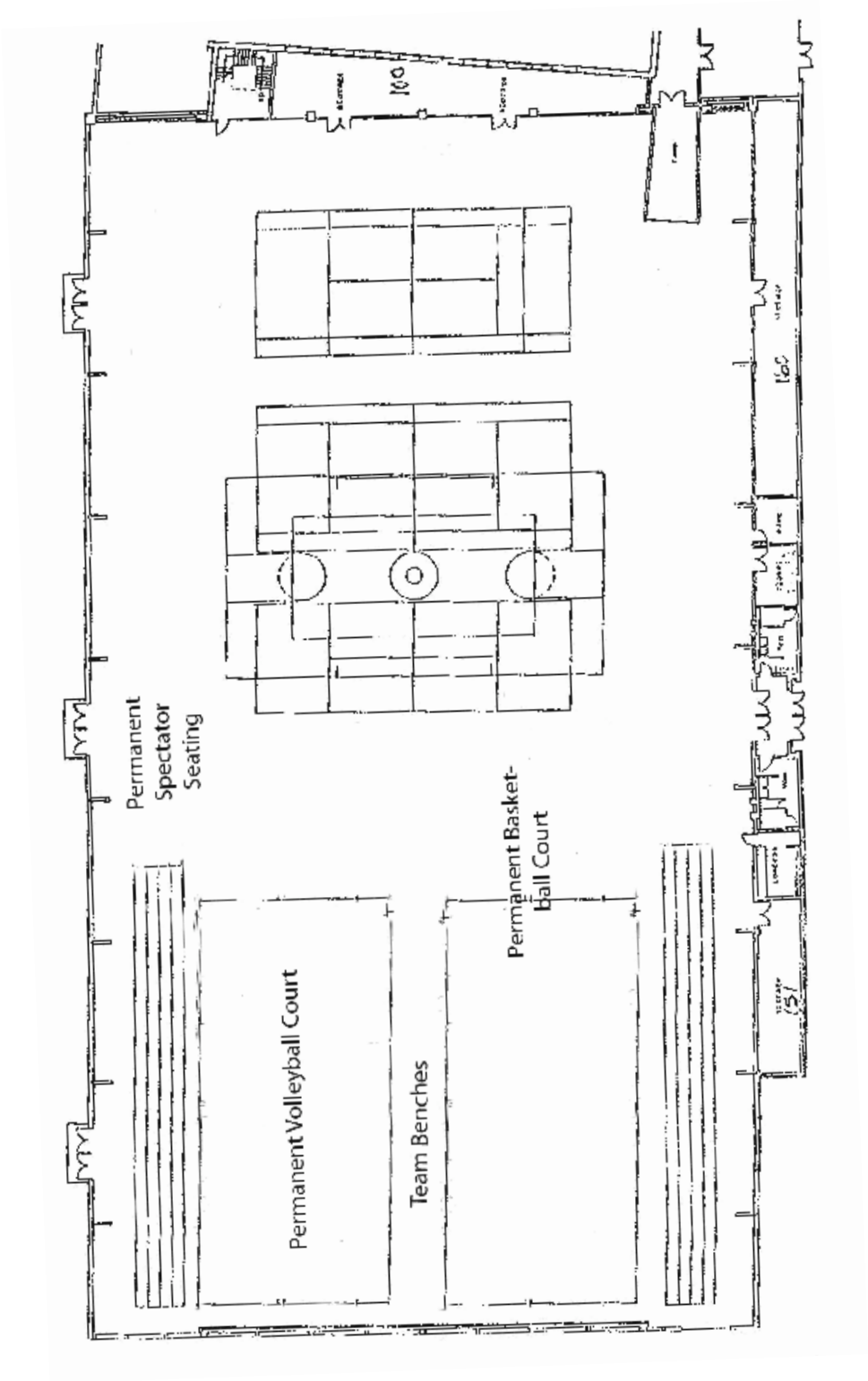

Figure 7. KSC Field House Recommendations

First Floor

At present, the front desk is located across from the entrance to the KSC. Re-locating the desk to directly to the right of the doors would greatly improve the KSC's appearance as well as help to better guide visitors to their destination. Moving the front desk area will create room for a visiting team locker room. The front desk could also then focus solely on providing rental equipment and administrative tasks such as signing in visitors, while the vending machine area could become a room devoted to the organization and storage of uniforms. Another major change we recommend is the replacement of the three racquetball and two squash courts with a cardio and weight lifting center. These changes will be described in more detail in the following pages.

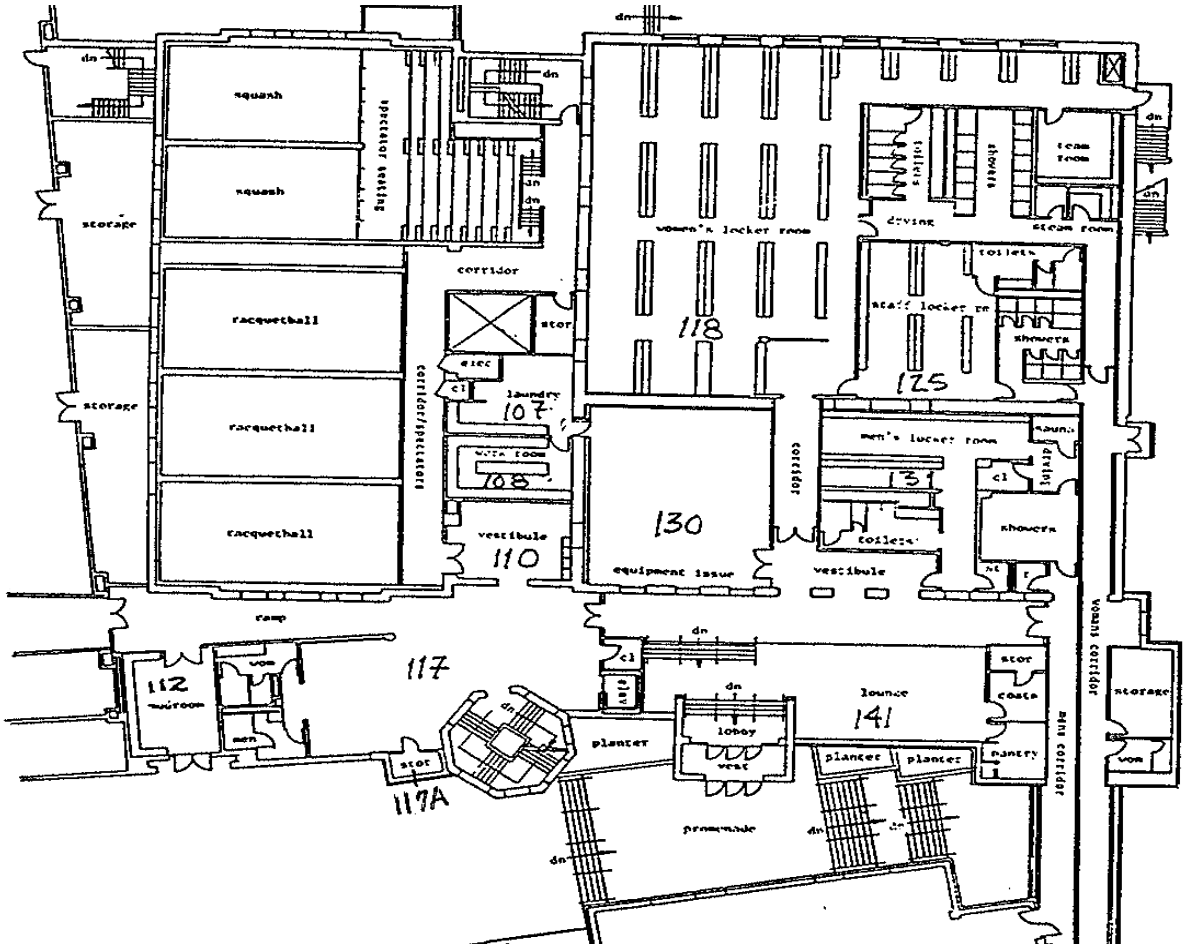

Figure 8. Current KSC First Floor

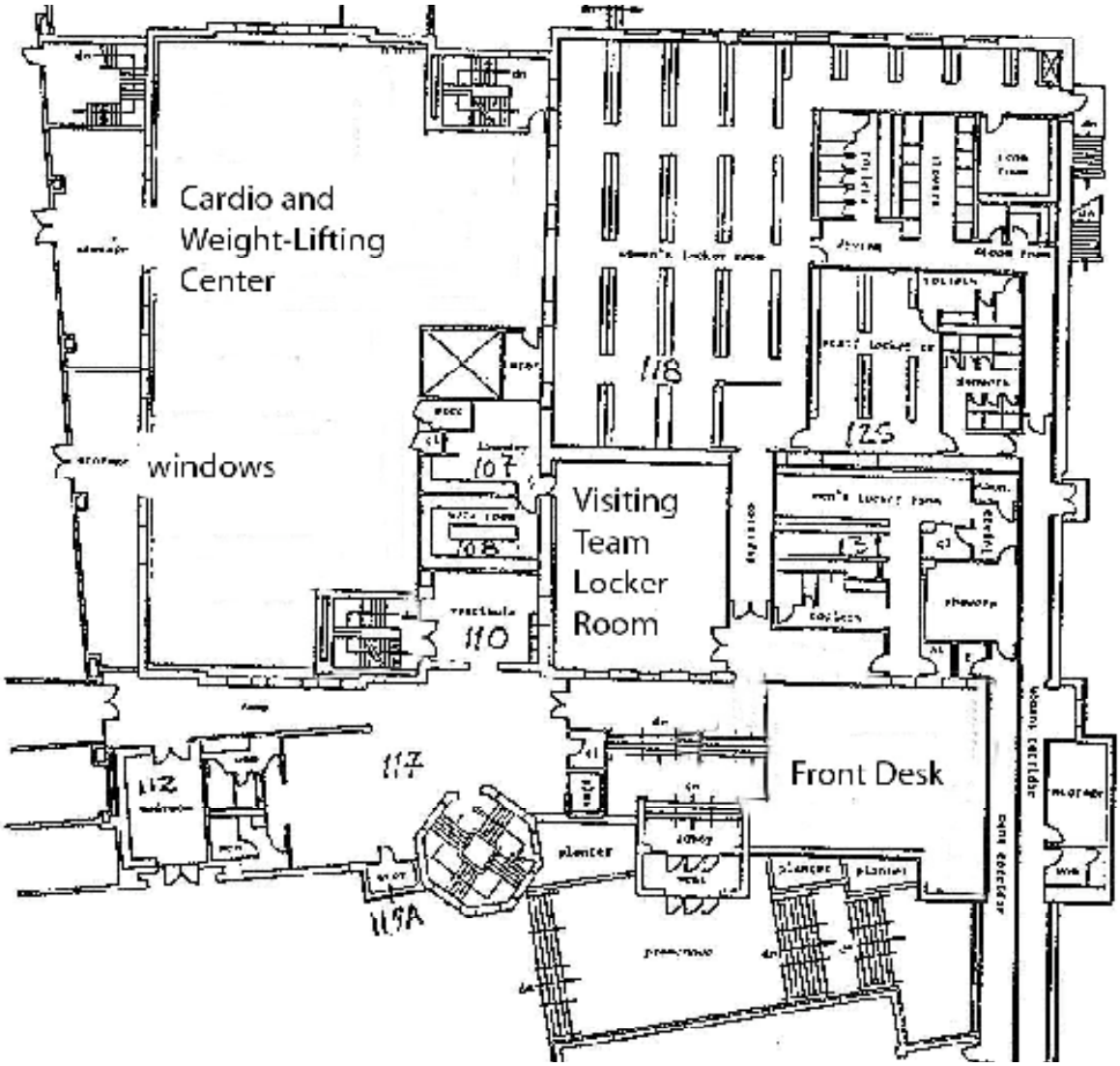

Figure 9. KSC First Floor Recommendations

Basement

The KSC currently has six squash courts and three racquetball courts accessible from the basement level. None of the squash courts are regulation size, and Wellesley has not been able to host other teams for competition. This would be the first priority in renovating the courts. The courts are roughly 31.2'x20. 5' and would only need to be adjusted to 32'x 21'. We suggest removing the walls between the racquetball courts as well as the two squash courts, which would create a large multi-purpose workout room in which all of the cardiovascular and weight lifting equipment could be placed. The four remaining squash courts could be modified to NCAA requirements, and benches in between the sets of two courts could be installed for spectators.

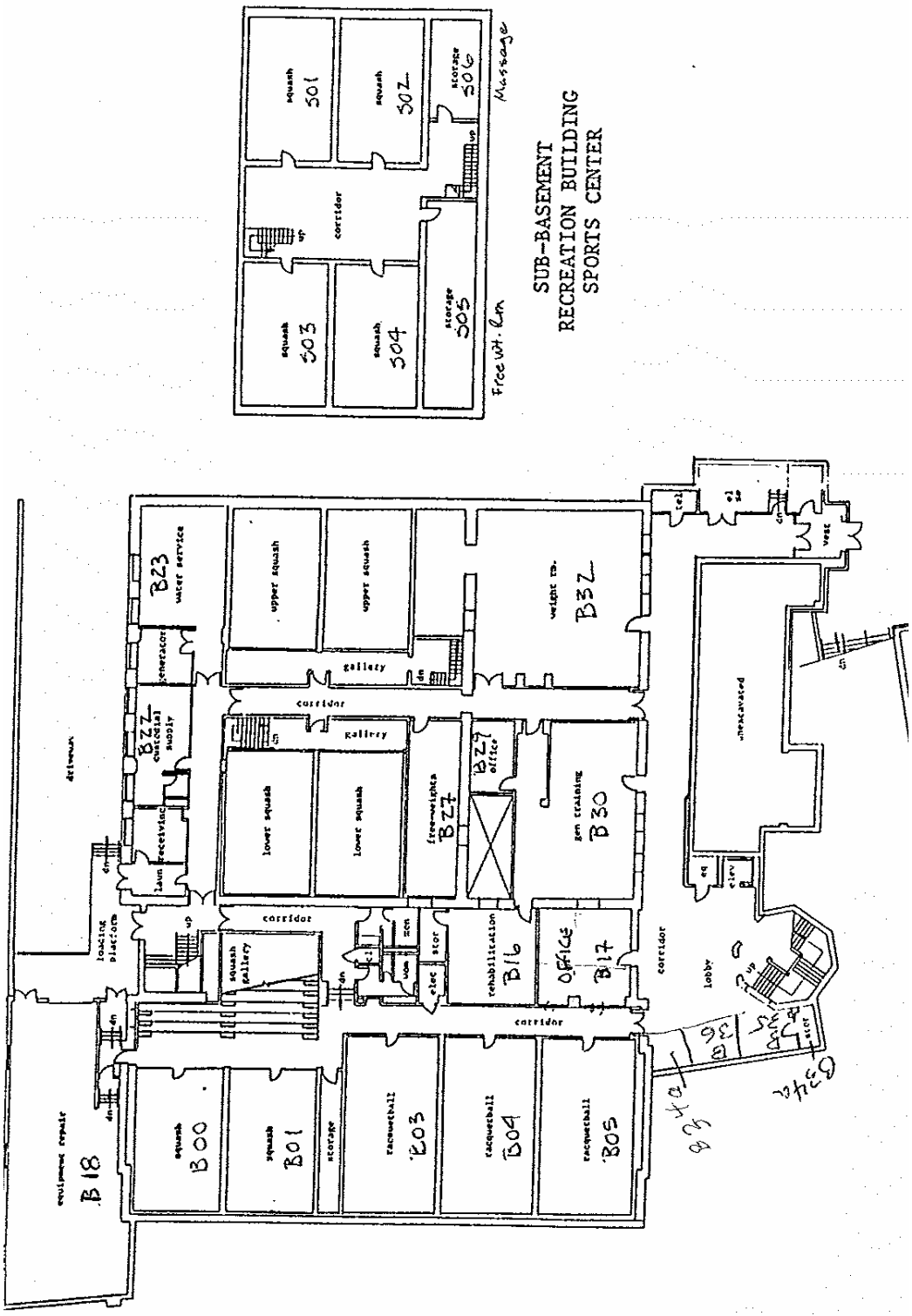

Figure 10. Current KSC Basement and Sub-Basement

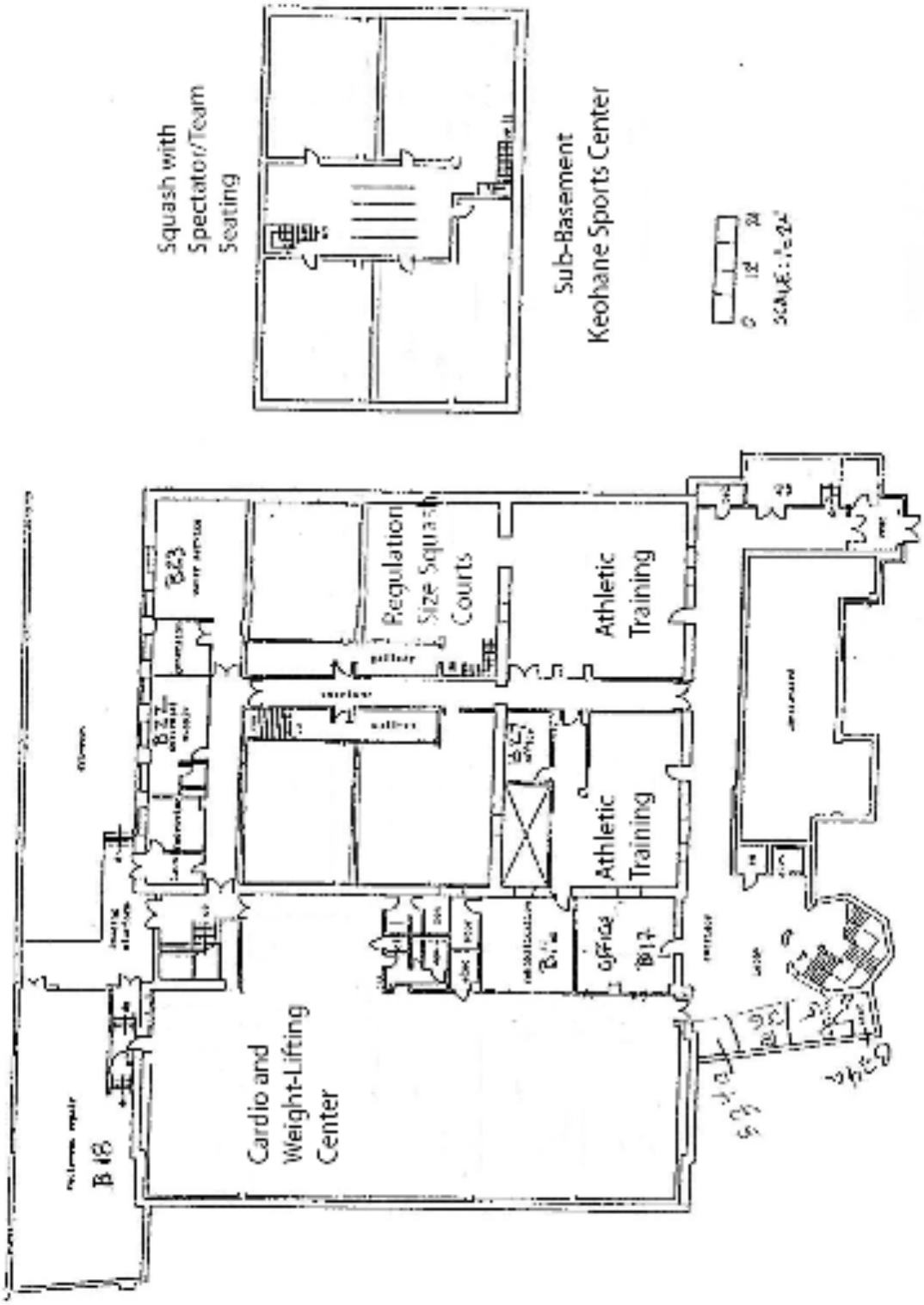

Figure 11. KSC Basement and Sub-Basement Recommendations

The weightlifting equipment currently occupies three rooms in the basement levels of the KSC. Students and staff are concerned about both the number and location of the weightlifting machines—it is frustrating to have the cardiovascular machines so far away from the weight room. Modifying two of the six squash courts as well as the three racquetball courts into one larger fitness center will eliminate these spatial problems, and create a better community environment for fitness.

Figure 12. KSC Weight Room

The athletic trainers are located on the basement level of the KSC. Their primary concern is the lack of space in which to both treat athletes' injuries, as well as for offices. Converting the existing weight room into either more space for treatment or for administrative purposes will ameliorate these problems. Space for more in-depth physical rehabilitation could also be established.

Second Floor

Space—or the lack thereof—is a dominant concern among the student body in regards to dance studios and multi-purpose space. Because our recommendations include moving the permanent volleyball space to the field house, the large multi-purpose gym on the second floor would become available for other uses. Physical Education classes and many other student organizations would be able to use this space, leaving the two dance studios primarily for use by Wellesley's many dance groups.

The current flooring in the two second-floor dance studios is both too hard and too slick for dancers to safely practice. Student responses showed a strong demand for new flooring in the dance studios. An all-purpose type of Marley flooring is best suited for installation in these two rooms. This type of flooring can be easily installed and will accommodate all dance types – from Irish step-dancing to hip-hop break-dancing. Marley flooring provides cushioning and support, as well as gripping stability for ballet pointe work. Marley flooring can also either be a permanent or temporary (depending on the model) installation over the existing flooring. Please see Appendix A for more information on flooring options.

Conclusions

In addition to our commitment to consider space, flooring, and fitness center concerns as expressed by members of the Wellesley Community, our underlying goal in assessing the physical space of the KSC was to make the recommendations separable. Our changes can be implemented piecemeal, with associated benefits to student organizations and sports teams.

It is also necessary to mention several assumptions we have made. Our collective expertise lies in environmental studies rather than architecture, and design recommendations are made with this handicap. Where possible, we have ensured that walls that we recommend be moved are not structurally load-bearing, but we are not certain of all the physical constraints of making major structural changes in the building. Similarly, we have made few attempts to calculate the costs associated with our physical space section. With these assumptions in mind, we hope that our suggestions will be taken as a holistic approach to better using the Sports Center; even if only a small number of our recommendations is implemented the community will be better served in working towards an active lifestyle.

III. ENERGY

Summary

Energy used by the Keohane Sports Center is currently generated by the on-campus cogeneration plant, which runs on natural gas and oil. Because of the negative environmental impacts of burning fossil fuels, we assessed four alternative methods of energy generation for the KSC: wind power, solar photovoltaics, human-powered exercise equipment, and geothermal power. We recommend a combination of these technologies for use in the Sports Center, including solar photovoltaic roof panels, a medium-sized wind turbine, and human-powered elliptical machines. Using a combination of alternatives in the Sports Center will enable a greater proportion of the KSC's energy to be generated renewably, especially as energy efficiency measures are implemented.

1. Energy Generation at Wellesley

Energy for supplying electricity and thermal regulation to the Wellesley College campus—including the Keohane Sports Center—is centrally managed by the college Physical Plant. Although the quantity of energy used may differ between campus buildings, the profile of fuels used to produce this energy is consistent campus-wide.

On-Campus Electricity and Heat Co-Generation

The majority of campus energy is supplied by an on-site co-generation plant that was built in 1994. This plant recycles waste heat produced during electricity generation for campus heating and cooling needs. Reciprocating engines generate electricity from natural gas. Waste heat generated during this process is redirected to the boilers and absorption chillers. Within the boilers, this heat energy vaporizes water and the resulting steam is used to heat campus buildings. Within the chillers, waste heat is used to regenerate air conditioning refrigerant so that it can be recycled within the AC system. Between 1991 and 2008, Wellesley College's electricity demand increased by 27% to 28 million kWh.

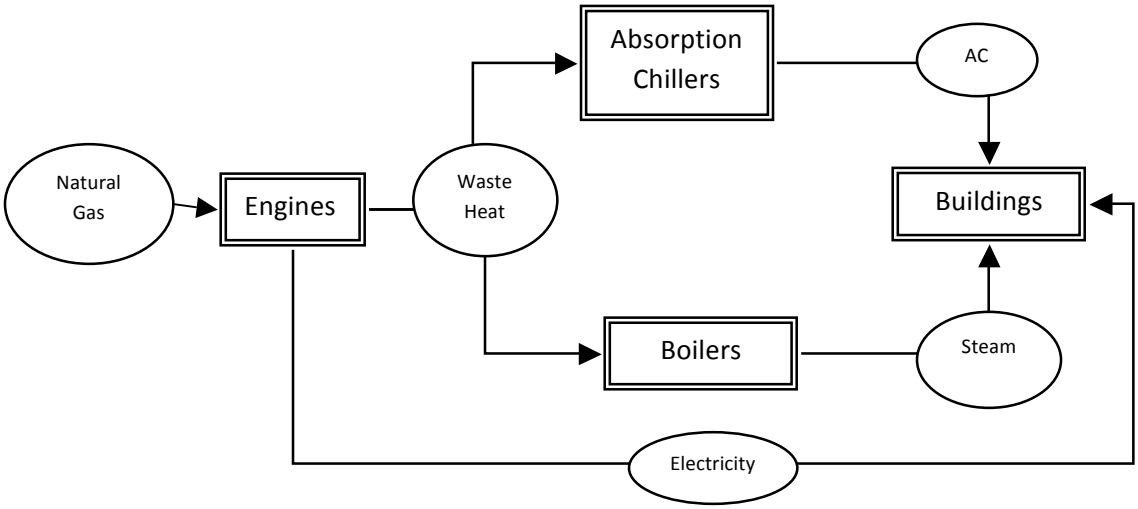

Figure 13. Schematic of co-generation plant operation

Supplemental Heating from Additional Fuel Combustion

When waste heat alone is not enough to meet campus demand, more heat is generated by running the boilers directly off of natural gas or #6 oil. Between 1990 and 2008, the amount of additional energy that Wellesley College required for this purpose fluctuated between 180,000 and 240,000 MMBtu annually, depending on factors such as seasonal temperature and College population.

Natural gas and #6 oil have different climate change impacts. Natural gas produces 0.06 $tCO_2eq/MMBtu$ while #6 oil produces 0.08 $tCO_2eq/MMBtu$.[17] Although the proportion of these fuels used to produce supplemental heat at the co-generation plant varies from year to year, the average annual greenhouse gas emissions associated with this activity equate to 13,993 tCO_2eq/a.

Keohane Sports Center Energy Demand

The Keohane Sports Center draws its energy from the Wellesley College central energy pool. Currently, the Sports Center does not have an air conditioning system. Therefore, its energy requirements are currently limited to electricity and heating. Evaluating the KSC's energy usage is difficult in the absence of complete building inventories and electricity meter readings. Although the energy usage per square foot of Wellesley campus building space is known, its electricity usage may be more than other buildings due to its pool pump, pool filter, flood lights, washing/drying machines, and exercise machines. Similarly, due to its large internal volume and heated pool, the KSC may require more heat energy than most campus buildings. These factors are likely to outweigh the Sports Center's lack of air conditioning, computers and hours of operation in determining its energy usage scenario. Keeping these factors in mind, we used two methods to estimate the Sports Center energy usage: a top-down and a bottom-up estimate.

Top-Down Estimate of Sports Center Energy Usage

For our top-down estimate of Sports Center energy usage, we determined how much energy the facility would use if its energy consumption per square foot were equal to the average energy consumption per square foot of Wellesley College building space. This estimate accounts for the size of the Sports Center, but assumes that its electronic facilities and heating needs are comparable to those of academic and residential campus buildings.

In 2008, Wellesley College consumed 28 million kWh of electricity. If we assume that every square foot of building space demands the same amount of electricity annually, we can divide the College's total electricity usage by the fraction of college building space represented by the Sports Center in order to determine the electricity requirement of the Sports Center (Appendix B). This yields 1,740,710 kWh as the electricity consumption of the Sports Center during the 2008 calendar year.

In 2008, Wellesley College consumed 232,080 MMBtu in order to heat its 2,543,100 ft^2 of campus building space. Making the same assumptions as above, we calculate that the Sports Center consumed 4,227,404 kWh of heat energy during the 2008 calendar year (Appendix B).

Combining these two values yields a top-down estimate of the Sports Center's total energy consumption equal to **5,968,114 kWh/a**. This value is likely to be an underestimate because it assumes that

[17] Unit Conversions, Emission Factors, and other Reference Data. US Environmental Protection Agency. 2004. http://www.epa.gov/appdstar/pdf/brochure.pdf Accessed February 2009.

all buildings on campus have equal energy consumption per square foot whereas the Sports Center's high ceilings, pool heating, and electricity intensive equipment are likely to result in a higher than average energy consumption per square foot.

Bottom-Up Estimate of Sports Center Energy Usage

We also undertook a bottom-up estimate of Sports Center energy usage to determine how much energy the KSC uses based on its specific electronic facilities and heating needs. This estimate accounts for the KSC's size and specific operations, but is still susceptible to inaccuracies. These inaccuracies are primarily due to an incomplete study inventory necessitated by inaccessible building records.

We took a rough inventory of Sports Center electrical appliances including the model and exact kW energy usage of lights, pool filters, and washing machines (listed in Appendix B). We estimated the energy consumption of other appliances based on literature values for comparable appliances. Yet this inventory is not complete and represents an underestimate of the actual electricity consumption of the Sports Center.

Space heating was again estimated using the equations in Appendix B. In addition to space heating, the KSC requires additional heat for two dry saunas and a 400,000 gallon pool. Literature values were used to compute the energy usage of the dry saunas and the energy required to maintain the heat of water were in order to derive the energy input required for pool heating. Because these values do not incorporate the heat up period, they represent an underestimation of the actual energy required to heat the pool.

Combining these values yields **5,423,891 kWh/a** as a bottom-up estimate of Keohane Sports Center Energy Use.

Conclusion

Both the top-down and the bottom-up approach are underestimates of the KSC's energy consumption. The top-down approach does not account for pool heating, electricity intensive equipment, or vaulted ceilings. The bottom-up approach underestimates the electricity usage and the energy needed to heat the pool. Therefore, in order to minimize error, we use the higher of the two estimates for our future energy calculations, that arrived at through top-down estimation: 5,968,114 kWh per year. In the following sections, we present the non-fossil fuel burning alternatives we considered: photovoltaics, wind, geothermal and human power. For each of these alternatives, we calculate the percentage of KSC energy use that each would contribute based on the top-down estimate.

2. Solar Photovoltaics

Summary

Solar power is becoming an increasingly valuable source of alternative energy generation. Photovoltaic (PV) technologies convert solar power into electrical energy using semiconductor materials such as silicon.[18] This report compares three potential photovoltaic alternatives for the Keohane Sports Center including roof mounted silicon flat panels, thin film flat panels, and window thin film panels. All three systems are comparable with regard to operation, maintenance, and end-of-life costs. A roof mounted silicon flat panel system costs the most overall, while the window photovoltaic panels are the least expensive option. Although the window photovoltaic panels have the lowest acquisition and installation costs, roof mounted thin film flat panels have the highest rate of energy payback, making them the most cost-effective option for installation on the Sports Center.

Introduction

Photovoltaic (PV) technologies harness the sun's energy and convert it into electricity via the photoelectric effect. When sunlight strikes a solar cell, an anti-reflective coating minimizes reflection and maximizes light transmission to the semiconductors inside the cell. These materials absorb photons of light and release electrons of corresponding energy. The resulting electrons are channeled across a potential stream created by the cell's semiconductor materials, generating a direct electrical current. This direct current is then converted to alternating current (AC) prior to entering an electrical grid or connecting to common appliances.

Photovoltaic systems have minmimal negative impacts on the environment, making them one of the cleanest electrical generating technologies available. During operation, they produce no noise pollution, air pollution or hazardous waste and do not require any liquid or gaseous fuels to be transported or combusted to sustain their operation.[19] Photovoltaic cells are extremely durable with long lifetimes, often capable of remaining operational for up to 30 years.[20] They are also extremely versatile energy options. Supplementary modules can be added at any time to increase maximum outputs. In addition, simple alterations of the circuit design (parallel versus series) can be employed to affect small adjustments in current and voltage output as necessary.

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[18] U.S. Department of Energy, "Solar Energy Technologies Program: PV Physics," http://www1.eere.energy.gov/solar/pv_physics.html. Accessed March 8, 2009.
[19] U.S. Department of Energy, "Why PV is Important to the Environment," http://www1.eere.energy.gov/solar/to_environment.html. Accessed March 14, 2009.
[20] National Renewable Energy Laboratory, "PV FAQs," http://www.nrel.gov/docs/fy04osti/35489.pdf. Accessed April 1, 2009.

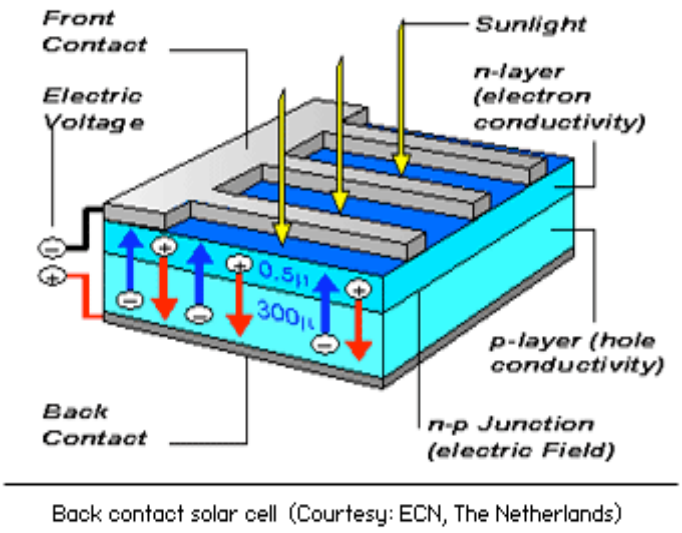

Figure 14. Diagram of Solar Photovoltaics[21]

Available Technologies

Single versus Multi-junction Cells

Traditional single-junction crystalline silicon PVC only generates electricity when struck by light of exactly the right energy to induce electrons to transition across their single band-gap. Multi-junction PVC uses layers of semiconductor junctions to affect multiple band gaps with different barrier energies, allowing cells to generate electricity across a wide range of light energies. Examples of multi-junction cells include gallium arsenide, amorphous silicon, copper indium diselenide, and gallium indium phosphide semiconductor cells. Both single and multi-junction cells are available in both a bulk variety and a thin film variety.

[21] European Commission, "Introduction to Photovoltaics," http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_pv/article_1105_en.htm. Accessed March 8, 2009.

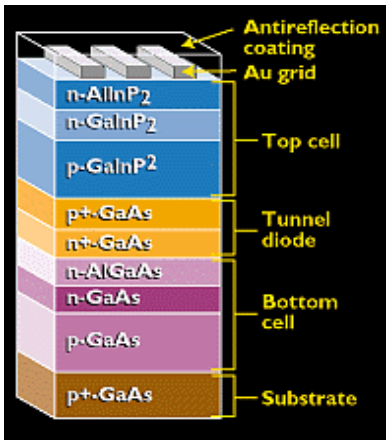

Figure 15. Artist rendition of a multi-junction cell[22]

Bulk versus Thin Film

Traditional bulk or silicon-wafers are inflexible, heavy, and expensive to manufacture but generally have high watt-to-watt energy conversion between sunlight and electricity. In contrast, thin film PVCs are less efficient at utilizing wavelengths of light longer than the visible range, reducing their overall energy efficiency relative to bulk cells. The benefits of installing thin film photvoltaics are that they are less expensive, more versatile and, due to their flexibility, can be fitted to roofs, windows, and curtains.

Solar Windows and Photovoelectric Dyes

Both opaque and translucent photovoltaic windows are also commercially available. Opaque systems are made from traditional semiconductor materials and have higher energy efficiency. Translucent systems employ solar dyes. Translucent systems are less efficient but can be used in tandem with other solar films and allow sunlight into the building at user defined wavelengths.

Photovoltaics at Wellesley College

The performance of a photovoltaic system depends on the availability of light and climate conditions.[23] The figure below illustrates the relative suitability of photovoltaic projects, by state, the price of

[22] NASA, "How do Solar Photovoltaics Work?," http://science.nasa.gov/headlines/y2002/solarcells.htm. Accessed March 9, 2009.
[23] U.S. Department of Energy, "Solar Energy Technologies Program: PV Physics," http://www1.eere.energy.gov/solar/pv_physics.html. Accessed March 9, 2009.

electricity, sunlight availability, and government programs.[24] Due to its geographic location, Wellesley College is highly suitable for photovoltaic projects.

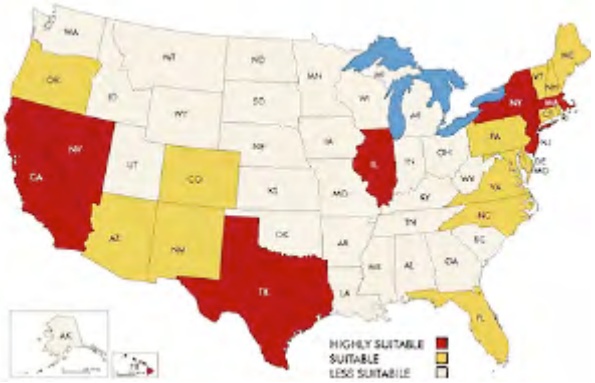

Figure 16. Map illustrating suitability of photovoltaic project by state[4]

Using photovoltaic technologies on the Wellesley College campus would have many benefits. Several elite colleges in the country have incorporated photovoltaics as a form of alternative energy generation. Harvard University began using renewable energy in 2003, with the installation of photovoltaic panels on the roof of the Harvard Business School's fitness center.[25] In 2000, Oberlin College completed the Adam Joseph Lewis Center for Environmental Studies which has 434 square meters of photovoltaic, mono-crystalline silicon cells on the roof.[26] In 2007, Massachusetts Institute of Technology (MIT) installed photovoltaic cells on top of its the alumni pool building.[27] Installing photovoltaics would allow the Wellesley College to become one of the leaders of liberal arts colleges on environmental stewardship and would reduce its environmental footprint, while stimulating educational interest for sustainable energy on college campuses and in the community.

Alternatives

This report details three alternatives for Wellesley College to incorporate photovoltaics into the KSC. We examine roof mounted bulk silicon flat panels, thin film flat panels, and thin film window panels. The individual unit specifications for these alternatives are given in Appendix C.

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[24] K-State Department of Architectural Engineering & Construction Science, "Photovoltaic Roof Systems," GreenbuildTech Bulletin, http://files.bnpmedia.com/EDC/Protected/Files/PDF/2006_01-GBTB-pvroofsystems.pdf . Accessed March 10, 2009.
[25] Harvard Business School. "Harvard Business School Installs Solar Panels on Fitness Center Roof." Press Release. October 21, 2003. http://www.hbs.edu/news/releases/102103_solar_panels.html Accessed March 2009.
[26] Oberlin Alumnae Magazine. "The Environment and Oberlin: An Update." Summer, 2002. Vol. 98 No. 1. http://www.oberlin.edu/alummag/oamcurrent/oam_summer2002/feat_enviro.htm. Accessed March, 2009
[27] Massachusetts Technology Collaborative. "Massachusetts Institute of Technology." http://www.masstech.org/project_detail.cfm?ProjSeq=821. Accessed March, 2009.

Alternative 1: Roof Mounted Silicon Flat Panels

Flat panel roof systems can be made of either traditional silicon cells or thin film silicon cells. The majority of photovoltaic production is dominated by single-junction solar cells based on silicon wafers including multi-crystalline silicon (mc-Si) and single crystal (c-Si) silicon.[28] Single crystal silicon is a highly efficient semi-conductor material capable of converting up to 23% of incoming solar energy into electricity (Figure 5).[29] These types of single-junction, silicon-wafer devices are now commonly referred to as the first-generation (1G) technology.

The Sports Center's 19,620 ft² field house roof[30] should be able to accommodate approximately 2,802 roof mounted silicon flat panels. This number of panels combined would build a 238 kW system that would capable of generating an estimated 256,825.8 kWh per year. The initial cost of a system this size would be approximately $1,926,974 including both acquisition and installation costs.

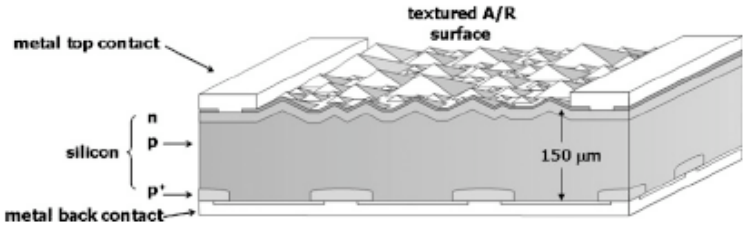

Figure 17. Schematic of a single-crystal solar cell[31]

Alternative 2: Roof Mounted Silicon Thin-film Panels

The thin film second-generation (2G) technology was invented as a low cost option to the predominant single-crystal silicon technology. Thin film modules are composed of either amorphous-Si (a-Si), CuIn (Ga)Se2 (CIGS), CdTe/CdS (CdTe), or polycrystalline-Si (p-Si).[32] Thin film elements are layered very thinly over a low-cost substrate like glass or steel. Using layers of silicon instead of a single-crystal silicon structure lowers the cost of thin film products. These cells typically have 5 to 10 layers on a substrate that total between 10 and 30 nm thick.[33] Copper indium gallium diselenide (CIGS) has demonstrated 19%

[28] U.S. Department of Energy. " PV Devices," http://www1.eere.energy.gov/solar/pv_devices.html. Accessed March 16, 2009.
[29] Neil Petchers, Combined Heating, Cooling & Power Handbook: Technologies & Applications An Integrated Approach to Energy Conservation. New York: Fairmont P, 2002.
[30] Pfister Energy, "Solar Project Description and Implementation Strategy," n.d. Accessed March 4, 2009.
[31] Bagnall, Darren M. & Matt Boreland. "Photovoltaic Technologies." Energy Policy, Vol. 36, Is. 12, Accessed December, 2009.
[32] M. Darren Bagnall & Matt Boreland, "Photovoltaic Technologies," Energy Policy, Vol. 36, Is. 12, Accessed December, 2009.
[33] S. Hegedus, "Thin Film Solar Technology: The Low Cost, High Throughput and Versatile Alternative to Si Wafers." Progress in Photovoltaics: Research and Applications. Vol. 14, Is. 5, Pp. 393 - 411. Accessed December, 2009.

efficiency in the laboratory, which propels it to the top of the thin film technologies.[34] Both traditional silicon and thin film flat panels can be positioned at fixed angles toward the sun (33° in Massachusetts) or mounted on moveable devices capable of tracking the sun, allowing them to maximize an array's exposure to direct sunlight.[35] Systems that are mounted in fixed locations or on two-axis tracking devices require a relatively small number of low-speed moveable parts, keeping operation and maintenance costs to a minimum.

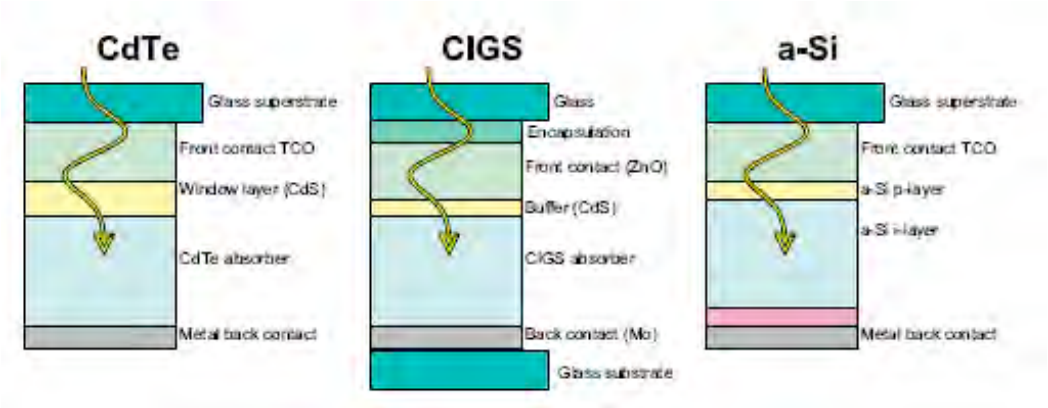

Figure 18. Schematic diagrams of thin-film CdTe, CIGS and a-Si thin-film PV devices[36]

A photovoltaic thin film flat panel system that covers the entire roof of the KSC field house would cost a total of $720,087. The cost of the system would be $546,493 for acquisition and $173,594 for installation. This system of 853 panels would generate 117,703 kWh of electricity annually for the sports center. The system would contribute 0.0028% of the Sports Center's energy needs and 6.31% of the sports center's total electricity usage of 1,864,911 kWh annually.

Alternative 3: PV Window Technologies

Solar PV windows can be used in place of glass windows in order to maximize the electricity generating surface area of a building. They are a low-cost and aesthetically pleasing option for renewable electricity generation. One of the core drawbacks of PV windows, however, is that, mounted vertically, they are unable to take advantage of the angle of solar irradiance and are considerably less energy efficient than roof mounted panels.[37] We examined opaque photovoltaic cell panels, covalent solar windows and

[34] Katherine Derbyshire, "New Technologies Promise Lower Costs, New Markets for Thin Film Photovoltaics," http://www.solid-state.com/display_article/291193/5/none/none/Dept/New-technologies-promise-lower-costs,-new-markets-for-thin-film-photovoltaic. Date Accessed: March 3, 2009.
[35] U.S. Department of Energy, "Guide to Tribal Energy Development: Solar Cells and Photovoltaic Arrays," http://www1.eere.energy.gov/tribalenergy/guide/pv_solar_cells.html. Date Accessed: March 16, 2009.
[36] Darren M. Bagnall & Matt Boreland, "Photovoltaic Technologies." Energy Policy, Vol. 36, Is. 12, Accessed December 2009.
[37] Harvard College, "Solar Glass Fact Sheet" http://green.harvard.edu/energy. Accessed March 15, 2009.

translucent solar glass. Due to the limited availability of the first two options, we further examine translucent solar glass windows.

Solar glass is composed of a translucent, hyper-thin PV film made from amorphous silicon.[38] This type of glass window allows users to control the amount of sunlight entering a building but is never fully transparent and should not be used where clear viewing is preferable.[39] The low thermal conductivity and lower general transmittance of solar glass windows has the advantage of enhancing thermal regulation (on par with contemporary window glazing) and can significantly reduce building heating and air conditioning needs.[40] An additional advantage of amorphous silicon panels is their ability to outperform crystalline panels at high temperatures.[41] A translucent PV window panel consists of 13 thin-film indium gallium phosphide layers and two protective glass panes.[19]

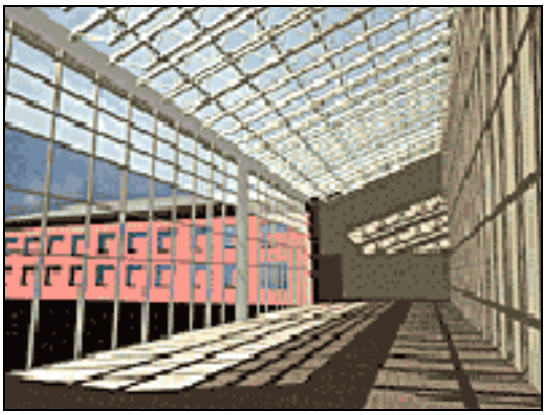

Figure 19. Translucent Solar Windows. University of Wisconsin Green Bay[42]

We estimated that the KSC has approximately 2,000 ft^2 of window space. Using this estimation, we estimated that the KSC would be able to accommodate 250 translucent solar window modules. This 10.75 kW system would allow the sports center to generate 11,589 kWh of solar electricity per annum (0.003% of total energy consumption and 0.6% of electricity consumption). The initial cost of this system would be $92,389 including both acquisition and installation costs.

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[38] J. Gutierrez Herrero et al., "Photovoltaic Windows by Chemical Bath Deposition." Thin Solid Films 361-362 (2000): 28-33. Accessed April, 2009.
[39] Energy Photovoltaics, Inc. Energy Photovoltaics Supplies Solar Windows to Microsoft's School of the Future," http://www.mseia.net/news_docs/9-11-06_epv(pr).pdf. Accessed March 4, 2009.
[40] University of Wisconsin, "Energy Features of Mary Ann Cofrin Hall," http://www.buildingsolar.com/design.asp. Accessed March 9, 2009.
[41] Solar Energy News, "RSI Announces First Transparent PV Window Solution," http://solarenergynewsandreview.blogspot.com/2008/12/rsi-announces-first-transparent-pv.html. Accessed March 19, 2009.
[42] Wisonsin Public Service Corporation, "Building Integrated Photovoltaics," http://www.buildingsolar.com/design.asp. Accessed March, 2009.

Life Cycle Analysis

Photovoltaic technologies are one of the most environmentally safe options available for generating power but cause some minor environmental impacts that should be noted.[43] Particulate matter can be released into the air from the extraction, crushing, ore beneficiation and transport of the elements that comprise thin film technology (mostly Zinc and its by-products). In addition, sulphur dioxide from the roasting process of Zinc can be released into the atmosphere, causing health and ecosystem problems.[44] Since Cadmium (used in the most efficient thin film technology, CIGS and also in CdTe) is toxic and carcinogenic, the method of its disposal is crucial.

Operation and Maintenance

Solar PVC options have minimal operation and maintenance costs but lose efficiency with prolonged exposure to UV light. The useful lifetime of silicon flat panels is approximately 30 years while that of thin films is 25 years.

End-Of Life Costs

The recycling of solar panels is complicated due to the decades-long interval between installation and removal, their low content of valuable material, and their geographic dispersion.[45] Photovoltaic products that are composed of soluble materials and are encased in glass or plastic are considered safe for landfills. Photovoltaic materials that need to be recycled can be collected and delivered to smelters for a total cost of approximately 4 to 5 ¢/W.[46]

Cost Analysis

The total costs of the systems described above are outlined in the figure below. Although window mounted solar PV panels have the lowest acquisition and installation costs, roof mounted thin film flat panels have the highest rate of energy payback largely due to the greater watt density per square foot achievable with this option.

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[43] Vasilis Fthenakis, et al., "Life Cycle Inventory Analysis of the Production of Metals Used in Photovoltaics," Renewable and Sustainable Energy Reviews 13 (2009), 493-517.
[44] Vasilis Fthenakis, Wenming Wang, & Hyung Chul Kim. "Life Cycle Inventory Analysis of the Production of Metals Used in Photovoltaics." Renewable and Sustainable Energy Reviews 13, 2009, 493-517.
[45] Brookhaven National Laboratory: Energy Sciences & Technology Department , "The Value and Feasibility of Proactive Recycling," http://www.bnl.gov/pv/abs/abs_142.asp. Accessed March 19, 2009.
[46] U.S Department of Energy, "Solar Energy Technologies Program: PV Panel Disposal and Recycling," http://www1.eere.energy.gov/solar/panel_disposal.html. Accessed March 16, 2009.

Figure 20. Overview of Total Costs and Outputs of Photovoltaics

Alternative #	Model/Identifier	Physical Size Specifications (ft2)	Electrical Output (kWs)	Estimated Annual Output (kWh/panel/a)	Initial Cost ($/panel)
1	Roof Mounted Silicon Flat Panels	7	0.085	91.63	449.00
2	Roof Mounted Thin Film Flat Panels	23	0.128	137.98	640.64
3	Window Thin Film Panels (MST-43-LV)	8	0.043	46.354	202.00

RECOMMENDATIONS

Wellesley College is located in an area that is highly suitable for photovoltaic projects and could benefit from their use to decrease its dependence on fossil fuels. Installing photovoltaics would also allow the College to reduce its environmental footprint by lessening its greenhouse gas emissions. In addition, these technologies could help spark interest in reducing energy usage on campus and in using renewable energy in the community.

While the roof mounted silicon flat panels are capable of generating more kilowatt-hours per year than the other options, they are also the most expensive option. If Wellesley chooses to pursue photovoltaic technologies, we recommend a roof mounted thin film flat panel system because of its high rate of energy payback. One of the primary benefits of installing photovoltaics is that each of the alternatives outlined in this report can be constructed to meet any size, and additional panels can be added at any point in time. This expansion capability will provide the College with flexibility in implementing photovoltaic projects now and in the future.

3. Wind

Summary

Wind power is an abundant and renewable energy source that carries a very low environmental cost. Wind turbines have been successfully incorporated into other college campuses, and would provide Wellesley College with environmental, educational, and social benefits. The drawbacks to wind power at Wellesley include the low local wind speeds and town zoning restrictions on structure height, from which the College would need an exemption in order to install most turbines. Here we examine six wind turbine models, ranging in size from 2.4 to 100 kW of instantaneous electrical output and built by five different manufacturers. Beyond the variation in energy output of the different models, they have many of the same accessory features and similar environmental impacts. The large turbine models are costly, but energy generation by most models will allow Wellesley to recoup the initial expense within the turbine's lifetime. After assessing the various options, we recommend ReDriven Power's 20 kW turbine for its relatively high power generation and short payback time.

Introduction

Wind power has emerged as the fastest growing source of electricity in the United States,[47] as concerns over rising energy prices and greenhouse gas emissions have shifted attention towards alternative forms of energy.[48] Wind energy is a particularly appealing way to generate electricity as it is essentially pollution-free.[49] It has been estimated that development of just 10% of the wind potential in the ten windiest states in the United States would provide more than enough energy to displace emissions from the nation's coal-fired power plants and eliminate the nations' major source of acid rain, reduce total United States emissions of carbon dioxide (CO_2) by 33% , and help contain the spread of asthma and other respiratory diseases caused by air pollution.[50] One third of the states in the United States have enough wind to generate electricity economically via wind, with some areas in other states windy enough to produce energy efficiently.[51]

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[47] Keith Johnson, "Wind Power: Subsidies Are Nice, But Strong Winds Are Nicer," Wall Street Journal, March 2, 2009, http://blogs.wsj.com/environmentalcapital/2009/03/02/wind-power-subsidies-are-nice-but-strong-winds-are-nicer/. Accessed April 27, 2009.
[48] J. Logan and S. Kaplan, "Wind Power in the United States: Technology, Economic, and Policy Issues," CRS Report for Congress, Congressional Research Service, June 20, 2008.
[49] American Wind Energy Association, "How Wind Works," http://www.awea.org/pubs/factsheets/HowWindWorks2003.pdf. Accessed April 27, 2009.
[50] American Wind Energy Association, "Wind Energy Basics," Wind Web Tutorial, http://www.awea.org/faq/wwt_basics.html. Accessed April 27, 2009.
[51] American Wind Energy Association, "Wind Energy Basics," Wind Web Tutorial, http://www.awea.org/faq/wwt_basics.html. Accessed April 27, 2009.

Wind is the movement of air masses along atmospheric pressure gradients.[52] The differential warming of the earth's atmosphere by the sun, variation in terrain, and the earth's rotation all contribute to the formation of pressure gradients and therefore wind.[53] Wind patterns can be local, as in sea and land breezes, or global, as in the Prevailing Westerlies of the mid-latitudes.[54] Wind power is one of the most environmentally friendly ways to generate energy, with relatively low life-cycle emissions of carbon and other air pollutants, and relatively small land and water use requirements as compared to other renewable and non-renewable energy sources.[55]

When wind turns the blades of a turbine, this movement turns gears inside the turbine housing. The smallest gears rotate fast enough that the generator can then create alternating current electricity.[56] Once current is generated, it can either flow directly into the utility grid or be converted into direct current and then back to alternating current at the grid frequency. The latter process allows the rotor to speed up or slow down its revolutions with changes in wind speed, taking advantage of the greater energy in strong gusts, but it also requires extra equipment.[57] If the wind speed gets too high, many turbines have an emergency brake on the rotor to prevent damage to the turbine.[58]

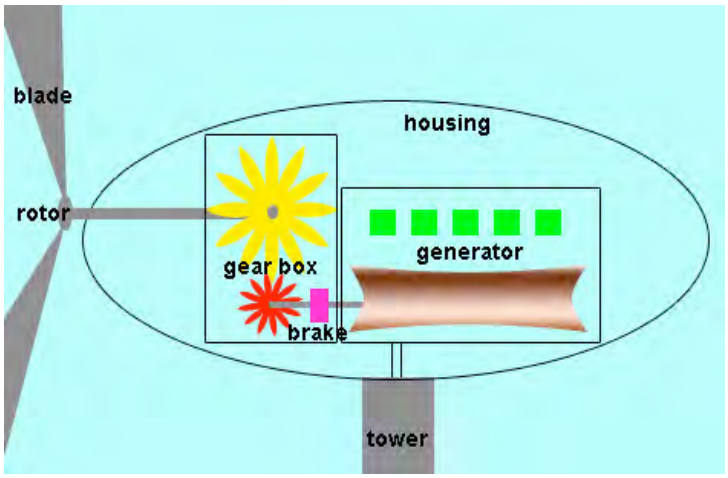

Figure 21. The inside of a horizontal-axis wind turbine[59]

[52] Encyclopaedia Britannica, s.v. "wind." Accessed March 9, 2009.
[53] U.S. Department of Energy, "How Wind Turbines Work," Wind and Hydropower Technologies Program, http://www1.eere.energy.gov/windandhydro/wind_how.html. Accessed March 8, 2009.
[54] Encyclopaedia Britannica, s.v. "wind." Accessed March 9, 2009.
[55] Mark Z. Jacobson, "Review of Solutions to Global Warming, Air Pollution, and Energy Security," Energy & Environmental Science 2 (2009): 148-173.
[56] United States Department of Energy, "How Wind Turbines Work," Wind and Hydropower Technologies Program, http://www1.eere.energy.gov/windandhydro/wind_how.html. Accessed March 9, 2009.
[57] Danish Wind Industry Association. "Indirect Grid Connection of Wind Turbines," Danish Wind Industry Association, http://www.windpower.org/en/tour/wtrb/indirect.htm. Accessed March 9, 2009.
[58] United States Department of Energy, "How Wind Turbines Work," Wind and Hydropower Technologies Program, http://www1.eere.energy.gov/windandhydro/wind_how.html. Accessed March 9, 2009.
[59] United States Department of Energy, "How Wind Turbines Work," Wind and Hydropower Technologies Program, http://www1.eere.energy.gov/windandhydro/wind_how.html. Accessed April 30, 2009.

Turbine technologies

Wind turbines can take multiple forms. The most common and conventional turbine form is a horizontal axis turbine with two or three blades. Because wind often changes direction, the rotor of a horizontal axis turbine must turn so that the plane of the rotor remains perpendicular to the wind direction. The wind turns "downwind" turbines to face away from the wind without any energy input from the turbine by what is known as a "passive yaw system." In "upwind" turbines, a yaw motor turns the rotor to face into the wind based on instructions from sensing equipment or a computer, giving the turbine an "active yaw system." Some wind turbine manufacturers make vertical axis turbines, with varying numbers and shapes of blades. Vertical axis turbines can use wind blowing in any direction without the need for a yaw system to orient the blades. Wind turbines can also vary greatly in size, from roof-top models powering residential buildings to the industrial-size models on wind farms. [60]

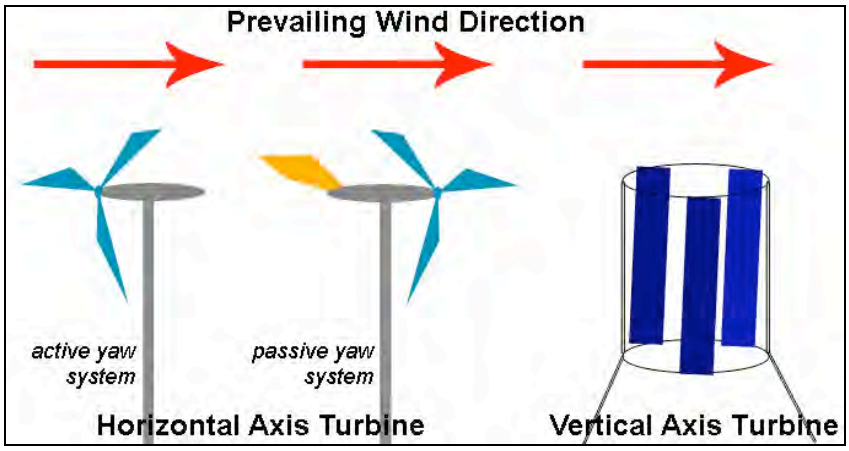

Figure 22. Basic types of wind turbines[61]

Wind Power at Institutions of Higher Education

Several colleges similar to Wellesley, including St. Olaf and Carleton, have undertaken wind turbine projects with great success. The wind turbine at St. Olaf is a 1.65-MW turbine built by the Danish company Vestas Wind Systems,[62] generating an estimated 6 million kWh of energy per year.[63] Press for St. Olaf's wind turbine has been overwhelmingly positive. The energy contribution of the wind turbine has reduced the

[60] U.S. Department of Energy, "How Wind Turbines Work," Wind and Hydropower Technologies Program, http://www1.eere.energy.gov/windandhydro/wind_how.html. Accessed March 8, 2009.
[61] United States Department of Energy, "How Wind Turbines Work," Wind and Hydropower Technologies Program, http://www1.eere.energy.gov/windandhydro/wind_how.html. Accessed April 30, 2009.
[62] David Gonnerman, "Let the Wind Blow: St. Olaf Wind Turbine Is In Place," St. Olaf College News, September 5, 2006, http://fusion.stolaf.edu/news/index.cfm?fuseaction=NewsDetails&id=3484. Accessed March 1, 2009.
[63] St. Olaf College, "The Story of St. Olaf's Wind Turbine," Black & Gold & Green, http://www.stolaf.edu/green/turbine/story.html. Accessed March 1, 2009.

college's carbon impact by over twenty percent, making St. Olaf College compliant with the Kyoto Protocol.[64]

Carleton's turbine replaces forty percent of its total electrical needs, and reduces the college's carbon dioxide emissions by 4,000 tons annually. It is expected that the turbine will reduce CO_2 output by 1.5 million tons over its 20-year lifespan.[65] On a day with winds of 27 mph or higher, the turbine can generate 1.65 MW of electricity. On a less windy (and more typical) day of 17 mph winds, its output is significantly lower, at 0.7 MW. The turbine cost $1.8 million, and to cover the capital cost, Carleton made an agreement to sell some of the power to a local energy utility. It is expected that the turbine will be paid for in less than twelve years. [66]

More locally, Babson College has installed a small wind turbine on their campus. The exact model is Southwest Windpower's Skystream 3.7®,[67] which is evaluated as the first alternative in this report. Although this turbine does not provide a significant electricity contribution to Babson, it serves as a visible reminder of energy conservation on the Babson campus,[68] and could be equally educational on Wellesley's campus. Using these schools as models, Wellesley can join the ranks of colleges committing to sustainability with the visible installation of a wind turbine on campus.

Figure 23. Carleton College's 1.65 megawatt wind turbine in Northfield, MN[69]

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[64] David Gonnerman, "Let the Wind Blow: St. Olaf Wind Turbine Is In Place," St. Olaf College News, September 5, 2006, http://fusion.stolaf.edu/news/index.cfm?fuseaction=NewsDetails&id=3484. Date Accessed: March 1, 2009.
[65] Carleton College, "The History of Carleton's Wind Turbine," Facilities Management, http://apps.carleton.edu/campus/facilities/sustainability/wind_turbine/. Accessed March 1, 2009.
[66] Carleton College, "Frequently Asked Questions About Carleton's New Green Power Wind Turbine," Facilities Management, http://apps.carleton.edu/campus/facilities/sustainability/Green_Power_Wind_Turbine/. Accessed March 1, 2009.
[67] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building A Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[68] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building A Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[69] Jim Gerhz, "A wind-blown rivalry between St. Olaf and Carleton," Minneapolis-St. Paul Star Tribune, February 23, 2009, http://www.startribune.com/local/south/40061447.html. Accessed March 15, 2009.

Trends in Wind Energy

Wind energy has great potential as a reliable energy source when incorporated into a diverse energy grid. Many European countries, including Spain, Denmark, and Germany are producing significant amounts of electricity through wind power generation. In the United States the Department of Energy found that twenty percent of American energy needs could be supplied by wind power by 2030.[70] Germany leads the world producing over 22,000 MW of electricity with wind power, which is small compared with North Dakota's wind potential.[71] In the United States, the installed wind power fleet is estimated to generate 48 billion kWh of wind energy in 2008, about 1% of U.S. electricity supply; however, the total potential electricity generated from wind in the U.S. has been estimated at 10,777 billion kWh annually—more than double the currently generated electricity in the U.S. today.[72] Advances in harvesting efficiency and the development of more resilient blades and specialized yaw systems have aided greatly in the propagation and spread of wind energy as a viable energy resource. Turbine manufacturers are constantly looking to improve the efficiency and decrease any negative environmental impacts of these technologies. These efforts, combined with public education and governmental support, lay the groundwork for wind power to become a significant piece of the United State's energy portfolio.

Wind Power at Wellesley

For Wellesley College, power generation using wind energy has several advantages over other energy generation methods. First, wind turbines would be highly visible signs of the college's commitment to environmental sustainability. The installation could generate positive publicity for the college at a time when being "green" is popular, potentially resulting in higher levels of alumnae giving and admissions selectivity. Second, most models can be integrated into the utility grid, so that wind power generated could be the primary source of energy for the college when available. Power from the existing cogeneration plant could smooth out inconsistencies in power generation due to the intermittency of wind. Finally, wind power installation can be very flexible. Because of the variety of sizes and power ratings of wind turbines, Wellesley can choose one or more turbines that closely fit its needs.

The main concerns surrounding wind turbines at Wellesley College would likely be neighborhood reaction, cost-effectiveness, and local zoning restrictions. A recent analysis on wind turbines at Wellesley College ruled out the hill near the water tower as a potential location due to the anticipated reaction of the town. This same analysis concluded that only utility-scale turbines would be cost-effective.[73] The local

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[70] American Wind Energy Association, "20% Wind Energy by 2030: Wind, Backup Power, and Emissions," http://www.awea.org/pubs/factsheets/Backup_Power.pdf. Accessed March 9, 2009.
[71] American Wind Energy Association. "Top 20 States with Wind Energy Resource Potential," http://www.awea.org/pubs/factsheets/Top_20_States.pdf. Accessed March 9, 2009.
[72] American Wind Energy Association, "Top 20 States with Wind Energy Resource Potential," http://www.awea.org/pubs/factsheets/Top_20_States.pdf. Accessed March 9, 2009.
[73] Boreal Renewable Energy Development, Wellesley College Wind Turbine Analysis – Pro Forma Results / Rooftop Review (Acton, MA: Boreal Renewable Energy Development, 2007).

zoning code in the town of Wellesley dictates wind turbines must not exceed 45 ft. in height; all utility-scale turbines exceed this limit.[74]

Installing cost-effective wind power at Wellesley College, given the College's location and the lack of applicable state incentives for wind power installation,[75] would be challenging but not impossible. Wind speeds in Wellesley are generally around 10 mph; because wind speeds are so low, a wind turbine may not produce energy at its maximum potential.[76] As Babson College learned during the process of installing its wind turbine in 2008, given the wind conditions and height restrictions on construction in the town of Wellesley, a small wind turbine may take all of its lifespan to pay back its worth in fossil fuels.[77] Wellesley College planners would need to decide whether financial gain is the only criterion by which to gauge the attractiveness of different alternative energy sources, or whether less tangible results such as good public relations and education about sustainability are also important.

Social and Educational Benefits of Wind Power

Because Wellesley College is an institution of higher learning, one of the attributes that should be sought through this project is a fostering of environmental awareness and progress. Increasing the visibility of "green" actions on the part of the College can create these perceptions. Because a wind turbine is significantly larger and more noticeable than an array of photovoltaic cells, a group of off-campus guests or prospective students is more likely to notice it. Towering over the athletic fields, a wind turbine could serve as a ubiquitous reminder to students, faculty, and even passersby, to behave in an environmentally sustainable manner.

Alternatives

Wind Turbine Options Not Considered for Wellesley's Campus

There are several wind power alternatives and turbine models we elected not to examine in depth as possibilities for Wellesley's campus. We limited our search to models that could be located near the athletic fields and did not consider alternative locations on campus, working from the recommendations of a previous campus wind power audit.[78] We also chose not to consider rooftop turbine models. They generate much less power than utility scale turbines, and are exposed to greater wind turbulence due to their proximity

[74] Patrick Willoughby, personal communication, 2009.
[75] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building a Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[76] Boreal Renewable Energy Development, Wellesley College Wind Turbine Analysis – Pro Forma Results / Rooftop Review (Acton, MA: Boreal Renewable Energy Development, 2007).
[77] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building a Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[78] Boreal Renewable Energy Development, Wellesley College Wind Turbine Analysis – Pro Forma Results / Rooftop Review (Acton, MA: Boreal Renewable Energy Development, 2007).

to other structures.[79] A stackable vertical axis turbine option that would use less roof area and could extend skyward for greater power generation would also be a possibility, but this option is less cost-effective than the other turbines we considered.[80] The roof of the Sports Center would be put to better use as a site for solar panels or a green roof installation.

Introduction to the Alternatives

The five turbine models considered below are all stand-alone turbines designed for powering homes and small businesses. Such a size is necessary to contribute significantly to Wellesley College's energy generation. As the KSC currently uses over 6 million kWh of energy annually,[81] even a large wind turbine can only produce a small percentage of that power given Wellesley's low wind resources. Yet in choosing a large turbine, Wellesley College needs to be prepared to challenge town zoning restrictions. Section XX of Wellesley's zoning code mandates that all new construction is less than 45 ft. above the average finished grade of the land, with the exception of *"parapets, chimneys, flag poles, solar collectors, or necessary projections."*[82] Four of the five turbines presented here have recommended tower heights greater than 45 ft., and the College must consider the height restriction if it chooses one of those four turbines. Although wind turbines may fall under the above exception category because they are not too different from flag poles or solar collectors, the college will also be able to apply for a specific exception to the height restriction, subject to approval by the town's planning board.[83]

Alternative 1. Southwest Windpower Skystream 3.7®

Southwest Windpower's Skystream 3.7® is a quiet 2.4 kW wind turbine specifically designed for residential use.[84] The Skystream's small size, relatively low cost, and exceptionally quiet operation even during high wind speeds has made it a popular choice among academic institutions as well.[85] Models of the

[79] Aerostar Inc., "Choosing the Right Tower," Aerostar Wind Turbines, http://www.aerostarwind.com/aerostarwindturbines.html. Accessed March 6, 2009.
[80] Aerotecture International Inc., 510V Aeroturbine, http://www.aerotecture.com/products_510V.html. Accessed March 8, 2009.
[81] See "Sports Center Energy Analysis."
[82] Robert Banagle, Jonah Eidus, and Clinton White, Babson Energy and Environmental Club "Babson Green: Building a Sustainable Future at Babson College" December 2007.
[83] Robert Banagle, Jonah Eidus, and Clinton White, Babson Energy and Environmental Club "Babson Green: Building a Sustainable Future at Babson College" December 2007.
[84] Southwest Wind Power, "Product Spec Sheet," Skystream 3.7®, http://www.windenergy.com/documents/spec_sheets/3-CMLT-1338-01_Skystream_spec.pdf. Accessed April 29, 2009.
[85] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building A Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).

Skystream 3.7® have been installed at locations as varied as Appalachian State University, Western Michigan University, and neighboring Babson College.[86]

The rotor diameter of the Skystream 3.7® is 12 ft. and the tower is 35 ft., making this the only turbine option that would not exceed the maximum structure height prescribed in the town of Wellesley's zoning code.[87] The cut-in speed of the turbine is 8 mph and the turbine is designed to withstand wind speeds of up to 140 mph,[88] which covers the range of wind speeds usually experienced by Wellesley College. The Skystream 3.7 is expected to produce 3,000 kWh/a during its operational lifetime of 25 years, leading to a total of 75,000 kWh of energy for the KSC that doesn't come from fossil fuels.[89]

The Skystream® 3.7 is the least expensive turbine considered here, with a suggested retail price of $5,400 and an estimated installed cost of $12,000 - $18,000.[90] The Skystream is also less expensive than other similarly-sized turbines.[91] The specific maintenance costs of the turbine are not listed, but we estimated the annual maintenance costs to be $108 (using the average annual maintenance cost for small turbines, which is 2% of the initial value of the turbine), the lowest of any wind turbine option we considered.[92] Even under relatively conservative energy output estimates the Skystream 3.7® is expected to recover its initial cost during its operational lifetime.[93] This and the Skystream's relatively high survival wind speed (140 mph) makes the Skystream® 3.7 a relatively low-risk investment for Wellesley College.[94]

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[86] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building A Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[87] Southwest Wind Power, "Product Spec Sheet," Skystream 3.7®, http://www.windenergy.com/documents/spec_sheets/3-CMLT-1338-01_Skystream_spec.pdf. Accessed April 29, 2009.
[88] Southwest Wind Power, "Product Spec Sheet," Skystream 3.7®, http://www.windenergy.com/documents/spec_sheets/3-CMLT-1338-01_Skystream_spec.pdf. Accessed April 29, 2009.
[89] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building A Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[90] Southwest Wind Power, "Introduction – SkyStream 3.7," http://www.skystreamenergy.com/documents/datasheets/skystrea_%203.7t_datasheet.pdf. Date Accessed: April 29, 2009.
[91] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building A Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[92] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building A Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[93] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building A Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[94] Southwest Wind Power, "Product Spec Sheet," Skystream 3.7®, http://www.windenergy.com/documents/spec_sheets/3-CMLT-1338-01_Skystream_spec.pdf. Accessed April 29, 2009.

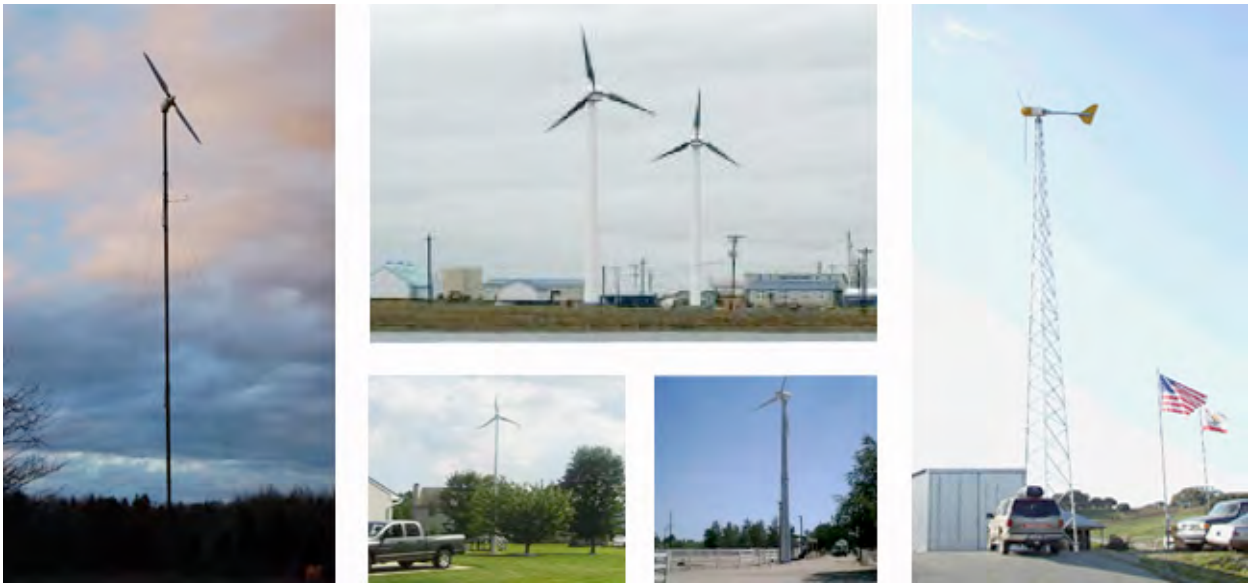

Figure 24. Appearance of alternative wind turbine models considered for Wellesley College

Clockwise from left: Aerostar® 6 Meter,[95] Northern Power Northwind 100™,[96] Bergey EXCEL,[97] ReDriven Power 20kW,[98] Southwest Windpower Skystream 3.7®.[99]

Alternative 2. Aerostar® 6 Meter

Aerostar Inc.'s 6 Meter wind turbine model is a stand-alone turbine with a horizontal axis, two-blade teetering rotor. With a maximum instantaneous electrical output of 10 kW at wind speeds greater than 33.6 mph,[100] the 6 Meter is one of the smaller turbines we are considering. It has a 22 ft.-wide rotor, and can be mounted on guyed or free-standing towers. The wind speed at the top of the smallest tower option (80 ft.) would be approximately 10 mph,[101] for which Aerostar predicts an annual turbine output of 6,912 kWh.[102]

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[95] Aerostar, Inc., "The Aerostar 6 Meter," Aerostar Wind Turbines, http://www.aerostarwind.com/aerostarwindturbines.html. Accessed April 25, 2009.
[96] Northern Power, "Northwind 100: Our Design, Your Solution," Northwind 100, http://northernpower.com/assets/files/NWind100_rev_to%20PDF.pdf. Date Accessed: March 18, 2009.
[97] Bergey Windpower Co., Small Wind Turbines for Homes, Businesses, and Off-Grid, http://www.bergey.com. Accessed March 18, 2009.
[98] ReDriven Power, Inc., "Products," Eco-Friendly Power, http://www.redriven.net/products_20kw.html. Accessed March 18, 2009.
[99] Southwest Windpower, Inc., "Product Photos," Skystream 3.7®, http://www.skystreamenergy.com/skystream-info/productphotos.php. Date Accessed: April 25, 2009.
[100] Better Generation, "the aerostar 6 wind turbine," Wind Turbine Models, http://www.bettergeneration.co.uk/wind-turbine-models/the-aerostar-6-wind-turbine.html. Accessed March 13, 2009.
[101] Boreal Renewable Energy Development, Wellesley College Wind Turbine Analysis – Pro Forma Results / Rooftop Review (Acton, MA: Boreal Renewable Energy Development, 2007).
"Wind Speed Calculator," Danish Wind Industry Association, http://www.windpower.org/en/tour/wres/calcular.htm. Accessed March 15, 2009.

The low annual energy output of the turbine may be due in part to its cut-in speed of 8.1 mph, which is not much lower than the average wind speed at the top of the tower. Using the tallest tower option (120 ft.) would increase the turbine's output to 9,000 kWh/year.[103] This amount of energy generation would account for 0.2% of the KSC's current energy needs.[104]

The initial cost of the most basic package of Aerostar® 6 Meter turbine and free-standing tower is currently $36,900. Add-ons to the turbine system itself include over- and under-voltage and frequency control, web interface for remote monitoring and an extended warranty. Choice of a guyed tower instead of a free-standing one involves an additional cost of $550 for an 80' tower, and a tilt option involves a further $1,890. If Wellesley College were to choose a turbine on an 80' guyed tower with tilt-down, voltage and frequency control, and web interface options, this would result in a unit price of $41,160. Disregarding cost, this option seems most appropriate for Wellesley. A tilt-down tower can be fully installed and maintained without a crane, resulting in cost savings, and it also requires less steel in construction.[105] A web interface showing the turbine's power generation has potentially large educational benefits, and thus would be a good investment for Wellesley.

Assuming installation costs approximately 25% of the purchase price,[106] the least expensive option described above yields a combined cost of unit purchase and installation of $46,125, while the more ideal option would have a combined purchase and installation cost of $51,450. As mentioned above, maintenance costs should be relatively low for a 6 Meter model with a tilt-down guyed tower. Because the model is designed to interface directly with the utility grid and thus has no inverters, maintenance costs are further reduced.[107] Aerostar 6 Meter turbines are designed for a lifespan of 25 years.[108] The turbine remains operational at wind speeds up to 50 mph and can withstand wind speeds of over 120 mph.[109] A tilt-down tower would further lower the risk of damage in high winds, because the tower could be lowered in anticipation of bad weather. A conservative estimate of removal price for the Aerostar 6 Meter is $1000, and the turbine is not expected to generate enough energy to pay back the initial investment over the course of its lifetime.[111]

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[102] Aerostar Inc., Aerostar Wind Turbines, http://www.aerostarwind.com/aerostarwindturbines.html. Accessed March 15, 2009.
[103] Aerostar Inc., Aerostar Wind Turbines, http://www.aerostarwind.com/aerostarwindturbines.html. Accessed March 15, 2009.
[104] See "Sports Center Energy Analysis."
[105] Aerostar Inc., Aerostar Wind Turbines, http://www.aerostarwind.com/aerostarwindturbines.html. Accessed March 15, 2009.
[106] Amanda Lavigne et. al., "Alternative Fuels & Small Scale Renewable Power Generation Opportunities," Report to the Land of Opportunity: The American Response to Climate Change Adirondack Conference, p. 17, http://www.usclimateaction.org/userfiles/Alternative%20Fuels%20FINAL.pdf. Accessed March 13, 2009.
[107] Aerostar Inc., Aerostar Wind Turbines, http://www.aerostarwind.com/aerostarwindturbines.html. Accessed March 15, 2009.
[108] Paul L. Gay of Aerostar, Inc., personal communication, March 16, 2009.
[109] Paul L. Gay of Aerostar, Inc., personal communication, March 16, 2009.
[111] Bergey Windpower Company, "Annual Cash Flow Model," Small Wind Turbines for Homes, Businesses, and Off-Grid, http://www.bergey.com/Technical/Excel.Cash.Flow5A.xls. Accessed March 18, 2009.

Alternative 3. Bergey EXCEL

The Bergey Excel is a 10 kW wind turbine designed to be highly reliable even in adverse weather conditions.[112] The rotor, which has a diameter of 22 ft., is usually installed on towers that are 60 to 140 ft. tall. The cut-in speed for the turbine is 6.9 mph and the start up speed is 7.6 mph, which is well within the mean annual wind speeds reported for Wellesley College.[113] The Bergey EXCEL was designed to withstand temperatures of -40 to 60°C and wind speeds up to 125 mph,[114] and with an active yaw system, it can even produce power under such conditions.[115] Installing a Bergey Excel at Wellesley on a 30 ft. tower—under the town's height restrictions—would yield 11,675 kWh of energy per year, while using a 50 ft. tower would result in an annual energy output of 18,125 kWh. This latter energy output would supply 0.3% of the energy currently used by the KSC.

The Bergey EXCEL is slightly less expensive than similarly-sized models, with a suggested retail price of $27,900[116] and an estimated installed cost of $35,000-$45,000.[117] To this comparatively low upfront cost is added high durability, a 30-year estimated lifetime and relatively low operation and maintenance costs. The EXCEL is one of the more durable turbines on today's market, having been designed for temps ranging from -40 to 60°C and wind speeds up to 125 mph (or up to 150 mph with special extra-stiff blades). Bergey Windpower provides a full warranty for five years and estimates that the operation and maintenance costs thereafter are less than $200 a year.[118] The estimated payback period for a Bergey Excel installed at Wellesley College is 21 years.

Alternative 4. ReDriven Power Inc. 10 kW / 20 kW

ReDriven Power Inc. produces four different turbine models: 2kW, 5kW, 10kW, and 20kW producers. These wind turbines have a specially designed electromechanical yaw system, which, like the Bergey Excel, allow them to operate without cut-out speeds in high winds. There are separate inverters and controllers for connection to the utility grid.[119] For Wellesley we have decided to further research the 10kW and 20kW models, since they would produce the most energy.

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[112] GenPro Energy Solutions, "Bergey WindPower Excel and Excel-R" www.genproenergy.com/bergey_excel.html. Accessed March 26, 2009.
[113] Boreal Renewable Energy Development, Wellesley College Wind Turbine Analysis – Pro Forma Results / Rooftop Review (Acton, MA: Boreal Renewable Energy Development, 2007).
[114] The Sustainable Village, "Bergey Excel Wind Turbine – Battery Charging," Products, http://www.thesustainablevillage.com/servlet/display/product/detail/37152. Accessed March 26, 2009.
[115] Bergey Windpower Co., "BWC Excel-R Description," Small Wind Turbines for Homes, Businesses, and Off-Grid, http://www.bergey.com/Products/Excel.Description.html. Accessed April 26, 2009.
[116] Robert Banagale, Jonah Eidus, and Clinton White, Babson Green: Building A Sustainable Future at Babson College (Wellesley, MA: Babson Energy and Environmental Club, 2007).
[117] Bergey Windpower Company, "BWC EXCEL Wind Turbine," Small Wind Turbines for Homes, Businesses, and Off-Grid, http://www.bergey.com. Accessed March 18, 2009.
[118] Bergey Windpower Company, "BWC EXCEL Wind Turbine," Small Wind Turbines for Homes, Businesses, and Off-Grid, http://www.bergey.com. Accessed March 18, 2009.
[119] ReDriven Power, Inc. Wind Turbine. http://www.redriven.net/index.html. Accessed March 20, 2009.

The 20kW model starts producing energy in 4.4 mph winds, and produces the full 20 kW of power at wind speeds above 24.6 mph. A 59-ft. hydraulic tower is recommended, although towers up to 120 ft. tall are available. Given the wind speeds at Wellesley, the 20 kW model is predicted to produce 24,978 kWh annually when mounted on the 59 ft. tower. The 10 kW model also starts producing energy with 4.4 mph winds, and produces 10 kW of power at wind speeds above 22.4 mph. For this model, the tower options range in height from 39 ft. to 120 ft. Although the 39-ft. tower would be under the town's 45-ft. height restriction, adding the rotor on top would make the whole apparatus taller than 45 ft. The predicted annual power output of the 10 kW turbine is 11,456 kWh.[120] Neither the 10 kW nor the 20 kW turbines would provide for more than 0.5% of the KSC's energy needs.

The 20 kW model costs roughly twice as much ($42,738 sans shipping and installation[121]) as the 10 kW model ($22,170 sans shipping and installation[122]). The 20 kW model would likely use a 59-ft. hydraulic tower which would cost $13,892. The total initial cost of the 20kW wind turbine would be $56,630. The 10kW model would have a 39-ft. or 53-ft. tower, which would cost $5149 and $6718 respectively. The 10kW model also has the option of using a 39-ft. or 53-ft. hydraulic tower, which would cost $7158 and $9088, respectively. The total initial cost of the 10kW wind turbine would be $31,257.

Assuming an annual energy output of 10,000 kWh, the 10 kW turbine has a payback period of 27 years.[123] The 20 kW turbine has a payback period of 21 years,[124] which, along with the Bergey EXCEL's payback time, is the shortest of the all the turbines considered here. However, the lifespan of these turbines is unknown and may be shorter than the payback periods.

Alternative 5. Northern Power Northwind 100™

The Northwind 100™ is a 100 kW turbine model, originally designed for generating power in remote locations, so one or two turbines can often generate enough power to supply the energy needs of schools and municipalities. It connects to utility grids with ease,[125] and all turbines come with a monitoring system that allows for local and web-based monitoring of power generation.[126] The turbine has a 69-ft. rotor diameter, which is mounted on a 121-ft. steel monopole. It generates 100 kW of instantaneous power at wind speeds

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[120] ReDriven Power, Inc. Wind Turbine. http://www.redriven.net/index.html, Accessed March 20, 2009.
[121] ReDriven Power Inc., "Products," Wind Turbine, http://www.redriven.net/products_20kw.html. Accessed March 15, 2009.
[122] ReDriven Power Inc., "Products," Wind Turbine, http://www.redriven.net/products_10kw.html. Accessed March 15, 2009.
[123] Bergey Windpower Company, "Annual Cash Flow Model," Small Wind Turbines for Homes, Businesses, and Off-Grid, http://www.bergey.com/Technical/Excel.Cash.Flow5A.xls. Accessed March 18, 2009.
[124] Bergey Windpower Company, "Annual Cash Flow Model," Small Wind Turbines for Homes, Businesses, and Off-Grid, http://www.bergey.com/Technical/Excel.Cash.Flow5A.xls. Accessed March 18, 2009.
[125] Northern Power, "Northwind 100: Our Design, Your Solution," Northwind 100, http://northernpower.com/assets/files/NWind100_rev_to%20PDF.pdf. Accessed March 18, 2009.
[126] Northern Power, "Specifications," Northwind 100, http://northernpower.com/assets/files/NWind100_Specs.pdf. Accessed March 18, 2009.

of 32.4 mph or higher, with a cut-in speed of 7.8 mph, comparable to the other turbines presented here. It has an active electromechanical yaw system but still cuts out at wind speeds greater than 56 mph.[127]

With its much greater power rating, the Northwind 100™ can generate much more power annually than the other turbine models considered. An analysis based on Wellesley's wind conditions estimates an annual output of 104,768 kWh, an order of magnitude greater than the other turbine models.[128] However, this turbine would still only generate about 2% of the energy consumed annually by the KSC.

The Northwind 100™ is by far the most expensive turbine considered here because of its great size; in terms of cost per kilowatt, the Northwind 100 is comparatively inexpensive. The initial cost of the unit is $330,000, which includes a two-year warranty and a system for local and web-based monitoring. Installation costs vary depending on location and the company performing the installation, but budgeting $200,000 for installation is recommended. Maintenance costs also tend to run higher for the Northwind 100, with the combination of materials and labor approximating $1000 to $1500.[129] While the end-of-life costs may be large for this turbine because of its large size, these costs may be offset to some degree by the greater amount of material that can be salvaged and sold as scrap metal. Despite the high power generation of this model, the large costs associated with it mean that it would not be able to pay back its costs within its 20-year lifespan.[130]

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[127] Northern Power, "Specifications," Northwind 100, http://northernpower.com/assets/files/NWind100_Specs.pdf. Accessed March 18, 2009.
[128] David Narwid of Northern Power, personal communication, March 18, 2009.
[129] Eco Depot USA, "Northwind 100 kW: Pricing and Maintenance Budgeting, Warranty Information," Eco Depot USA, http://www.ecodepotusa.com/Products/Wind/WindProduts/Northwind/NW100_Cost_Budgeting_maintenance_warranty_info.htm. Accessed April 30, 2009.
[130] David Narwid of Northern Power, personal communication, March 18, 2009.

Figure 25. Summary of alternative wind turbine models considered for Wellesley College

Alternative	Manufacturer	Model	Size Specifications	Instantaneous Electrical Output (kW)	Estimated Annual Output (kWh/year)
1	Southwest Windpower	Skystream ®3.7	12' rotor 35' tower	2.4	3000
2	Aerostar Inc.	6 Meter	22 ft. rotor 80-120 ft. tower	10	6900-9000
3	Bergey	EXCEL	22 ft. rotor 60-140 ft. tower	10	11,700-18,100
4a	Redriven Power Inc.	10 kW	18 ft. rotor 39-120 ft. tower	10	11,500
4b	Redriven Power Inc.	20 kW	18 ft. rotor 59-120 ft. tower	20	25,000
5	Northern Power	Northwind 100™	69 ft. rotor 121 ft. tower	100	104,000

Life Cycle Analysis

All of the wind turbines considered have the same basic environmental impacts in each part of the life cycle, although the magnitude of the impact can vary between models. There will be some negative environmental impacts associated with any model that the college chooses to implement, simply because this is a new structure and thus requires resources and energy for its manufacture and installment at Wellesley. Nevertheless, a wind turbine would still enable the college to avoid many other environmental impacts through reduced fossil fuel use.

Materials Sourcing and Processing

The first stage of the life cycle includes the extraction of raw minerals and the process those materials go through to become useful in manufacturing the turbine. The largest material component of wind turbines is steel. About half of the steel produced in the US is produced by recycling scrap steel. The recycling process produces greenhouse gas emissions through the burning of large amounts of fossil fuels and can sometimes release contaminants contained within the scraps. Virgin steel manufacture, in addition to greenhouse gas emissions, releases carbon monoxide, sulfur oxides, nitrous oxides, and particulate matter into

the atmosphere, as well as wastewater contaminants and hazardous solid wastes.[131] Despite the large manufacturing-end impacts of the steel tower, overall life-cycle impacts are reduced if the tower materials are recycled into new structures at the end of the turbine's life.

Manufacturing

For wind turbines, the environmental impacts of the manufacturing stage include the emissions due to the manufacturing of the tower, rotor, and nacelle. The most significant factor in determining the impact of these emissions is the type of electricity used in the manufacturing process. The "greener" the energy that is used when producing the turbine, the lower the turbine's environmental impact will be.[132] We have no evidence that any of the manufacturers of the turbines considered here use renewable energy in their facilities.

Materials used in manufacture and their disposal should also be considered for environmental impacts in the manufacturing stage. For example, an Aerostar turbine has a urethane coating on the blades.[133] Urethane is an organic compound, and its main environmental impacts come from improper use and disposal, as it can leach into groundwater and is unlikely to biodegrade.[134] However, assuming that Aerostar controls urethane use appropriately, its environmental impacts should not be large.

Transportation

The transportation category includes the transportation of raw materials to the processing location and the transport of manufactured materials to the construction site of the turbine. The emissions from this category can vary widely depending on where the turbine was produced and where it will be installed (Appendix B). Transportation emissions can also be affected by whether the turbine is shipped to a dealer before being shipped to the consumer, because this could create additional emissions depending on where the dealer is located.

Operation

There are environmental impacts from the operation and maintenance of the turbine on-site. Wind turbines have few operational emissions, and maintenance emissions come from emissions generated in the manufacture of replacement parts and transportation emissions as maintenance workers travel to the turbine.

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[131] US Environmental Protection Agency, "Iron and Steel," Sector Strategies Program, http://www.epa.gov/ispd/ironsteel/index.html. Accessed March 15, 2009.
[132] Soren Krohn, ed., "The Energy Balance of Modern Wind Turbines," Wind Power Note, no. 16 (December 1997), http://www.windpower.org/media(444,1033)/The_energy_balance_of_modern_wind_turbines,_1997.pdf. Accessed April 30, 2009.
[133] Aerostar Inc., Aerostar Wind Turbines, http://www.aerostarwind.com/aerostarwindturbines.html. Accessed March 15, 2009.
[134] Spectrum Laboratories, "Chemical Fact Sheet: CAS #51796," http://www.speclab.com/compound/c51796.htm. Accessed March 15, 2009.

Noise pollution and ecosystem disruption are additional sources of environmental impacts at this stage. Most turbine manufacturers now make efforts to reduce the noise produced by their turbines. The Aerostar® 6 Meter, due to its constant rotor speed and acoustic isolation of different components, produces 43 dBA when on a 100-ft. tower in winds of 10 mph.[135] The Northwind 100 has an apparent noise level of about 50 dBA, comparable to normal conversation or soft music.[136] Because the suggested location for installation is the athletic fields, already a highly unnatural habitat, the installation and operation of the turbine will not cause much additional disruption to wildlife.

End of Life

The end-of-life category is important in the life cycle of wind turbines, as recycling the used materials can greatly reduce negative environmental impacts of the turbine. As such, the college would want to make sure it can recycle as much of the turbine as possible when it is decommissioned. Researchers continue to work on the problem of recycling fiberglass,[137] a material commonly used in wind turbine blades,[138] so it may well be recyclable by the time a Wellesley College turbine would have reached the end of its life. Steel, the largest material component in the turbine, is already highly recyclable.[139]

Cost Analysis

Wind turbines vary in cost primarily in the purchase and installation phase, although many of the operational, maintenance, and end-of-life are also based on turbine size. Wellesley College should expect to spend a minimum of $10,000 on the turbine itself based on the size needed to make any considerable contribution to campus energy generation. Installation costs are expected to be roughly 25% of the purchase price of the turbine.[140]

Typically, operational costs for turbines include property taxes on the turbine site, management and administrative costs, and insurance for the turbine.[141] Property taxes are not an issue for Wellesley College and the college would most likely use existing staff to cover administrative duties for the turbine, so these

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[135] Aerostar Inc., Aerostar Wind Turbines, http://www.aerostarwind.com/aerostarwindturbines.html. Accessed March 15, 2009.
[136] Northern Power, "Northwind 100: Our Design, Your Solution," Northwind 100, http://northernpower.com/assets/files/NWind100_rev_to%20PDF.pdf. Date Accessed: March 18, 2009.
[137] Argonne National Laboratory, "Recovery and Recycling of Glass-Manufacturing Waste and Fiberglass Scrap," Argonne National Laboratory Energy Systems Division, http://www.es.anl.gov/Energy_systems/factsheets/index.html. Date Accessed: March 16, 2009.
[138] Paul L. Gay of Aerostar, Inc., personal communication, March 16, 2009.
[139] US Environmental Protection Agency, "Iron and Steel," Sector Strategies Program, http://www.epa.gov/ispd/ironsteel/index.html, Accessed March 15, 2009.
[140] Amanda Lavigne et. al., "Alternative Fuels & Small Scale Renewable Power Generation Opportunities," Report to the Land of Opportunity: The American Response to Climate Change Adirondack Conference, http://www.usclimateaction.org/userfiles/Alternative%20Fuels%20FINAL.pdf. Accessed March 13, 2009.
[141] National Wind Coordinating Committee, "Wind Energy Costs," Wind Energy Issue Brief, http://www.nationalwind.org/publications/wes/ibrief11.htm. Accessed March 18, 2009.

operational needs would not increase the turbine's lifetime price. In terms of insurance coverage, a standard insurance premium for a wind turbine is approximately $2 for every $1000 of coverage.[142] Insurance coverage for a wind turbine is useful in case of particularly bad weather or vandalism.

Annual maintenance costs range from one to three percent of initial installation cost for a small turbine system. Accidental severe damage before the end of this period would only be expected in storms with very high winds. All of the turbines described here can withstand 120 mph wind speeds, which correspond to a Category 3 hurricane[143] or a significant (F2) tornado.[144] According to the National Climatic Data Center, since 1950 Norfolk County has only experienced two tornadoes of this magnitude or higher and no hurricanes or tropical storms,[145] so the risk of high winds to a wind turbine at Wellesley College is low.

Because much of a wind turbine is made of steel, which can be recycled and sold as scrap metal, disposal costs are likely to be fairly low. The Recycling Services Directory for Massachusetts[146] lists 31 New England-based companies servicing Norfolk County that will recycle steel waste from large institutions, allowing Wellesley College to compare costs between many different options. A survey of several turbine projects estimates the net cost of turbine removal, land restoration, and sale of salvageable materials to range from $0 to $100 per kW capacity of the turbine.[147]

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[142] Mike Sagrillo, "Insuring Your Wind System: Potential Insurance Needs/Costs," American Wind Energy Association, http://www.awea.org/faq/sagrillo/ms_insur2.html. Accessed March 18, 2009.
[143] National Weather Service, "The Saffir-Simpson Hurricane Scale," National Hurricane Center, http://www.nhc.noaa.gov/aboutsshs.shtml. Accessed March 16, 2009.
[144] The Tornado Project, "The Fujita Scale," Tornado Project Online, http://www.tornadoproject.com/fscale/fscale.htm. Accessed March 16, 2009.
[145] US Department of Commerce, "Storm Events," National Climatic Data Center, http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms. Accessed March 16, 2009.
[146] WasteCap of Massachusetts, "Recycling Services Directory for Massachusetts," http://www.wastecap.org/wastecap/RSD2003/index.asp. Accessed March 19, 2009.
[147] Paul Gipe, "Removal and Restoration Costs in California: Who Will Pay?," Wind-Works, http://www.wind-works.org/articles/Removal.html. Accessed March 16, 2009.

Figure 26. Comparison of life cycle costs of alternative turbine models[148]

Alternative	Turbine Model	Initial Cost of Unit Purchase ($)	Combined Purchase and Installation Cost ($)	Operation Costs ($/year)	Maintenance Costs ($/year)	Estimated Lifetime (years)	End of Life Cost ($)
1	Southwest Windpower Skystream® 3.7	5400	12,000-18,000	11*	108*	25	0-240*
2	Aerostar® 6 Meter	37,545-41,160	46,931-51,450*	80*	500-1000*	25	0-1000*
3	Bergey® EXCEL	27,900	35,000-45,000	60*	200 (max.)	30	0-1000*
4a	ReDriven® Power 10 kW	31,257	39,071*	60*	313-938*	N/A	0-1000*
4b	ReDriven® Power 20 kW	56,630	70,788*	120*	566-1700*	N/A	0-2000*
5	Northern Power® Northwind 100™	330,000	500,000-530,000	660*	1500	20	0-10,000*

Recommendations

Wellesley College's choice whether to use wind power as a form of alternative energy generation on campus will depend on what the College hopes to achieve by installing a wind turbine. From the cost analyses presented above, it is clear that wind power requires a significant investment and small turbines are slow to earn back the money expended to get them installed and running. Therefore, wind power is not a recommended energy generation option if the college wishes to be cost-effective in its choice of alternative energy sources. Furthermore, Wellesley's wind resources are so small that even a large turbine could not provide for more than 5% of the sports center's annual energy needs. However, wind power would have particularly large educational and social benefits for the community. A turbine is more striking and visible from a greater distance than any of the other alternative energy forms considered. The image of the turbine would provide the community with a clear message about the College's commitment to sustainability, and would draw attention to the other, less visible efforts towards sustainability that we have made in recent years. Overall, wind power may not work well as a primary mechanism for generating alternative energy on

[148] Costs generated from formulas described in the "General Costs" section of the Introduction Chapter (rather than from information obtained from manufacturers) are marked with an asterisk.

Wellesley's campus, but it could be an excellent teaching tool as well as a way to generate energy if used in combination with other technologies.

After examining the life cycles and costs associated with each of these turbines, the most appropriate turbine for Wellesley's energy needs is ReDriven's 20 kW model. All of the 10 kW models considered produce too little energy to make a significant contribution to Wellesley College's energy generation; if it is not possible to obtain a larger model due to permitting issues, however, Wellesley could install multiple smaller turbines. This option wouldn't be the most cost effective way to power the KSC with renewable energy, but it might be one of the only feasible options. On the other hand, the largest model considered, the Northwind 100™, is so expensive that it cannot pay for itself within its lifespan, given the wind resources of Wellesley College. The ReDriven 20 kW model is moderately priced and is predicted to have a payback period of 21 years, which is relatively short for a turbine of this size in a location with such low wind resources.

4. *Geothermal Energy*

Summary

Geothermal power is a clean source of energy that uses the temperature below the surface of the earth to power turbines or to heat and cool residential and commercial buildings. The geothermal energy sources investigated here are horizontal, vertical, and lake water heat pumps. Horizontal heat pumps are primarily used in smaller residential settings and vertical pumps are better suited for commercial installations. Wellesley College has drawn water for cooling from Lake Waban but this process is currently disabled, pending further review. We therefore consider geothermal to be the lowest priority of alternative energy generation we evaluated.

Introduction

Geothermal energy generation harnesses heat from the earth's molten core, which radiates approximately 42 million megawatts (MW) of power per year.[149] The American West is geologically active and is an excellent source of heat energy near the surface; wells of a mile or more capture steam that vaporizes a secondary fluid that drives turbines. Large power plants that utilize subsurface steam are increasing in popularity as the technology is further developed.

Other forms of geothermal energy do not require the subsurface heat resources found only in the western region of the United States. These are loosely termed "heat pumps." Heat pumps use the relative temperature difference of subsurface soil or a local body of water to provide heating in the winter and cooling in the summer months. In the winter, when the subsurface soil is warmer than the air, the process involves pumping cool water through the ground or water and through a heat exchanger that provides heat to an indoor duct system—the process is reversed in the summer, when the soil is cooler than the air temperature.

Geothermal energy generation is clean, efficient, and has no carbon emissions. It is a stable source of energy, unaffected by seasonal or other variations and does not involve the cost fluctuations that plague fossil fuels. Energy from geothermal power plants and smaller scale heat pumps is generated within the United States, reducing dependence on foreign oil.

The benefits of geothermal energy are that once a significant amount of geothermal heat is sited, the reliability of that energy remaining constant is significantly high (95%) and impacts to the environment after initial set up of power plants or installation of heat exchangers is minimal. The major limiting factor is whether or not geothermal energy can be located in a concentrated or high enough amount. The western United States has larger geothermal reservoirs than the east, so geothermal power plants are not really an option here, but it would be possible to use geothermal heating and cooling through heat pumps or lake water.

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[149] "What is Geothermal Energy?" Geothermal Energy Association, http://www.geo-energy.org/aboutGE/basics.asp. Accessed April 25, 2009.

Other Colleges

Other colleges and universities across the country now successfully employ different forms of geothermal energy on their campuses to help off-set their energy needs. The geothermal system most commonly used is a geothermal heat pump (GHP). Eastern State Connecticut University employs a two-pipe fan coil GHP system to generate heating and cooling water. It has helped the university save $10,000 a year in heating and cooling costs.[150] Lake Land College in Illinois has also incorporated a GHP into its heating and cooling system to reduce its carbon footprint[151] and Feather River College in California's Sierra Mountains was able to save $50,000 and reduce energy consumption for heating and cooling by 421,000 kWh per year after installing their GHP.[152] While none of these colleges rely solely on geothermal systems for energy production, they were all able to reduce fossil-fuel energy dependency, lower carbon emissions, and spend less money on heating and cooling systems than they had in the past by tapping into the readily available natural energy stored just below the earth's surface.

Types of Geothermal Energy Generation

Power Plants

There are three main ways in which geothermal energy is harnessed in power plants: dry steam, flash steam, and binary-cycle. The dry steam method is the classic form of obtaining energy by drilling and capturing steam as far down as a mile into the earth's crust, which powers a turbine that in turn powers a generator.[153] Flash-steam operations are created when hydrothermal fluids over 360ºF are discovered, drawn out of the earth's surface, and sprayed with a chemical that causes a portion of the fluid to rapidly vaporize, or "flash." The vapor created then powers a turbine connected to an energy generator. The third power plant set-up, a binary-cycle system, draws on elements from both the previous systems. This process uses a moderately hot (below 400ºF) water source, which is combined with a lower-pressure added fluid that is passed through a heat exchanger, causing the secondary fluid to flash-vaporize. Although this technology is sustainable and environmentally friendly, it is not a realistic option for energy generation in the KSC because of the lack of viable geothermal sources in Massachusetts.

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[150] United States Environmental Protection Agency (EPA) Region 1 New England EPA Newsroom: "Best Management Practices for Colleges and Universities." Updated January 2007. http://www.epa.gov/region01//assistance/univ/pdfs/bmps/ECSUGeotherma1-8-07l.pdf. Accessed April 30, 2009.
[151] Lake Land College. "Leaving Less Carbon: Geothermal." http://www.lakeland.cc.il.us/green/geothermal_energy.html. Accessed April 30, 2009.
[152] The California Energy Commission. 1999 Releases, "Geothermal Energy Heats, Cools Mountain College." http://www.energy.ca.gov/releases/1999_releases/1999-08-09_geothermal.html. Accessed April 30, 2009.
[153] U.S. Department of Energy: Energy Efficiency and Renewable Energy. "Geothermal Technologies Program: Geothermal Basics." http://www1.eere.energy.gov/geothermal/geothermal_basics.html. Accessed April 30, 2009.

Direct Heat

Direct heat is a non-electric means of retrieving geothermal energy that is useful for small- and large-scale projects.[154] The energy harvested is used immediately instead of undergoing a conversion process to create electricity or another form of energy.[155] It is necessary to have direct access to geothermal reservoirs, which are mostly located in the western states, such as Alaska and Hawaii. Hot water is piped directly into buildings to use for space heating, greenhouses, vegetable dehydration, heating water, and to pasteurize milk.[156] These systems require lower geothermal fluid temperature, within the range of 50 to 150°C. Municipal uses include de-icing city streets in the winter,[157] and a network of piped hot water to heat buildings and entire communities.[158] This type of geothermal energy retrieval is similar to the standard geothermal power plant, and therefore also not a viable source of energy for Wellesley.

Heat Pump

Vertical heat pumps can be used in residential or commercial contexts. This technology uses the naturally stable temperatures in the upper 10 meters of the Earth to provide heating and cooling. It does this by pumping the warmer or cooler ground temperatures throughout the building, which depending on the time of the year are either warmer or cooler than the air inside of the building, effectively heating or cooling the indoor environment. The figure on the following page illustrates this process. The piping underground is connected to the central air and water inside the building. The liquid that is piped through the system either disperses or absorbs heat from underground and returns to the building with either cooler or warmer temperatures. And according to the U.S. Environmental Protection Agency (EPA), "geothermal heat pumps are the most energy-efficient, environmentally clean, and cost-effective systems for temperature control,"[159] and therefore could be an option for heating and cooling in the KSC.

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[154] U.S. Department of Energy: Energy Efficiency and Renewable Energy. "Geothermal Technologies Program: Geothermal Basics." http://www1.eere.energy.gov/geothermal/geothermal_basics.html. Accessed April 30, 2009.
[155] Encyclopedia of Energy, Volume 2. 2004. Geothermal Direct Use. John W. Lund. p. 859.
[156] U.S. Department of Energy: Energy Efficiency and Renewable Energy. "Geothermal Technologies Program: Geothermal Basics." http://www1.eere.energy.gov/geothermal/geothermal_basics.html. Accessed April 30, 2009.
[157]U.S. Department of Energy: Energy Efficiency and Renewable Energy. "Geothermal Technologies Program: Geothermal Basics." http://www1.eere.energy.gov/geothermal/geothermal_basics.html. Accessed April 30, 2009.
[158] U.S. Department of Energy: Energy Efficiency and Renewable Energy. "Geothermal Technologies Program: Geothermal Basics." http://www1.eere.energy.gov/geothermal/geothermal_basics.html. Accessed April 30, 2009.
[159] Energy Information Administration, "Geothermal Energy – Energy From the Earth's Core" Energy Information Administration, http://www.eia.doe.gov/kids/energyfacts/sources/renewable/geothermal.html#HeatPumps. Accessed April 30, 2009.

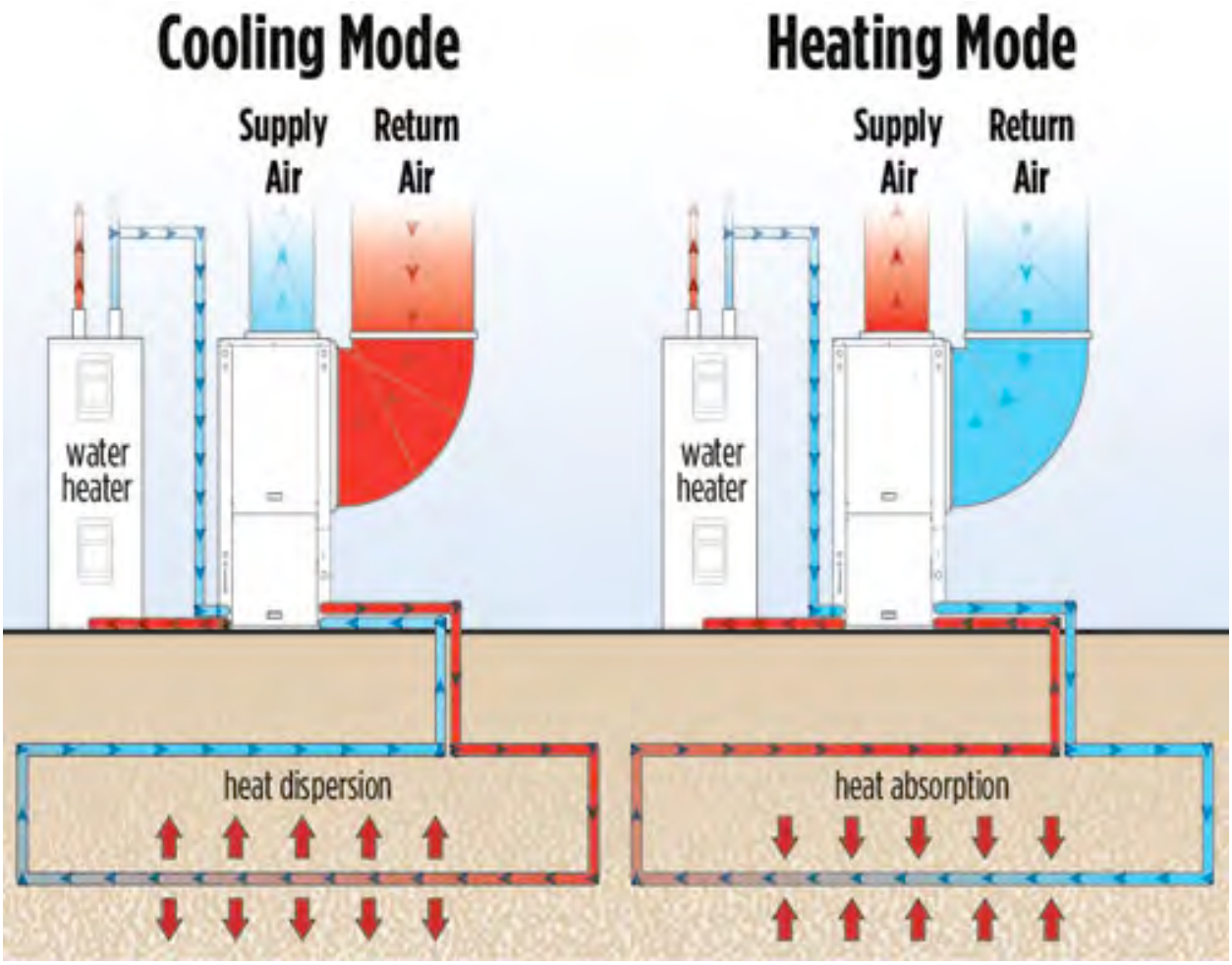

Figure 27. Geothermal Heat Pump[160]

There are closed-loop and open-loop heat pump options.[161] These options require different combinations of soil, land, and installation cost factors. Two methods, a closed-loop vertical system and a closed-loop lake system, are the most compatible with Wellesley's resources. The vertical system would be the most appropriate option for the KSC because it is most widely used in commercial buildings and would generate the greatest amount of energy. The horizontal loop system is positioned under a pond or lake and doesn't generate enough energy to be a cost effective option for the KSC.

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[160] Montara Ventures, "Renewable Energy Journal," http://montaraventures.com/pix/geothermalheatpump.jpg. Accessed April 30, 2009.

[161] U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, "Types of Geothermal Heat Pump Systems," U.S. Department of Energy, http://apps1.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12650. Accessed April 30, 2009.

Lake Water Cooling

Lake Water Cooling (LWC) is a process by which cold lake water is used to remove heat from a building or buildings. There are two options for LWC: direct heat exchange or indirect heat exchange. The latter option is employed by Cornell University in Ithaca, New York; cold water from the depths of Cayuga Lake is pumped to a heat exchanger near shore, where a secondary fluid transfers its heat and is returned to buildings in a continuous loop.[162] The other method, direct heat exchange, has already been employed until recently at Wellesley College. During the summer months, 7% of the volume of Lake Waban was removed at a depth of 31 feet and then pumped to Clapp Library and the College Club.[163] The colder water was used in these buildings to provide air conditioning, and once it was warmer it was returned to Lake Waban near Tupelo Point.

Alternatives Feasible at Wellesley College

Figure 28. Geothermal Alternatives Feasible at Wellesley College

Alternative #	Model/Identifier	Physical Size Specifications (ft)	Electrical Output (kWs)	Estimated Annual Output (kWh/a)	Initial Cost ($)
1	Vertical heat pump	150-450ft deep piping with small box unit above ground	14-21 kilowatts		Approx. $2,500/ton capacity
2	Lake water cooling	500 - 600ft of underground piping	unavailable	3 million – 23 million[164]	Under $1 million

Vertical Closed-Loop Heat Pump

Vertical heat pumps, or "closed loop vertical energy systems," are characterized by 100 to 400 feet of vertical piping that circulates water or antifreeze, which absorbs the temperature of the subsurface soil. These pipes provide buildings with heating or cooling.[165] This technique is most often used for large commercial buildings, like the Sports Center. It requires less land area than a horizontal heat pump, can be installed in

[162] "How Lake Source Cooling Works," Cornell University Facilities Services, Utilities, and Energy Management. Accessible at http://www.utilities.cornell.edu/utl_lscfte_howlscworks.html. Accessed March 15, 2009.
[163] Email correspondence with James Besancon, March 12, 2009.
[164] Cornell University Facilities Services Utilities and Energy Management. "About Lake Source Cooling Project - Lake Source Cooling: An Idea Whose Time Has Come." Copyright 2006. Accessed April 30, 2009. http://www.utilities.cornell.edu/utl_lscabout.html, Accessed April 30, 2009.
[165] Ingrams Water and Air Equipment. Heating and Air Conditioning: Geothermal Heat Pump 5 Ton. http://ingramswaterandair.com/geothermal-heat-pump-p-487.html?cvsfa=1207&cvsfe=2&cvsfp=487. Copyright 2009. Accessed April 30, 2009.

areas with shallow soil, and requires the least amount of disturbance of the surrounding landscape.[166] This system could be installed underneath the soccer practice fields located adjacent to both the field and pool houses.

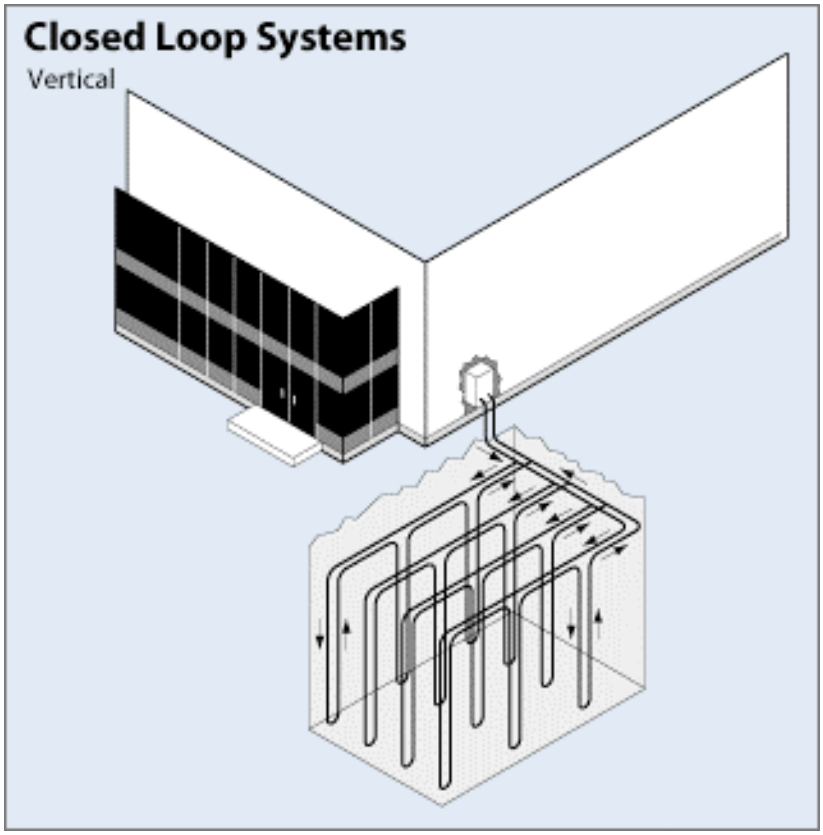

Figure 29. Closed-Loop Vertical System[167]

Lake Water Cooling

Lake Water Cooling (LWC) has already been employed at Wellesley College. During previous summer seasons, 7% of the volume of Lake Waban was removed at a depth of 31 feet, and then pumped to Clapp Library and the College Club.[168] The colder water was used in these buildings to provide air conditioning, and once it warmed was returned to Lake Waban near Tupelo Point. Including the KSC in this system would only require extending the water piping (500-600 feet) to the facility, and adding cooling mechanisms to the interior of the KSC.

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[166] U.S. Department of Energy: Energy Efficiency and Renewable Energy. "Energy Savers: Your Home." http://apps1eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12650. Accessed April 30, 2009.
[167] U.S. Department of Energy: Energy Efficiency and Renewable Energy. "Energy Savers: Your Home." http://apps1.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12650. Accessed April 30, 2009.
[168] Email correspondence with James Besancon, March 12, 2009.

At present, Lake Water Cooling at Wellesley has been put on hold, pending review of the impacts it might be having on the lake ecosystem and application for permits to allow it.[169] Although the presence of LWC at Wellesley is an advantage to expansion, it also provides a disincentive to add the KSC to the lake water circuit. The 7% of the lake water that was used was disproportionately from the coldest and deepest part of the lake, and that amount would increase with the addition of the KSC. This additional removal could have potentially harmful effects for the ecosystem of the lake, as the temperature might rise with the removal of more of the coldest water. In addition, Lake Waban suffers from heavy metal contamination, as is well documented. The removal of water from the lake could disrupt the suspension of these contaminants,[170] and removing more water would have unknown consequences. As mentioned, the use of lake water has recently been discontinued due to permitting issues,[171] and it is uncertain as to whether it will resume in the future. For now, the college has employed chillers connected to the cogeneration plant to cool the Clapp Library and the College Club.[172]

Cost Analysis

Because the LWC infrastructure is already in place at Wellesley College, many of the initial installation costs would be avoided if it is expanded to include the Keohane Sports Center (KSC). Cost estimation is difficult, however, because LWC is a recent technology and is not popular enough to yield accessible cost specifications. Existing projects nevertheless can provide a range of possible costs. Cornell University's Lake Source Cooling project replaced the entire campus chilled water system, at a cost of $55 million.[173] Because of the much smaller scale and existing infrastructure regarding a project at Wellesley, costs would be a fraction of those at Cornell. Likewise, the city of Toronto recently completed a LWC project to heat a much larger building, and the project price tag was $2.9 million.[174]

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[169] Email correspondence with Patrick Willoughby, March 2009.
[170] Email correspondence with James Besancon, March 12, 2009.
[171] Email correspondence with Patrick Willoughby, March 17, 2009
[172] Email correspondence with Suzanne Howard, April 26, 2009.
[173] Cornell University Facilities Services Utilities and Energy Management.. "Lake Source Cooling." http://www.utilities.cornell.edu/utl_ldlsc.html . Copyright 2006. Accessed March 15, 2009.
[174] Toronto Energy and Waste Management Renewable Energy Case Study, 1. "Metro Hall: Deep Lake Water Cooling." http://www.toronto.ca/ewmo/pdf/dlwc.pdf. Accessed March 15 2009.

Figure 30. Geothermal Cost Estimation

Alternative	Initial Cost of Unit Purchase ($)	Initial Cost of Installation ($)	Operation Costs ($/annum)	Maintenance costs ($/annum)	Estimated Lifetime	End of life Cost ($)
Vertical heat pump	$2,500/ton capacity	$10,000 to $30,000	Low	Easy and low	25-50 years	$0-25[175]
Lake Water Cooling	Under $1 million	$500-600[176]	Very low[177]	N/A[178]	75-100 years[179]	N/A[180]

Recommendations

Most geothermal energy options are not feasible at Wellesley College due to the school's geographic location and issues of scale. Yet the College has a lake water cooling system in place which already has saved energy and costs. Based on our analyses of various geothermal energy alternatives, we recommend the installation of a vertical closed-loop heat pump be considered for the renovation of the Keohane Sports Center. Lake Water Cooling is an excellent and cost-effective alternative, but recent problems have rendered the process temporarily unavailable. If these permitting problems are resolved, this energy source could be a viable option for the KSC as well.

[175] California Energy Commission: Consumer Energy Center.
"Geothermal or Ground Source Heat Pumps."
http://www.consumerenergycenter.org/home/heating_cooling/geothermal.html#cost. Copyright 2006. Accessed April 30, 2009.
[176] Greenline Plumbing, Atlanta Georgia. http://www.polybutyleneatlanta.com/polybutylene_exterior.html. Copyright 2007. Date Accessed March 17, 2009.
[177] Personal Communication Patrick Willoughby, March 2009. Because LWC would be included in HVAC maintenance, additional costs are negligible.
[178] Personal Communication Patrick Willoughby, March 2009. Because LWC would add an entire AC system which the KSC lacks, maintenance costs are inherently tied to total HVAC costs, and therefore outside the purview of this analysis.
[179] Cornell University Facilities Services Utilities and Energy Management.. "Decision Analysis."
http://www.utilities.cornell.edu/utl_lscanalysis.html. Copyright 2006. Date Accessed March 15, 2009.
[180] This estimate assumes that a newly installed AC system would remain in the KSC until the building's demolition, and that end of life costs would be impossible to separate from the costs of razing the building.

5. Human Power

Summary

Human power generators are energy production mechanisms that turn human motion into electricity. Most cardio exercise equipment can be retrofitted or designed to harness this form of energy. The Human Dynamo, a newly designed exercise machine, is extremely efficient at capturing human motion energy, but would require the purchase of this new type of machine. Retrofitting existing equipment is considered in this report with elliptical trainers as the most efficient energy-capturing piece of exercise equipment. Human power offers students a unique opportunity to recognize the amount of energy required to produce electricity We therefore recommend that the College retrofit existing exercise equipment, especially ellipticals, to harness energy from human motion.

Introduction

Human power describes the process by which energy is created from human motion. Using motion to power electronics and supply electricity is not a new idea. For millennia human power was the only source of energy available. More recently, engineers and innovators have begun developing methods of harnessing human motion to create electricity in developing countries where the electrical supply is unreliable at best.[181] The greatest challenge in the development of human powered devices is the sporadic and fluctuating energy input which poses a challenge to systems and appliances built to work on steady energy input. Some of the devices used to produce this fluctuating input are gym equipment generators, revolving door generators, and electricity generating flooring. Because people visit in order to exert energy, a sports center is an ideal venue for harnessing human motion.

Several gyms across the country already use exercise machines to power their facilities. At the Alumni Gym at the Massachusetts Institute of Technology (MIT), students use a stationary bike to power a laptop.[182] Without using electricity, members can respond to email as they exercise. Gym equipment generators use cardio equipment to spin flywheels that power generators. The electricity from the generator can be stored in a battery or directly connected into the electrical grid. In the case of the laptop computer in MIT's Alumni Gym, a bike is attached to a battery that is charged by the power created by pedaling. The battery then powers a computer, or a similar type of machine, such as a TV. The MIT students who designed the spin bike powered laptop believe that the incentive of creating energy will push those exercising to work harder,

[181] Vijaysree Venkatraman, "An Electric Workout Through Pedal Power," Christian Science Monitor, 13 November 2008, http://features.csmonitor.com/innovation/2008/11/13/an-electric-workout-through-pedal-power/. Accessed March 2009.
[182] Vijaysree Venkatraman, "An Electric Workout Through Pedal Power," Christian Science Monitor, 13 November 2008, "http://features.csmonitor.com/innovation/2008/11/13/an-electric-workout-through-pedal-power/" Accessed March 2009.

creating more energy.[183] At Wellesley, harnessing the energy from cardio equipment would help decrease the electrical draw of the Sports Center on the Physical Plant and reduce the carbon footprint of the building.

Batteries are limited by the amount of energy and length of time that they can retain energy, and they can only power those devices to which it is directly connected. In terms of an environmental life cycle analysis, producing new batteries requires fossil fuels and lead mining, an environmentally damaging process. Batteries must be replaced every three to five years and due to the chemicals contained inside should be recycled at an appropriate hazardous waste site. The benefits of using batteries include low initial installation costs and the fact that they allow TVs or other similar devices to function solely on stored human power even though the exercise machine is not in use.

Harnessing energy from exercise equipment is not just an environmentally friendly operation. The machines may not produce a large amount of energy, but they may start a discussion on campus about energy use, and serve as a reminder to students about energy reduction. Most importantly, they can educate students about how much work is required for energy generation. As part of an environmental education campaign, these machines could act as teaching tools to allow Wellesley to make a clear statement that we are serious about sustainability. If these machines cause students to make behavioral changes that reduce the amount of energy they use, the machines will have even more far-reaching benefits and cost savings than those brought on by the energy they produce alone. The installation of one or more of these human powered energy sources will also increase visibility of the sustainability efforts Wellesley is taking and will act as an investment in further research and development in the field. It may also encourage more visitors to use the equiupment, or use it more intensively, leading to increased fitness.

Different types of exercise equipment require and generate different amount of energy. Ellipticals, for example, are extremely efficient harnessers of human motion; treadmills, on the other hand, actually require more energy to run than they can create. It can nevertheless be helpful to use this machine to create energy allowing it to offset some of the energy it requires to function. The average treadmill uses 1,500-2,000 watts of electricity to operate during an hour-long run.[184] At a gym in Portland, Oregon Team Dynamo Ellipticals and Spin Bikes collectively generate up to 350 watts per hour.[185] A typical group cycling class with about 20 bikes has the potential to produce up to 3.6 Megawatts of renewable energy each year.[186] These figures are dependent on the number of bikes in use, the hours used, and the cadence and resistance level.

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[183] Vijaysree Venkatraman, "An Electric Workout Through Pedal Power," Christian Science Monitor, 13 November 2008, "http://features.csmonitor.com/innovation/2008/11/13/an-electric-workout-through-pedal-power/" Accessed March 2009.

[184] Vijaysree Venkatraman, "An Electric Workout Through Pedal Power," Christian Science Monitor, 13 November 2008, "http://features.csmonitor.com/innovation/2008/11/13/an-electric-workout-through-pedal-power/" Accessed March 2009.

[185] The Green Microgym. "Fifteen ways our gym is green." http://thegreenmicrogym.com/index.php?itemid=82 Accessed March 2009.

[186] "Energy Matters, " The Green Revolution, Inc. http://www.egreenrevolution.com. Accessed March 2009.

Alternatives

Alternatives not considered

Revolving door generators use the kinetic energy of a spinning door to turn a generator. They also cut down on heat and air conditioning loss during the winter compared to regular sliding or swinging doors. A revolving door generator was recently installed in a Netherlands train station, where the energy is used to power the overhead LED lights.[187] The amount of energy produced depends on the number of people that enter and exit a building, and therefore this option would be most practical when installed in a high traffic area. A revolving door may not be a practical entry for the KSC due to the need to move large equipment and injured players in and out of the building. Moreover, such a door is unlikely to generate a significant amount of energy for the building, as the Sports Center is not a high traffic area.

Special electricity generating flooring also uses human motion to create useable energy. By installing subflooring made of moveable blocks that sink and rise slightly under the weight of people moving across it, the motion of walking or jumping is able to power a dynamo that creates electricity.[188] While a single step would generate only enough energy to power two 60W light bulbs for one second, the combined movement of a crowd in motion could generate a substantial amount of power.[189] One such floor is currently in use in the Rotterdam Sustainable Dance Club's Club Watt where movement on the dance floor helps power the club's lighting.[190] The floors the KSC do not receive enough traffic to make this innovative design practical, but as the technology advances becoming more efficient the option may become viable, especially for dance studios.

For our purposes, utilizing gym equipment is the best option for human power due to its low cost and educational benefits. Many types of exercise equipment, including stationary bikes, ellipticals, rowing machines, treadmills and stairmasters, can be retrofit to harness human motion. Here we examine a Team Dynamo exercies machine, a Spin Bike Retrofit, and an elliptical machine by ReCardio.

Team Dynamo

The Team Dynamo is a team exercise machine that couples pedaling with rotating handlebars for a full body cardio workout. Four Human Dynamo machines are connected to a central energy capture system that is used to power a generator or is directly connected to the electrical grid.[191] Currently, this machine is

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[187] Megan Treacy, "Revolving Door Helps Power Train Station," Ecogeek, December 10, 2008, http://www.ecogeek.org/content/view/2376/85/ Accessed March 10, 2008.
[188] Sarah H. Wright, "MIT Duo Sees People-Powered 'Crowd Farm,'" MIT News, July 25, 2007, http://web.mit.edu/newsoffice/2007/crowdfarm-0725.html Accessed March 10, 2008.
[189] Sarah H. Wright, "MIT Duo Sees People-Powered 'Crowd Farm,'" MIT News, July 25, 2007, http://web.mit.edu/newsoffice/2007/crowdfarm-0725.html Accessed March 10, 2008.
[190] Elisabeth Rosenthal, "Partying Helps Power a Dutch Nightclub," Rotterdam Journal, October 23, 2008, http://www.nytimes.com/2008/10/24/world/europe/24rotterdam.html?_r=2&bl&ex=1225166400&en=96e7a637508715b5&ei=5087%0A&oref=slogin Accessed March 10, 2008.
[191] "Human Power: Fitness + Clean Energy," Team Dynamo, http://www.humandynamo.net/teamdynamo.html. Accessed March 2009.

not available in the Sports Center. Because the Human Dynamo "lends itself to group exercise"[192] it would be an ideal type of machine for PE classes and athletic teams to use. A Team Dynamo can generate 150-450 watts of electricity per hour, depending on the participants' fitness levels.[193] Assuming that the machine would be used 270 days a year for 5 hours each day, it would generate between 202.5 and 607.5 kW a year.

Spin Bike Retrofit

Another option for use in the Sports Center is the Spin Bike Retrofit kit. This kit can be used for any type of spin bike and adds minimal size to the actual dimensions of the bike. A spin bike is estimated to produce 35 watts of electricity per hour. The same assumptions (270 days a year, 5 hours a day) are used to calculate the annual energy provided by one bike.

Elliptical by ReCardio

Because of their gear ratios and small amount of moving mass, ellipticals are the ideal machines to retrofit. They also offer the best electrical output.[194] An individual elliptical costs $300 to retrofit, with the price declining as the order increases,[195] making the simultaneous conversion of multiple machines ideal. The machine use assumptions (270 days a year, 5 hours a day) are used to calculate the annual energy generated.

Figure 31. Human Power Alternatives Feasible at Wellesley College

Alternative	Physical Size Specifications (ft)	Electrical Output (kW)	Estimated Annual Output (kWh/a)	Initial Cost ($)
Team Dynamo	About 4'x5'x3' per Human Dynamo	.15-.45 kW/hr depending on team's fitness (indiv. 50 w/hr)	202.5- 607.5	$1450 per Human Dynamo and cost of connection
Spin Bike Retrofit by Green Microgym	Small, 2'x2'x2' at most	.035 kW	47.25	$225 and cost of connection to grid
Elliptical by ReCardio	Small	300 watt-hours or .1kW/hr	135	$300 to retrofit (cost decreases with big orders)

[192] Human Power: Fitness + Clean Energy, "Photo Gallery," http://www.humandynamo.net/photogallery.html. Accessed March 2009.
[193] Human Power: Fitness + Clean Energy, "Team Dynamo," http://www.humandynamo.net/teamdynamo.html. Accessed March 2009,
[194] Zarda, Brett, PopSci.Com, "Sweatin' for the Planet," July 18, 2008. http://www.popsci.com/entertainment-gaming/article/2008-07/sweatin-planet.
[195] Zarda, Brett, PopSci.Com, "Sweatin' for the Planet," July 18, 2008. http://www.popsci.com/entertainment-gaming/article/2008-07/sweatin-planet.

Cost Analysis

The initial costs associated with retrofitting existing equipment are similar for ellipticals and bikes, two types of machines Wellesley already has. The Human Dynamo machine is significantly more expensive because the machine must first be purchased. The high initial cost of installation for all three options is due to the cost of connection to the grid or to a bank of batteries.

As a new technology, little information is available about the cost of connecting these types of machines directly into the power grid. We obtained estimates by looking at the connection costs for other renewable energy generators. Small solar power grid connections in Australia cost about $12,800 US before rebates.[196] The grid connection inverter, which changes the current from DC to AC for use on the grid, can be bought online directly from Energy Matters if you live in Australia. These inverters cost between about $2,000 and $4,000 US depending on the size of inverter needed. The smallest 700 watt inverter is available for $1,822 US, not including shipping costs, taxes, or manufacturer fees.[197]

Figure 32. Human Power Cost Analysis

Alternative	Initial Cost of Unit Purchase ($)	Initial Cost of Installation ($)	Operation Costs ($/annum)	Maintenance costs ($/annum)	Estimated Lifetime (years)	End of Life Cost ($)
Team Dynamo	$1450	$4000-12000	0	Minimal	7	$15-35 each
Spin Bike Retrofit by Green Microgym	$225	$4000-12000	0	Minimal	7	$15-35
Elliptical by ReCardio	$300	$4000-12000	0	Minimal	7	$15-35
Car Battery	$124-334				5	-$5±$20
Safety Casing with Caution Signs	$30-50					
Educational Signs	$50					

[196] Energy Matters, "Grid Connect FAQ's," http://www.energymatters.com.au/renewable-energy/solar-power/grid-connected-systems/home-grid-faq.php. Accessed March 2009.
[197] Energy Matters, "Grid Connection," http://www.energymatters.com.au/inverters-grid-connection-c-151_197.html?zenid=e9536f7afbae6396aa4f3f11bf3eef0a. Accessed March 2009.

Connecting exercise equipment to the electrical grid can be expensive. For some users it is not cost effective to connect only one machine to the grid, as the connection may cost between $4,000 and $10,000; it makes more economic sense if a bank of bikes or ellipticals, as would be available in the Sports Center, is connected to the grid at the same place and time.[198] As the cost of connection equipment decreases, it will become more economical to serve customers in their homes with single machine connections.[199]

If the machines are directly connected to the power grid, human-powered electricity can be used anywhere on the grid. While the motion energy is not powering a specific piece of equipment, it is adding energy to the power grid, offsetting energy that would otherwise be supplied by other sources, such as fossil fuels. It is estimated that a person who spends one hour per day for a year moderately exercising on one of these machines, could generate 18.2 kilowatts of electricity, and prevent 4,380 liters of CO_2 from being released into the atmosphere.[200]A Spin bike retrofit kit can be purchased from The Green Microgym for $200, but it does not include the battery that stores the energy generated.[201]

Connecting retrofitted machines to car batteries is much cheaper and easier than connecting directly to the grid. Costs are associated with purchasing and installing batteries and DC/AC inverters as well as creating a protective casing around the battery to ensure the safety of all users. Most car batteries cost between $124-$334, depending on the size, expected lifetime, and intended car model of the battery.[202] Batteries have a lifetime that ranges between three and five years depending on the aforementioned specifications. [203] There are over 405 programs in the state of Massachusetts currently recycling lead-acid car batteries, some of which pay for these recycled materials.[204] As an electrical device that would most likely be stored above ground that contains potentially dangerous chemicals, some safety measures would be required. The building of a simple casing around the battery or embankment of batteries should meet all necessary safety regulations. We anticipate that currently employed skilled Facilities staff can build this protective casing for less than $50.

These machines are run by human power, and therefore have no operational costs. Maintenance costs are difficult to determine. No sources yet list maintenance costs because much of the equipment is so new. The addition of energy harvesting equipment should not shorten the lifespan of exercise equipment.

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[198] The Green Revolution. "About the Technology- FAQ's." http://www.egreenrevolution.com/faqs.aspx?setting=1. Accessed March 2009.
[199] The Green Revolution. "About the Technology- FAQ's." http://www.egreenrevolution.com/faqs.aspx?setting=1. Accessed March 2009.
[200] Tylene Levesque, "Human Powered Gyms in Hong Kong," Inhabitat, March 8, 2007, http://www.inhabitat.com/2007/03/08/human-powered-gyms-in-hong-kong/ Accessed March 10, 2009.
[201] The Green Microgym. "Spink Bike Retrofit." http://thegreenmicrogym.com/greenmicrogym.php?itemid=133. Accessed March 2009.
[202] Apex Battery: Power your life, work and play, "Batteries," Visited March 2009. http://www.apexbattery.com/car-batteries.html. Accessed March 2009.
[203] Ofria, Charles, Familycar.com, "My car won't start, what should I do?" http://www.familycar.com/carrepair/nostart.htm. Accessed March 2009.
[204] Waste Cap of Massachusetts, "Information on Recycling Lead Acid/Automotive Batteries," Waste Cap of Massachusetts, http://www.wastecap.org/wastecap/commodities/batteries/leadbatteries.htm#benefitsleadbatteries. Accessed May 1, 2009.

Energy Savings

Electricity from exercise equipment will generate very little of the total electricity needed to supply the Sports Center. Assuming that the total electricity use of the Sports Center is 1,740,710 kW per year, ten stationary bikes and ten ellipticals could produce .01% and .03% of the electricity needed to power the Sports Center respectively. A single Team Dynamo machine could supply between .005% and .014% of the Sports Center electricity.

Assuming that the energy produced by the cogeneration plant costs $0.125, the installation of the Human Dynamo could save $76 worth of electricity in a year, ten bikes could save $60 worth of electricity, and ten ellipticals could save $168 worth of electricity per year. These machines will never pay back their initial costs based on their energy generation alone. It would take ten ellipticals more than 25 years to make enough energy to cover the costs of retrofitting the machines plus attaching them to the grid.

Based on cost comparisons, retrofitting an elliptical is the most cost effective option. Ellipticals produce more energy than bikes and retrofitting one costs much less than purchasing a new Human Dynamo machine. As users of the Sports Center will continue to want a variety of machines available, multiple types of machines should be retrofitted.

Recommendations

Wellesley should pursue human motion energy production because of the educational benefits as well as its ability to produce energy at no extra cost after the initial installation. Students would learn exactly how much energy is required to produce a certain amount of electricity. With proper educational signage around retrofitted exercise machines students will make the connection between energy consumption, fossil fuel use, and energy reduction. This system as a part of a broader environmental education campaign will invoke behavioral changes that will affect electricity use across campus, having a much larger effect than simply reducing the Sports Center's draw on electricity and impacting student energy use far into the future.

Green Grant

With the support of PERA Staff and Patrick Willoughby, members of ES300 received a Green Grant, a grant awarded by the Sustainability Committee that will provide $2000 for the installation of two ReCardio® retrofitted elliptical machines. The Green Grant is listed in Appendix E. These ellipticals will power a cable television or DVD player and will be used as a pilot program for further expansion of Human Power at the KSC. The members of the class of 2010 in ES300 have committed to sponsoring the pilot program and the installation of these machines next fall. It is our hope that this installation will be the first of many implementations of our recommendations.

6. Energy Conclusion

Within each category of energy generation technologies, we evaluated several alternatives and determined the most beneficial options for the KSC. We recommend the combination of a roof-mounted thin-film photovoltaic flat panel system, a Redriven 20 kW wind turbine, and retrofitted energy-generating exercise equipment. The first two options will provide significant amounts of energy, reducing the extent to which we burn fossil fuels on campus. The exercise equipment will have educational benefits for the community by allowing students to link their work to energy production and use. Although the geothermal power options of a vertical closed-loop heat pump and lake water cooling would be able to significantly reduce current energy use for heating the Sports Center, implementation of these options is a lower priority. Drilling for a heat pump can be expensive and lake water cooling is not currently an option on campus due to permitting issues.

Using a combination of energy generating technologies in the Sports Center will provide the college with an opportunity to test a variety of options that could then be employed elsewhere on campus. Even when used in combination, none of our recommended energy options will provide a large percentage of the KSC's current energy needs. However, as energy efficiency measures are implemented in the Sports Center and the KSC's total energy use drops, the proportion of energy generated from renewable sources will increase accordingly.

Figure 33. Summary of energy generation by recommended alternatives

Alternative	Energy generated (kWh/a)	Percentage of KSC energy demand met
Roof-mounted thin film flat panels	118,000	2.0
Redriven 20 kW turbine	25,000	0.4
Elliptical by Recardio	135	0.0

IV. Energy Efficiency

Summary

It is important to consider energy efficiency in order to transform the KSC into a clean, green, athletics machine. The KSC currently uses a substantial amount of energy for routine operations, and many aspects of its daily use can improve in energy efficiency. In this section, we investigate alternative models for appliances, with a special focus on energy star models, in addition to heating system alternatives, including space heating, pool heating, and solar water heating. Behavioral changes have great potential for improving energy efficiency on the Wellesley campus. Finally, we make specific suggestions for improving the energy efficiency of the KSC across all of these aspects. With physical appliance replacements and positive behavioral changes in the student body, the KSC will lead to a healthier body and a healthier planet.

Introduction

Planning for a more sustainable and green Sports Center would not be complete without evaluating and improving the building's energy efficiency. Because the facility requires a substantial amount of energy, many aspects of the KSC can be significantly improved in their energy efficiency. Higher education institutions spend close to $2 billion each year on energy.[205] Adopting a strategic approach to energy management can lower energy bills by 30% or more.[206] Energy efficiency improvements would not only save money by decreasing the total amount of energy required by the building, but would further enable our alternative and renewable energy technologies to contribute a greater proportion of the building's total energy use.

Wellesley should promote energy efficiency as a major component of its sustainability program. The promotion of energy awareness through campaigns and educational events is an important outreach tool to the Wellesley College community, but to be most effective Wellesley needs to demonstrate active dedication to improving energy efficiency and decreasing energy consumption on campus. Contemporaries to Wellesley area leading the way in promoting awareness and education on their campuses, such as Oberlin College which has visible energy meters installed in the student dorms,[207] or Smith College and Harvard University which have partnered with Energy Star in promoting energy efficiency on their campuses.[208]

There are many different means by which to approach energy efficiency. These approaches include small-scale personal or behavioral changes that individual users can implement, appliance replacements with more efficient models, as well as large-scale infrastructure changes within the building's physical makeup. In the following sections we briefly consider lighting, appliances, heating, and behavioral changes as they relate to the KSC. Finally, we close with a vision for a more energy efficient Sports Center, including specific recommendations for Wellesley.

Energy Star

The Energy Star program was created by the United States Environmental Protection Agency and the Department of Energy in 1992.[209] It was initiated to promote energy efficient products and practices in conjunction with money saving and environmental protection plans.[210] Energy Star products were successful not only within residential communities, but also at larger-scale commercial operations. Energy Star products

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[205] 1999 EIA CBECS data for healthcare, http://www.energystar.gov/index.cfm?c=higher_ed.bus_highereducation. Accessed April 13, 2009.
[206] For Higher Education, http://www.energystar.gov/index.cfm?c=higher_ed.bus_highereducation. Accessed April 13, 2009.
[207]Naggy, Amanda. Oberlin College News & Features, Dorm Competition Lights Up With Energy Orbs, http://www.oberlin.edu/news-info/08apr/energyorbs.html. Date Accessed: April 13, 2009.
[208] Energy Star: Buildings and Plants Partner List, http://www.energystar.gov/index.cfm?fuseaction=PARTNER_LIST.showPartnerResults&partner_type_id=CID&s_code=ALL. Accessed April 13, 2009.
[209]Energy efficiency timeline: Wisconsin Energy Conservation Corporation, http://www.weccusa.org/main/abouttimeline/title/Energy%20efficiency%20timeline. Accessed April 14, 2009.
[210] Energy Star, About Energy Star, http://www.energystar.gov/index.cfm?c=about.ab_index. Accessed April 14, 2009.

are easily identified by their signature logo and enable quick decisions for consumers who are pursuing energy efficient choices.

Figure 34. Energy star symbol[211]

Lighting

Lighting plays a significant role in the energy consumption of the Keohane Sports Center. Currently there is a wide range of bulbs and fixtures installed throughout the building, from incandescent to compact fluorescents in the lobby and metal halides in the field house. Assessing the energy efficiency of the KSC requires an understanding of the lighting scheme within the building. This is considered extensively in the Lighting chapter of this report, which recommends a more efficient lighting scheme.

Energy Efficiency for Miscellaneous Appliances

In the KSC, five of the top ten uses of energy (after heating and lighting) relate to localized appliances rather than large-scale heating and lighting systems. These five energy uses are for pool filters (214,620 kWh/a), exercise machines (68,438 kWh/a), computers (19,710 kWh/a), refrigerators (14,016 kWh/a), and hand dryers (13,410 kWh/a).[212] Saving energy is possible in almost all of these categories without complete elimination of the appliance, although replacement of the appliance with a more efficient one is often necessary.

[211] For Higher Education, http://www.energystar.gov/index.cfm?c=higher_ed.bus_highereducation, Accessed April 13, 2009.
[212] See Appendix B

Figure 35. Appliance Improvements

Action	Energy savings per unit (kWh/a)	Initial cost per unit	Lifetime
Replace current treadmills with SportsArt Fitness T680 Treadmill	1,700	$8,000	3+ years
Switch from desktop to laptop computers	584	little to no added cost [213]	3+ years[214]
Replace current refrigerators with Energy-Star refrigerators	2,750 (minimum)	under $3,000	15 years[215]
Replace current hand dryers with XLERATOR® hand dryers	792	$540[216]	5+ years

Pool Filters

The simplest way to maximize the energy efficiency of a pool's filters is to maintain them well and to run them as little as possible. The manual for the filters contains instructions on appropriate procedures for cleaning the filter, and the filter should be checked regularly for debris that could be blocking the flow of water through the filter.[217]

A commercial-size pool in Oakland, CA, provides an example of how energy efficiency can be improved in a public pool. The pool ran into a public health barrier to improving filtration energy efficiency by limiting filtering time, but was able to reduce energy use in other ways. According to an assessment of the pool's construction, the Oakland pool could improve energy efficiency by installing an additional filter to obtain a more optimal water pressure gradient and thus make passage of water through the filters more efficient.[218] A similar assessment of Wellesley's Chandler Pool should be undertaken for pool energy efficiency before implementing purported energy efficiency measures to make sure that this specific pool's issues are addressed correctly. In the meantime, appropriate maintenance and replacement of filter parts will help the individual filters to operate as efficiently as possible.

[213] Matt Owen, "Reducing Cost and Going Green," British Computer Society, http://www.bcs.org/server.php?show=ConBlogEntry.934&displayMode=comment. Accessed April 13, 2009.
[214] Martyn Williams, "HP Starts Selling Batteries Guaranteed for Laptop's Lifetime," PCWorld, http://www.pcworld.com/article/161287/hp_starts_selling_batteries_guaranteed_for_laptops_lifetime.html. Accessed April 12, 2009.
[215] U.S. Department of Energy, "Why Buy an Energy Efficient Refrigerator?" HealthGoods, http://www.healthgoods.com/Education/Healthy_Home_Information/Home_Appliances/refrigerators.htm. Accessed April 14, 2009.
[216] NexTag Inc., "Excel Dryer," NexTag Comparison Shopping, http://www.nextag.com/excel-dryer/stores-html. Accessed April 14, 2009.
[217] California Energy Commission, "Pools and Spas," Consumer Energy Center, http://www.consumerenergycenter.org/home/outside/pools_spas.html. Accessed April 12, 2009.
[218] Donald M. Cooper, "Energy Efficient Commercial Pool Program Preliminary Facility Report," City of Oakland Public Works Agency, http://www.oaklandpw.com/AssetFactory.aspx?did=2613. Accessed April 12, 2009.

Exercise Machines

The majority of exercise machines in the Keohane Sports Center—ellipticals, stationary bicycles, and stair steppers—require no energy input to operate; on the other hand, the average treadmill uses as much energy as fifteen incandescent light bulbs.[219] The easiest way to eliminate this use of energy is to encourage treadmill users to use the indoor or outdoor tracks instead. The addition of a cantilevered track, as detailed in the Physical Space Chapter, would facilitate this shift.

Because treadmills have other advantages besides being a place to walk or run indoors, a more practical solution to the problem of treadmills' high energy use would be to purchase more energy efficient treadmills. Washington-based SportsArt Fitness produces three such models: the T650, T670, and T680. All three of these models are for heavy-use commercial applications, and they will be well suited to the frequent use they would experience in the Sports Center. These treadmills models are built with an EcoPower™ motor that uses 32% less energy than conventional treadmill motors while still running at five horsepower. The T680 model has the most similar features to the Life Fitness treadmills currently in the field house, including an LCD entertainment screen.[221] A SportsArt Fitness T680 treadmill costs approximately $8000,[222] which is comparable to the price of a similar-sized Life Fitness treadmill.[223] The treadmills differ little in component materials, thus it makes little difference from an environmental standpoint which model is used to replace the current machines.

Computers

The Keohane Sports Center houses thirty computers used on a daily basis, making computers the eighth-largest use of energy in the building. Because computers are essential for most office work, cutting back on the number of Sports Center computers to reduce energy consumption is not feasible. A reduction in energy consumption is possible if the building switches from desktop to laptop computers, as the latter use an average of 25 W of energy,[224] while the current computers in the sports center use an estimated 225 W. Part of this difference in energy comes from the common use of cathode ray tube (CRT) monitors for desktop computers and the use of liquid crystal display (LCD) monitors for laptops; LCD screens use only 10

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[219] Lloyd Alter, "Treadmills Suck. (Kilowatts)," Treehugger, January 22, 2008, http://www.treehugger.com/files/2008/01/treadmills_suck.php. Accessed April 13, 2009.
[221] "SportsArt Fitness Goes Green With The First EcoPowr™ Treadmill Motor," SportsArt Fitness press release (Woodinville, WA, December 27, 2006), http://www.sportsartamerica.com/saf/aboutus/press_releases/SportsArt_Intros_EcoPowr.pdf. Accessed April 13, 2009.
[222] "SportsArt® T680 Treadmill," iFitness Direct, http://www.fitdir.com/product-937.html_SportsArt_T680_Treadmill. Accessed April 13, 2009.
[223] "Life Fitness," iFitness Direct, http://www.ifitnessdirect.com/index.php?manufacturers_id=78. Accessed April 13, 2009.
[224] Matt Owen, "Reducing Cost and Going Green," British Computer Society, http://www.bcs.org/server.php?show=ConBlogEntry.934&displayMode=comment. Accessed April 13, 2009.

to 20% of the energy used by CRT screens per square inch.[225] Therefore, significant energy reductions could be accomplished simply by switching computer screens from CRT to LCD screens, which are also available for desktop computers. From a broader environmental view, though, laptops could enable employees to telecommute on some days, which would save on the use of fossil fuel energy for transportation and reduce greenhouse gas emissions. They might, however, be subject to a greater likelihood of loss or damage.

Despite the energy savings possible when switching from desktop to laptop computers, the Sports Center should only switch to laptops when the current computers are no longer usable, because disposal of computers is a serious environmental concern. Less than 20% of "e-waste" is currently recycled, and most of what is given to "recyclers" is actually shipped to the developing world under the guise of reuse of the machines by people living in these countries. Wellesley's computers are currently recycled through the Institutional Recycling Network (IRN). Computers are recycled locally, at facilities the organization audits."[226]

Another argument for choosing laptops over desktops is that the life cycle of laptops has a smaller impact on the environment than the life cycle of desktop computers. Most obviously, laptops are smaller and so require less material overall to be extracted and processed or else recycled from other forms in order to produce the computer. LCD screens also represent a significant improvement over the CRT displays usually found on desktop computers, because LCD screens have greater environmental effects than CRT screens in only two categories of effects, water eutrophication and aquatic toxicity. CRT screens have greater environmental effects than LCD screens in terms of energy use, resource use, ozone depletion, and human health toxicity.[227]

Refrigerators

The Sports Center currently uses four refrigerators that each require a massive 3500 kWh/a. All Energy Star refrigerators, which use less than 750 kWh/a, represent very significant improvements over the current refrigerators in terms of energy use.[228] Replacing old and inefficient mid-sized refrigerators with new energy-efficient models will have an immediate impact on efficiency, but the economic and environmental costs of disposing of old refrigerators and manufacturing new ones must be considered. In the case of the current refrigerators, which use over 1000 kWh/a, environmental, cost and energy use perspectives all argue

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[225] Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory, "Home Office Equipment," Home Energy Saver, http://hes.lbl.gov/hes/makingithappen/no_regrets/homeoffice.html. Accessed April 12, 2009.
[226] IRN, "IRN Recycles 1.75 Million Pounds of Computers in 2008," http://www.ir-network.com/prog_elec.html. Accessed May 9, 2009.
[227] Maria Leet Socolof, Jonathan G. Overly, and Jack R. Geibig, "Environmental life-cycle impacts of CRT and LCD desktop computer displays," Journal of Cleaner Production 13, no. 13-14 (2005): 1281-1294.
[228] U.S. Department of Energy and U.S. Environmental Protection Agency, "ENERGY STAR Qualified Refrigerators & Freezers," Energy Star, http://www.energystar.gov/index.cfm?fuseaction=refrig.display_products_html. Accessed April 13, 2009.

for immediate replacement.[229] The cost of replacing the current refrigerators with Energy Star refrigerators would be under $3000 per refrigerator.[230] As additional encouragement, the College actually has a little-enforced policy that requires energy-star appliances around campus.

Hand Dryers

The hand dryers in the KSC, which use 2.2 kW, represent the building's tenth-largest use of energy. By contrast, the Dyson Airblade model dryer is able to dry hands using only 0.00468 kWh per dry, using no heaters and rapid drying times.[231] While this model is highly innovative, it is not particularly appropriate for the Sports Center. Hand dryers at the KSC are primarily used to dry hair, and the Dyson Airblade is designed to have the person's hands stuck inside it, which would be much more difficult with hair. A more practical, though less efficient, model is EXCEL Dryer, Inc.'s XLERATOR® Hand Dryer. This model uses 900 W of energy,[232] thus representing an annual savings of 792 kWh/a for each dryer that would be replaced. The XLERATOR® Hand Dryer is similar in size and shape to conventional hand dryers, allowing it to be used for drying hair as well as hands. Additionally, this hand dryer is listed in GreenSpec, the national directory of 1650 green building products.[233]

The XLERATOR® Hand Dryer is made primarily of a zinc alloy.[234] Zinc is an essential metal, though it can bioconcentrate in upper trophic levels of the food web and cause disease at high levels of exposure. It is released into the atmosphere during smelting, and can contaminate water during extraction. However, some zinc can be salvaged and reused instead of being sent to landfills, so recycling of the material would reduce the environmental impact of this product.[235] Another environmental benefit of this hand dryer model is the manufacturer's nearby location in East Longmeadow, MA,[236] which cuts down on the release of greenhouse gases through the transportation of the products to Wellesley College. As with the energy efficient replacement products described in the above sections, the environmental costs of disposal of the old appliance and manufacture of the new appliance should be compared against energy savings to determine whether immediate replacement is desirable or whether the College can wait until the current appliances are no longer useful.

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[229] Hyung Chul Kim, Gregory A. Keoleian, and Yuhta A. Horie, "Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost," Energy Policy 34, no. 15 (2006): 2310-2323.
[230] NexTag Inc., "Energy Star Refrigerator," NexTag Comparison Shopping, http://www.nextag.com/energy-star-refrigerator/compare-html. Accessed April 13, 2009.
[231] "Dyson Airblade: Technology & Specs," AirEfficient.com, http://www.airefficient.com/air-efficient-products/dyson-airblade/technology-and-specs.php. Accessed April 14, 2009.
[232] Excel Dryer, "Specifications," XLERATOR® Hand Dryers. http://www.exceldryer.com/Products/xlerator.asp. Accessed April 14, 2009.
[233] "BuildingGreen Announces Top-10 Green Building Products," BuildingGreen press release (Austin, TX, November 14, 2002), http://www.exceldryer.com/TopTen2002.asp. Accessed April 14, 2009.
[234] Excel Dryer, "Specifications," XLERATOR® Hand Dryers. http://www.exceldryer.com/Products/xlerator.asp. Accessed April 14, 2009.
[235] Spectrum Laboratories, "Zinc," Spectrum Chemical Fact Sheet, http://www.speclab.com/elements/zinc.htm. Accessed April 14, 2009.
[236] Excel Dryer, "About Excel Dryer," http://www.exceldryer.com/Products/xlerator.asp. Accessed April 14, 2009.

Heating Efficiency

Heating is a key part of HVAC (heating, ventilation, and air-conditioning) systems, which account for 40 to 60% of the energy used in US commercial and residential buildings.[237] As such, replacing less efficient heating equipment with newer, more efficient equipment can yield substantial reductions in building operating costs. According to the EPA, replacing components of a less efficient HVAC system typically cuts energy costs by about 20%.[238] Improving HVAC systems also provides a better environment for employees, as issues like user discomfort, improper ventilation, and poor indoor air quality are linked to HVAC system design and operation.[239] Improved filtration technology decreases the amount of particulates and biocontaminants such as fungus, mold, and viruses. More efficient HVAC systems are also more effective at filtering out air pollutants such as nitrogen oxides, carbon monoxide, and sulfur oxides.[240]

There are currently a wide variety of technologies available for heating buildings, including gas- or oil-fired boilers or furnaces, heat pumps, gas-fired rooftop units, and electric-resistance heat. Other heating technologies include infrared radiation and radiant floor heat.[241] Many of these options contain certain supporting elements in common (like thermostats and ducts). When completing renovation projects the presence of common supporting elements will be an important factor in which heating systems you can use. Generally when completing renovations the easiest route is to replace the existing technology with an updated model of the same type, as things become more complicated when switching among different heating technologies. For example, many systems that use steam or hot water heating, radiant heating, or electric resistance heating do not have ducts which can make switching to those systems prohibitively difficult and expensive.[242]

There are also many commercial options available for heating pools, including gas-fired, electric-resistance, heat pump, and solar options. Heat loss is an important consideration which is particularly relevant to pools, and as such should be considered as part of the heating requirements.

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[237] U.S. Department of Energy, 06.04.2008, Energy Efficiency and Renewable Energy Building Technologies Program, Commercial Buildings – Heating, Ventilation, and Air Conditioning. http://www1.eere.energy.gov/buildings/commercial/hvac.html Accessed April 10, 2009.

[238] National Resources Defense Council. No date. Green Business: Green Business Guides – Replacing Older HVAC Systems. http://www.nrdc.org/enterprise/greeningadvisor/cri-hvac.asp Accessed April 10, 2009.

[239] U.S. Department of Energy, 06.04.2008, Energy Efficiency and Renewable Energy Building Technologies Program, Commercial Buildings – Heating, Ventilation, and Air Conditioning. http://www1.eere.energy.gov/buildings/commercial/hvac.html Accessed April 10, 2009.
National Resources Defense Council. No date. Green Business: Green Business Guides – Replacing Older HVAC Systems. http://www.nrdc.org/enterprise/greeningadvisor/cri-hvac.asp Accessed April 10, 2009.

[240] National Resources Defense Council. No date. Green Business: Green Business Guides – Replacing Older HVAC Systems. http://www.nrdc.org/enterprise/greeningadvisor/cri-hvac.asp Accessed April 10, 2009.

[241] N. C. Department of Natural Resources, Division of Pollution Prevention and Environmental Assistance, 2003, Energy Efficiency in Industrial HVAC Systems, http://www.p2pays.org/ref/26/25985.pdf, Accessed April 10, 2009.

[242] U.S. Department of Energy, 03.24.2009, Energy Efficiency and Renewable Energy Energy Savers – Space Heating and Cooling, http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12300 Accessed 4.10.2009.

Current Heating Systems at the KSC

It currently takes just over 4 million kWh of energy a year to heat the KSC, which accounts for two-thirds of the energy used by the building (Energy Chapter). The heating for the KSC is currently divided into three separate zones: the pool, the field house, and the main building. All three facilities are monitored for air temperature and the condition of the fans, motors and air filters and can be controlled remotely by computer. All three areas utilize forced hot air from steam, in which the steam warms heat exchangers in the buildings. Cool indoor air is passed over the heat exchangers and the warmed air is then re-circulated throughout the building. The steam for this system is either piped in from the cogeneration plant near the Lulu Chow Want Campus Center or generated on-site.

There are three such units in the main building that utilize forced hot air from steam generated using on-site boilers. These units are near the end of their useful life and as such are of the highest priority when considering potential heating improvements.

Heating systems in both the field house and pool utilize forced hot air with steam piped in from the cogeneration plant. Under this system waste heat from the cogeneration plant's engines is used to partially heat water going into the boilers. The boilers then heat the water further to produce steam that is piped to multiple campus buildings, including the KSC. The units in the field house are newer than those in the pool; however, the pool house also has a dehumidification system with a fairly efficient heat recovery component. It is important to note however, that the heat recovery system is experiencing some maintenance issues at this time.

Opportunities for improvement

There are many ways of making a building's heating system more efficient including improving the efficiency of the heating technologies, reducing the required heating loads (through improved building insulation), and the use of heat recovery systems.

Space Heating

Efficiency of the heating system

Heating systems that use forced hot air from steam are generally fairly cost efficient compared to other technologies. The systems in the field house and pool are more efficient than the units in the main building, not only because they are newer, but also because the water is partly heated with waste heat from engines in the cogeneration plant. As such, when the units in the main building reach the end of their useful lifetime (estimated to be relatively soon) we recommend upgrading to a higher-efficiency model or system. Most heating systems have gone through incredible technological improvement in the past twenty years and are much more efficient than their older commercial counterparts. The U. S. Government's Energy Star website has a comprehensive list of efficient heating technologies (including boilers, gas furnaces, and heat

pumps), some of which are combined heating/AC units. Other major improvements in the energy-efficiency of heating come from minimizing the use of the heating system through system optimization.

System optimization

The first major optimization strategy is creating and implementing an energy management system that automatically monitors and controls the heating system for maximum efficiency. A good energy management system will reduce HVAC operation when the building or space is unoccupied, reduce HVAC operating hours, and reduce unnecessary heating through zoning technology.[243] While the current heating system at the KSC is effectively zoned we recommend implementing these other techniques to minimize the use of the heating system.

Other important system optimization steps include minimizing the amount of air delivered to the heated space, minimizing exhaust and make-up air, and employing a heat recovery system. Heat recovery systems can help make heating systems more cost-effective by reclaiming energy from exhaust airflows.[244] The pool is currently the only part of the KSC with heat recovery. We recommend doing a cost-benefit analysis before adding a heat recovery system to other parts of the KSC, as other less costly measures (improved insulation, etc) will minimize heat loss in winter as well. The last important system optimization step is to implement a comprehensive maintenance plan including checking dampers and ducts, repairing any leaks, cleaning condenser coils, replacing air filters, and ensuring all windows and doors have tight seals.

Insulation

It has been shown that proper insulation of the walls, roof, and foundation minimizes heat loss to the outside and can lead to lower heating requirements during the winter months. Insulation can be an important strategy for maximizing the energy efficiency of buildings in cold climates such as New England.[245] Improving the insulation in the KSC will lead to major reductions in heating costs and major increases in building efficiency.

Boosting wall insulation levels in existing buildings is generally difficult without expensive building modifications. One less-expensive option for existing buildings is adding an exterior insulation and finish system (EIFS) on the outside of the current building skin.[246] One must take care to install a system that

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[243] N. C. Department of Natural Resources, Division of Pollution Prevention and Environmental Assistance, 2003, Energy Efficiency in Industrial HVAC Systems, http://www.p2pays.org/ref/26/25985.pdf, Accessed April 10, 2009.
[244] Toolbase Services, no date, Toolbase Resources – Energy and Heat Recovery Ventilators (ERV/HRV), http://www.toolbase.org/Technology-Inventory/HVAC/energy-recovery-ventilators, Accessed April 10, 2009.
[245] U.S. Department of Energy, 06.04.2008, Energy Efficiency and Renewable Energy Building Technologies Program, Commercial Buildings – Walls and Roofs, http://www1.eere.energy.gov/buildings/commercial/walls.html, Accessed April 10, 2009
[246] U.S. Department of Energy, 06.04.2008, Energy Efficiency and Renewable Energy Building Technologies Program, Commercial Buildings – Walls and Roofs, http://www1.eere.energy.gov/buildings/commercial/walls.html, Accessed April 10, 2009.

includes a drainage layer to accommodate small leaks that may occur over time and to avoid barrier-type systems.[247]

While increasing wall insulation is difficult, roof insulation can be increased relatively easily, especially when the roof is being replaced. At the time of re-roofing, we propose switching to a protected-membrane roofing system, which allows reuse of the rigid insulation during future re-roofing.[248] Insulation efforts at the KSC should be focused on the roof as it is easier and less expensive than adding additional insulation to the walls and the field house roof is likely to be replaced within the next few years. When larger-scale renovations are undertaken, adding more efficient wall insulation should be an important consideration.

Pool Heating and Heat Recovery

The current system of heating the pool is relatively efficient compared to other alternatives because it utilizes the waste heat from the cogeneration plant's engines. If we wanted to consider more environmentally-friendly alternatives we would have to consider what else could be done with the waste heat from the cogeneration plant. Within alternative heating technologies solar options emerge as a particularly desirable option as they provide the heating from a renewable energy source and offer lower heating costs over time (since the energy doesn't cost anything once the system has paid for itself).

Initial heating of the pool isn't the only source of energy for swimming pools. There are two forms of heat loss from swimming pools, both of which must be addressed by the heating and/or heat recovery systems. The loss of sensible heat is due to temperature differences, while the loss of latent heat is due to moisture evaporating from the pool surface.[249] Sensible heat loss can be reduced by adjusting the indoor air temperature and properly insulating the building.[250] The indoor air temperature of the Chandler pool is currently closely monitored to ensure minimal sensible heat loss; however, the insulation of the pool can likely be improved. As such, we recommend improving the insulation of the pool building when the pool roof is due to be replaced, as improving the insulation of the roof will be less intrusive and expensive than adding insulation to the walls.

Latent heat loss can be reduced by adjusting the indoor temperature and humidity, using a pool cover when the pool is unoccupied for long periods of time, and installing a heat pump dehumidifier (preferably one with heat recovery capabilities).[251] The Chandler pool has an efficient dehumidification system with heat

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[247] U.S. Department of Energy, 06.04.2008, Energy Efficiency and Renewable Energy Building Technologies Program, Commercial Buildings – Walls and Roofs, http://www1.eere.energy.gov/buildings/commercial/walls.html, Accessed April 10, 2009.
[248] U.S. Department of Energy, 06.04.2008, Energy Efficiency and Renewable Energy Building Technologies Program, Commercial Buildings – Walls and Roofs, http://www1.eere.energy.gov/buildings/commercial/walls.html, Accessed April 10, 2009.
[249] Western Area Power Administration Energy Services Bulletin, 2006, "Calculating energy savings of indoor swimming pool measures", http://www.wapa.gov/es/pubs/ESB/2006/oct/oct06SPOT.htm, Accessed April 10, 2009.
[250] Western Area Power Administration Energy Services Bulletin, 2006, "Calculating energy savings of indoor swimming pool measures", http://www.wapa.gov/es/pubs/ESB/2006/oct/oct06SPOT.htm, Accessed April 10, 2009.
[251] Western Area Power Administration Energy Services Bulletin, 2006, "Calculating energy savings of indoor swimming pool measures", http://www.wapa.gov/es/pubs/ESB/2006/oct/oct06SPOT.htm, Accessed April 10, 2009.

recovery but is experiencing maintenance issues with the system at this time.[252] We strongly recommend fixing this system as soon as possible to increase the efficiency of the pool's heating system back to its previous level. Other methods of improving the heating and energy efficiency of a swimming pool include installing a properly sized, energy-efficient circulation pump and/or operating it less.[253] The current size and efficiency of the circulation pump are not known, but operating the current pump less is not likely to be possible due to the high use the Chandler pool receives (and required water cleanliness standards).

Solar Water Heating

The Sports Center's unique set of needs and moderate demand for hot water make it a prime candidate for the installation of a solar hot water system for both domestic needs (showers, sinks, etc) and for the temperature of the pool. Heating pools via solar hot water systems is highly cost effective because they are already equipped with pumps and filters - two of the four necessary pieces of a solar heating system[254] Additionally, because pools require lower water temperatures than domestic water heating systems, returns on initial investment costs tend to occur relatively quickly.[255]

Solar swimming pool heaters are generally composed of four parts: a solar collector, which captures and stores the heat from the sun and transfers that heat to water as it moves through the collector, a filter, to remove debris before pool water is sent through the collector, a pump, which circulates water from the pool through the filter, collector, and back into the pool, and a flow control valve which sends water through the filter and collector with a manual switch or a computer operated sensor as necessary.[256] Water is pumped through the filter and into the collector where it is heated directly and then returned to the pool. Pool heaters generally do not utilize heat transfer fluids or heat exchangers simply because water does not need to reach temperatures above 212°F. In areas where environmental temperatures frequently dip below freezing, such additional equipment is often necessary.

Commercial-sized solar hot water heaters require many storage tanks with multiple variations of solar collectors. In the case of these water heaters, back-up water heaters are necessary to provide hot water in the event that the sun cannot heat water quickly enough to provide hot water during times of high demand.[257]

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[252] Patrick Willoughby, personal communication April 2009.
[253] U.S. Department of Energy, 02.24.2009, Energy Efficiency and Renewable Energy Energy Savers – Swimming Pool Heating, [http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13130], Accessed April 10, 2009.
[254] Harvard University Office of Sustainability, "Renewable Energy: Solar Thermal," Harvard University Office of Sustainability, http://www.greencampus.harvard.edu/cre/solarthermal.php Accessed March 17, 2009.
[255] Harvard University Office of Sustainability, "Renewable Energy: Solar Thermal," Harvard University Office of Sustainability, http://www.greencampus.harvard.edu/cre/solarthermal.php Accessed March 17, 2009.
[256] US Department of Energy, "A Consumer's Guide to Energy Efficiency and Renewable Energy: Solar Swimming Pool Heaters," US Department of Energy, http://apps1.eere.energy.gov/consumer/your_home/water_heating/index.cfm/mytopic=13230 Accessed March 17, 2009.
[257] US Department of Energy, "Commercial Buildings: Building Technologies Program, Solar Water Heating ," US Department of Energy,

Many water heating systems are designed to meet 100% of hot water demand on the sunniest day of the year so that they meet 70% of total hot water demand yearly.[258]

In order to heat the water, a heat transfer fluid, often a non-toxic food-grade propylene glycol-water mixture, or the water itself, is run through a solar collector and is either used directly or, in the case of heat transfer fluid, is run through a heat exchanger where the potable water is heated by the transfer fluid. Hot water is then stored in an insulated tank or a standard water heater. As technology continues to advance, solar water heaters increasingly act as the sole provider of hot water, several older systems, however, act as intermediaries in the process of heating water, bringing the water to a higher temperature so that less conventional water heating is necessary.[259] More and more colleges and universities are turning to solar power to meet domestic hot water demands such as Leicester College, U.K.[260] Guilford College in North Carolina[261] and Northland College in Wisconsin[262] have both installed domestic solar water heating systems. Amherst College, along with a growing group of universities, has begun implementing solar water heating on a small scale, beginning first with the president's house and the physical plant administrative offices with plans to expand the program in the future.[263] More than 300,000 pools in the United States are heated using solar energy.[264]

Types of Solar Hot Water Systems

There are five primary types of solar hot water systems: thermosiphon, direct-circulation systems, drain-down, indirect air, and indirect water heating.[265] In thermosiphon systems, an antifreeze solution is heated and naturally conducted through the heat exchanger via convection (hot water rises above cold water)

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http://www1.eere.energy.gov/buildings/commercial/water_heating.html#Solar_Water_Heating. Date Accessed: March 11, 2009.

[258]Andy Walker, "Solar Water Heating," Whole Building Design Guide, National Renewable Energies Lab, http://www.wbdg.org/resources/swheating.php. Accessed March 11, 2009.

[259] US Department of Energy, "Commercial Buildings: Building Technologies Program, Solar Water Heating ," US Department of Energy, http://www1.eere.energy.gov/buildings/commercial/water_heating.html#Solar_Water_Heating Accessed March 11, 2009.

[260] Kingspan Solar, "Leicester College gets Cooking with Solar Thermal Technology," Kingspan Renewables, http://www.kingspansolar.com/news/leicester-college-install-solar-thermal-technology.shtml Accessed March 14, 2009.

[261]Guilford College, "Shore Hall Solar Hot Water Project Dedication Rescheduled for April 25," Guilford College, http://guilford.edu/about_guilford/news_and_publications/releases/ShoreHallSolarDedication.html Accessed March 14, 2009.

[262] WisconSUN: Solar Use Network, "WisconSUN Case Study: Environmental Living and Learning Center Northland College," Energy Center of Wisconsin, http://www.ecw.org/wisconsun/learn/cs_northland.shtml Accessed March 14, 2009.

[263] Amherst College, "Renewable Energy," Amherst College, https://www.amherst.edu/campuslife/greenamherst/renewable_energy Accessed March 14, 2009.

[264] Harvard University Office of Sustainability, "Renewable Energy: Solar Thermal," Harvard University Office of Sustainability, http://www.greencampus.harvard.edu/cre/solarthermal.php Accessed March 17, 2009.

[265] The following paragraph is summarized from: US Department of Energy, "Commercial Buildings: Building Technologies Program, Solar Water Heating ," US Department of Energy, http://www1.eere.energy.gov/buildings/commercial/water_heating.html#Solar_Water_Heating . Accessed March 11, 2009.

where it heats water. Absolutely no pumps are required in the process, but the antifreeze does not circulate freely without high levels of solar radiation. In direct circulation systems, hot water is pumped from collectors during daylight hours and recirculated through the system at night to prevent freezing. In drain-down systems, water acts as a heat-transfer fluid and heats water in the heat exchanger. This system uses gravity to drain the heating water out of the collector when temperatures dip below freezing, but requires energy to pump water through the system. Indirect solar air systems may be used throughout the year. In these systems, air is the heat transfer fluid and an air-water heat exchanger must be employed. Indirect water heating systems employ an antifreeze solution as a heat transfer fluid in a closed loop system.

Each of these systems has a different menu of solar collector options. There are two main types of collectors: flat-plate and evacuated tube collectors. Flat-plate collectors are weatherproofed boxes containing dark-colored absorber plates covered with one or two layers of a glazed or unglazed translucent or transparent material, usually glass or plastic.[266] Water or a heat transfer fluid flows through pipes running through the box and is warmed directly by the sun.[267] Evacuated tube solar collectors come in three forms: glass-glass, glass-metal and glass-glass water flow path – each type is comprised of a series of glass tubes connected to a header pipe. These systems are able to achieve very high temperatures (170˚F - 350˚F), making them suitable for commercial purposes.[268]

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[266] US Department of Energy, "Commercial Buildings: Building Technologies Program, Solar Water Heating ," US Department of Energy, http://www1.eere.energy.gov/buildings/commercial/water_heating.html#Solar_Water_Heating. Accessed March 19, 2009.

[267] Apricus Solar Hot Water, "Types of Solar Collectors," Apricus Solar Hot Water, http://www.apricus.com/html/solar_typesofsolar.htm. Accessed March 19, 2009.

[268] US Department of Energy, "Commercial Buildings: Building Technologies Program, Solar Water Heating ," US Department of Energy, http://www1.eere.energy.gov/buildings/commercial/water_heating.html#Solar_Water_Heating. Accessed March 19, 2009.

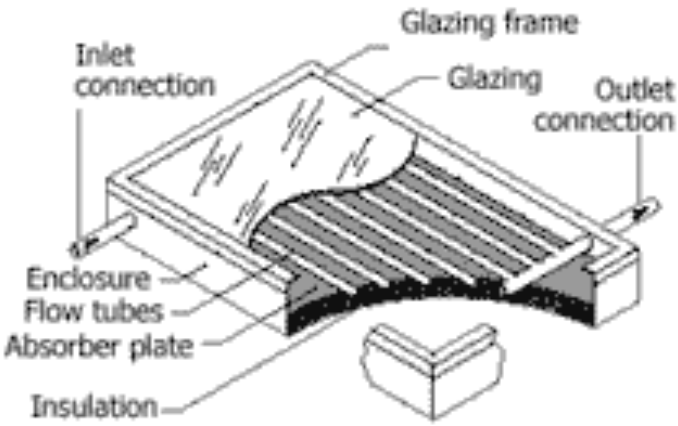

Figure 36. Diagram of a flat-plate solar panel[269]

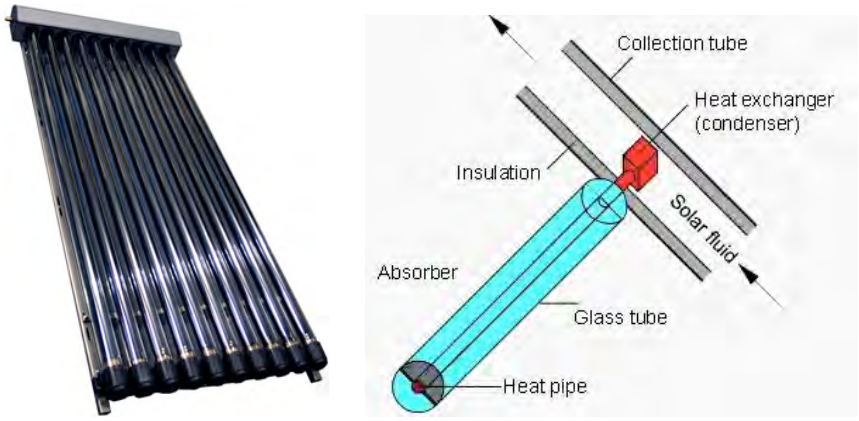

Figure 37. Picture and diagram of a standard glass-metal evacuated tube solar collector, complete with a series of glass pipes connected to a header pipe[270]

Glass-glass evacuated tube solar collectors are created from two glass tubes fused together at one end. The air in the space between the walls of the tubes is removed, creating a vacuum, thus reducing heat loss and decreasing the interior pressure of the tube. A small amount of liquid is placed inside each tube. This liquid, usually an alcohol or purified water, boils when exposed to sunlight, quickly vaporizing and rising to

[269] Flasolar.com, "Solar Water Heating: Flat Plate Solar Collectors," Flasolar.com, http://www.flasolar.com/active_dhw_flat_plate.htm. Accessed March 19, 2009.
[270] GreenTerraFirma.com, "Evacuated Tube Solar Collector," GreenTerraFirma.com, http://greenterrafirma.com/evacuated_tube_collector.html. Accessed March 19, 2009.

the top of the pipe where it moves through a heat exchanger in the header pipe. This hot vapor eventually condenses and flows back to the bottom of the pipe where the cycle repeats as long as the sun is shining.

Glass-metal evacuated tube solar collectors have a metal sheet wrapped between the two glass tubes[271] or a metal plate inside of a single glass tube that is connected directly to a heat exchanger or water pipe.[272] While the coated metal increases the heating efficiency of the system, glass-metal systems often suffer from loss of vacuum due to unstable seals between glass and metal.[273]

Glass-glass water flow evacuated tube systems consist of a series of single-ended glass tubes connected directly to a water tank. As water is heated, it moves by convection from the tube into the tank and is replaced by colder water.[274]

Cost Analysis

At present, there are few financial benefits from solar heading. According to a 2008 article published by the National Renewable Energy Lab, solar hot water becomes cost effective in areas where the cost of electricity is above $0.034/kWh, where there is a consistent demand for hot water, and where the daily average of solar radiation is above 4.5 kW/m^2/day.[275] Although there is a consistent demand for hot water at the KSC, Wellesley's current cost of energy production is between $0.115 and $0.125/kWh,[276] and the average daily solar radiation for the Wellesley area is 3-4 kW/m2/day using a two-axis tracking concentrator.[277] Until the cost of energy for the college increases above $0.034/kWh, passive solar technology is unlikely to be a cost-effective way to heat water.

The educational benefits of solar technologies are two-fold. First, solar collectors are highly visible no matter the form. The simple addition of signs explaining the purpose and function of the technology could greatly enhance student and community understanding of solar technology and the impacts of energy use in general, perhaps even contributing to a reduction in overall energy consumption through increased student awareness. Second, any form of solar heating equipment could be used in environmental studies courses, physics courses, computer science courses, or geosciences courses, providing hands-on lab experience for the environmental designers, activists and entrepreneurs of tomorrow. The only potential

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[271] US Department of Energy, "Solar Energy Technologies Program," US Department of Energy, http://www1.eere.energy.gov/solar/sh_basics_collectors.html. Accessed March 20, 2009.
[272] Apricus Solar Hot Water, "Types of Solar Collectors," Apricus Solar Hot Water, http://www.apricus.com/html/solar_typesofsolar.htm. Accessed March 20, 2009.
[273] Apricus Solar Hot Water, "Types of Solar Collectors," Apricus Solar Hot Water, http://www.apricus.com/html/solar_typesofsolar.htm. Accessed March 20, 2009.
[274] Budihardjo, I, Morrison, G, and M Behnia, "Natural circulation flow through water-in-glass evacuated tube solar collectors," Solar Energy 81, no. 12 (2007), http://www.sciencedirect.com. Accessed March 20, 2009.
[275] Walker, A, National Renewable Energy Lab, "Solar Water Heating," Whole Building Design Guide, http://www.wbdg.org/resources/swheating.php Accessed March 20, 2009.
[276] Interview with Michael Dawley, February 25, 2009.
[277] National Renewable Energy Lab Resource Assessment Program, "Average Daily Solar Radiation Per Month ANNUAL," National Renewable Energy Lab, http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/serve.cgi. Accessed March 20, 2009.

limitation of the usefulness of this new technology is sunlight availability, though, as mentioned before, these constraints may be outweighed under conditions of overpriced energy resources.

Figure 38. Solar Pool Heating comparisons

Alternative #	Model/Identifier	Physical Size Specifications (ft)	Electrical Output (kW)	Estimated Annual Output (kWh/a)	Initial Cost ($)
1[278]	Thermo Dynamics Ltd. Flat Plate, Closed Loop Indoor Pool Heating System	5610 ft^2 (85% of pool surface area)	Unknown	Unknown	$157,956.56 (estimated ft2/32 ft2 (4'x8'panel) * $901
2[279]	Helicol Flat Plate collector with drain-down system and temperature control	4400 ft^2 (2/3 pool surface area)	Unknown	Unknown	$66,000 (estimated ft^2 x $15/$ft^2$)
3[280]	Evacuated tube collector with drain-down system	7.2 ft x 6.6 ft	.61	5437	$2,387.69

Pool heating has low heat requirements and most often relies on flat-plate systems to serve all necessary heating functions, though evacuated tube systems are also used. Since the Wellesley College system is in use year-round in a cold climate, such flat-plate systems would need to be glazed in order to improve longevity and efficiency. Choices for heat transfer technologies are limited to drain-down systems with an electric pump and indirect air and water systems, all of which use antifreeze solutions and have protections (active pumping, draining when not in use, etc.) against freeze damage.

Solar pool heating systems comprise the largest number of solar installations in the United States, out-competing solar domestic hot water and solar electric power. In 2006, 33,000 pool systems were installed, 9,000 more than in 2004.[281] Clearly, solar pool heating is a growing field. The technology, however, has not changed significantly in over thirty years and there is little development.

[278] Thermo Dynamics Ltd., "Solar Pool Heating," Thermo Dynamics Ltd., http://www.thermo-dynamics.com/solar_pool_heating.html. Accessed March 21, 2009.
[279] Sunshine Solar Technologies, "Commercial Pool Heaters – Solar Pool Heating Systems," Sunshine Solar Technologies, http://www.sunshinesolartech.com/commercial-pool-heaters.html. Accessed March 21, 2009.
[280] Silicon Solar Inc., "SunMaxx Solar Pool Heater with 1 Sunmaxx 25 Evacuated Tube Collector," Silicon Solar Inc., http://www.siliconsolar.com/sunmaxx-solar-pool-heater-with-1-sunmaxx-25-evacuated-tube-collector-p-18122.html. Accessed March 21, 2009.
[281] Marcelle S. Fischler, "Going Solar to Keep the Pool Comfortable," New York Times, May 25, 2008, "In the News".

Recommendations

Increasing numbers of both commercial and residential installations of solar hot water heating systems have helped lower prices and encourage new market competition. More and more contractors are trained in proper installation of solar systems, eliminating the need for specialized labor and further decreasing prices. As space efficiency, aesthetic appeal, and the cost of fossil fuels increase, the price of solar hot water will continue to decline, making this option more cost-effective and viable on the Wellelsey campus. In addition, most solar water heating systems pay for themselves in less than five years.[282]

Behavioral Changes for Energy Efficiency

Energy efficiency does not always have to be about making drastic changes, such as tearing out walls to add a whole new heating and cooling system. Small changes that each person makes in her everyday life can have a big impact on the amount of energy she consumes. One way to consume energy in an efficient manner is to keep the thermostat of a building low, especially at nighttime, when there isn't anyone in the building. When buying new appliances, such as microwaves and televisions, another method is to buy Energy Star products.[283] Making sure that computers are completely off at the end of the day would save a lot of energy - it would be much better to run a computer for an eight-hour workday than for a full twenty-four hours. For a desktop computer, this would save between 0.96 and 4 kW of energy per night.[284] Some energy waste comes from "phantom energy", which occurs when an appliance is plugged in, but not in use - the appliance continues to pull electricity. In the United States, phantom energy accounts for an average of 5% of household energy use.[285] Appliances can be plugged into a power strip, which would only be turned on when the appliances were in use.[286]

Behavioral changes do not occur overnight; it takes time for habits to develop. The Wellesley College Administration can implement certain strategies to help facilitate the development of these habits and behavioral changes. Setting rules, establishing consequences, sharing information, and providing incentives are all ways the Administration can encourage behavioral changes in students, faculty, and staff. Signs providing information about the amount of energy saved by turning off lights or turning down the heat inform the public of the benefits of "green" habits. Similarly, a contest among athletic teams about which team took the shortest average showers could help encourage the athletes to use less hot water. Rules about turning off the office computers at night would promote this habit among faculty members, or the computers can be scheduled to turn off at a certain time in the evening and to turn on at a certain time in the morning.

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[282] Sunshine Solar Technologies, "Solar Pool Heaters and Water Heating Systems," Sunshine Solar Technologies, http://www.sunshinesolartech.com/commercial-pool-heaters.html. Accessed March 21, 2009.
[283] About.com, "Top Ten Tips for Saving Energy Right Now," http://saveenergy.about.com/od/energyefficientappliances/tp/SaveNow.htm. Accessed April 13, 2009.
[284] Office of Energy Efficiency and Renewable Energy, "Energy Savers Booklet: Tips on Saving Energy & Monday at Home," United States Department of Energy. www.eere.energy.gov. Accessed April 13, 2009.
[285] Michael Bluejay, "How Much Electricity Do Computers Use?" http://michaelbluejay.com/electricity/computers.html. Accessed April 13, 2009.
[286] Strategic Sustainability Consulting, "10 Simple Ways to Cut Energy Costs: A Guide for Small Businesses," www.sustainabilityconsulting.com. Accessed April 13, 2009.

In any form, both the behavioral changes and the strategies for getting students and faculty to make them are relatively modest compared to other methods of increasing energy efficiency.

Vision for the Future

The energy use of miscellaneous appliances in Keohane Sports Center can be greatly reduced in most cases by the replacement of old and less energy-efficient models with new and more energy-efficient models. In particular, immediately replacing the current refrigerators with Energy Star certified models will provide the sports center with a minimum of 11,000 kWh/a in energy savings, while other significant energy savings can be achieved by the gradual replacement of desktop computers with laptop computers, and current treadmills and hand dryers with more efficient models. In all cases, the energy savings possible through replacement of the appliance should be weighed against the environmental costs of disposal of the old appliance and manufacture of the new appliance.

We suggest comparing our findings with the available information on the current HVAC system in the KSC. Improving insulation in the building overall could lead to significant improvements in energy efficiency in the building. Re-roofing the building, especially the roof over the field house provides an additional opportunity to improve the insulation throughout these parts of the building. Finally, we suggest maximizing the use of the heat recovery system in the pool area of the KSC and potentially extending this heat recovery system throughout the building.

Incorporating behavioral changes into any plan to enhance the energy efficiency of the Sports Center is vital. Behavioral changes have the advantage of having an infinite lifecycle – when a person develops a habit; it becomes a permanent change. Even the smallest behavioral changes can encourage people to make larger changes in their everyday lives. An energy efficient heating system cannot operate to its maximum efficiency if it is always turned all the way up; a computer not in use continues to use energy if it is left on. When a person sees that the little things that she does make a big difference, it empowers action to make even bigger changes.

There are many paths to increasing the energy efficiency at the Keohane Sports Center, which range in scope from small-scale behavioral changes to large-scale structural alterations. We propose an integrative approach that includes an educational component aimed at altering perceptions of energy consumption and reduction in overall energy use, in conjunction with increased utilization of energy-efficient technologies. Improvements in the insulation of the building overall will also greatly increase energy efficiency through the KSC. A successful combination of these efforts will extend beyond any one user group and have far-reaching educational effects that echo throughout the Wellesley community, in addition to creating a greener sports center.

V. LIGHTING

Summary

The quality of lighting in the KSC is important to staff, faculty and students. Proper lighting can benefit athletes during sporting events and can help increase the productivity of staff and faculty. To increase the lighting in the Sports Center, we recommend that the College install passive solar devices like skylights and solar tubes. In addition, we suggest that step-dimming ballasts be used in conjunction with photosensors to control the lighting output from the metal halide lamps. All fluorescent lights should be replaced with LED lights at the end of their lifetime and infrared occupancy sensors should be used throughout the hallways and corridors.

Background

The Sports Center is the hub for exercise on campus, and it is essential that it promote the pursuit of healthy living. Lighting is essential to the building's functions; athletes and exercisers require lighting that will help them perform at their best. The lights in the field house cannot glare into the eyes of athletes shooting baskets or catching fly balls. The faculty and staff, whose offices are in the center, would benefit from natural daylighting that will improve their health and productivity. Club sports teams and organizations should be able to exercise and congregate in spaces where they will perform at their best. All of these activities require adequate lighting and, ideally, natural light.

The desire for improved light quality in the KSC is a trend seen consistently in reports from staff, students, coaches and student-athletes. The desire for sunlight, windows, and improved lighting has often been expressed. Two levels of the building are underground, including the Athletic Training Room, the varsity squash courts, the weight rooms and multiple administrative offices. None of these spaces have windows, and often the lighting is not adequate for the needs of the people occupying them. On the top floor, the studios—where fencing, yoga, dance, and other activities take place—do not have windows, and neither do most of the administrative offices on that floor. The top floor also houses the original Sports Center gymnasium, now the multi-purpose gym. This space was built in the 1930s, and its windows are very high and thin, allowing for little light or natural warmth. On the ground floor is the field house, which also does not have any windows. The field house is where most varsity sports teams train when the weather isn't adequate for outdoor practicing. The field house also houses some administrative offices and most of the college's cardio equipment. It is essential to the overall wellbeing of Sports Center visitors that the lighting in the building be conducive to high performance in all areas of activity.

In addition to concerns about the quality of light in the KSC, the environmental impact of the lighting choices is also a main consideration. Here we evaluate three main methods by which the current Sports Center lighting could be improved, enhancing both overall comfort and energy efficiency in the building.

Passive Solar Devices

Passive solar lighting collects, amplifies and directs natural sunlight into buildings to offset the use of artificial lighting. Unlike solar panels, which are "active" systems, passive solar lighting, or "daylighting," does not convert sunlight into electricity. Instead, it relies on architectural considerations like building site and window placement, as well as the use of skylights, reflective surfaces, solar tube lights, and fiber optic solar lighting fixtures, to bring daylight directly into a building. Passive solar lighting has been employed in one form or another at almost every sustainable design building, including Oberlin's Center for Environmental Studies, Microsoft's School of the Future, and the University of Edinburgh's Rankine Building, because of the dramatic effect it can have on reducing electricity consumption from artificial lighting. Additionally,

studies have shown that increased natural light has significant positive impacts on the performance and well being of building users.[287]

While window placement and building site are usually decided during the construction phase, various passive solar mechanisms can be installed post-construction. Skylights, for example, can be added to provide lighting to rooms with roof access. At the University of Notre Dame's Recreation Center, a skylight made of Kalwall provides the main lighting for the entryway and lobby.[288] Solar tube lights are a variation on skylights that provide concentrated and amplified sunlight. Wellesley has already installed a handful of solar tube lights inside of its Motor Pool building. On a larger scale, 148 solar tube lights were used for the 7,874 square foot gymnasium at Beijing's Science and Technology University, which hosted competitions in the 2008 Olympic Games.[289]

The newest development in passive solar lighting, fiber optic solar lighting, uses lenses on the exterior of a building to collect sunlight and focus it through fiber optic cables. These cables can then transport light through a building to a solar light fixture, resembling an ordinary lamp or ceiling light panel, which emits sunlight instead of artificial light. At the University of Edinburgh's William Rankine Building, fiber optical lighting designed by the Swedish company Parans supplies daylight to rooms lacking both windows and roof access.[290]

Passive solar lighting does not generate energy; rather it cuts energy used to provide artificial lighting. Considering that lighting accounts for up to 40% of a building's electricity use,[291] there are significant benefits to substituting artificial light with natural daylight. Environmentally, cutting energy use reduces greenhouse gas and particulate emissions and prevents environmental damage from fossil fuel extraction. Passive solar lighting requires no energy to run, and even the materials used—glass, aluminum, and plastic—are fairly non-toxic, and should have fewer environmental effects from production and disposal than other technologies such as solar photovoltaic cells. With certain types of passive solar technology, such as windows and skylights, there is the possibility of overheating due to increased light, although many of those problems can be dealt with through planning and additional technologies. Financially, the college would be purchasing less natural gas and oil, reducing its annual fuel costs. Instead, it would be investing in a one-time purchase and installation price for passive solar equipment.

Mechanically, the energy replacing capacity of passive solar lighting systems is dependent on the actual sunlight in the area. On days that are overcast and cloudy, passive solar lighting cannot produce as

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[287] Mariana G Figueiro et. Al, "Daylight and Productivity--A Field Study." www.eceee.org/conference_proceedings/ACEEE_buildings/2002/Panel_8/p8_6/Paper/. Date Accessed May 13, 2009.
[288] "Active Rec. Center for an Active University," Kalwall, http://www.kalwall.com/rcntproj/10.htm Accessed March 20, 2009.
[289] "Project Case Study: Beijing Science & Technology University Gymnasium," Solatube, http://www.solatube.com/commercial/cs_beijing.php Accessed March 9, 2009.
[290] Sally Gould, "Sunlight Options for Workers in the Dark," Channel 4 News, http://www.channel4.com/news/articles/science_technology/sunlight+option+for+workers+in+dark/191925 Accessed March 20, 2009.
[291] Nancy Stauffer, "Daylight Device Lightens Electricity Cost," MIT Tech Talk, http://web.mit.edu/newsoffice/2007/energy-daylight-0509.html. Accessed March 20, 2009.

much light as on sunny days. For this reason, passive solar lighting cannot be the sole lighting source for a building. Wellesley is not in the prime location for passive solar lighting, since the Northeast has long winters and many overcast days, but with new advances in sunlight gathering technology, passive solar lighting has been able to both gather and amplify even low light. It is estimated that good passive solar lighting design can cut up to 75% of the electricity used for lighting a building, saving anywhere from 50 to 75 cents per square foot of building.[292]

Socially and symbolically, passive solar lighting has the benefit of incorporating buildings and their inhabitants into natural solar cycles. By associating inside and outside light levels, passive solar lighting reduces the boundary between inside and outside, nature and artifice. Educationally, passive solar lighting could be another way to show how we can harness nature in a positive way to provide human services. Increased sunlight also results in higher productivity and better mood. According to research in school districts in California, Washington, and Colorado, students in daylit schools perform 5%-14% better on standardized tests than students in non-daylit schools.[293] Increased daylight also helps to regulate human circadian rhythms[294] and improve productivity by anywhere from 6%-16%.[295]

Passive Solar Lighting Alternatives

For the remodeling of KSC, we have chosen to focus on three types of passive solar lighting: skylights, solar tube lights, and fiber optic solar lights. Since we are not rebuilding the sports center, we do not have the option of choosing a passive solar building site or re-orienting the building to maximize solar exposure. Adding windows requires removing infrastructure and careful attention to load-bearing walls. We chose to focus instead on technologies that could be added during the upcoming replacement of the field house roof, or that could be added with minimal invasiveness to the existing facility.

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[292] David Kozlowski, "Using Daylighting to Save on Energy Costs," Building Operating Management, http://www.facilitiesnet.com/energyefficiency/article/Harnessing-Daylight-For-Energy-Savings—4267 Accessed March 20, 2009.
[293] Patricia Plympton, Susan Conway and Kyra Epstein, "Daylighting in Schools: Improving Student Performance and Health at a Price Schools Can Afford," National Renewable Energy Laboratory, http://www.nrel.gov/docs/fy00osti/28049.pdf Accessed March 20, 2009.
[294] Sasha Brown, "Building Technology Expert Describes Studies of Daylight," MIT Tech Talk, http://web.mit.edu/newsoffice/2006/building-tech-1108.html Accessed March 20, 2009.
[295] L. Edwards and P. Torcellini, "A Literature Review of the Effects of Natural Light on Building Occupants," National Renewable Energy Laboratory, http://www.nrel.gov/docs/fy02osti/30769.pdf. Accessed March 20, 2009.

Figure 39. Passive Solar Lighting Device Alternatives

Alternative #	Model/Identifier	Physical Size (ft^2)	Visible Light Transmission	Estimated Annual Output (lumens)	Initial Unit Cost ($)
1	Kalwall Standard Skylight	16 ft^2	20%	46,222	640
2	Solatube 21-O	2.4 ft^2	60%	20.800	489
3	Parans SP2 L1	8.7 ft^2	14%	14,000	12328

Kalwall Standard Skylight

Skylights could be easily integrated into the construction of a new field house or pool house roof. Most skylights suffer from the problems of thermal insulation and glare, which could be particularly problematic in a competitive athletics environment. A company called Kalwall based in Manchester, New Hampshire has created a translucent aerogel-filled skylight with insulation values comparable to that of a solid wall. Light transmission can be controlled from a range of 14% to 60%, minimizing glare, while letting in sunlight and maintaining insulation.[296] Standard skylights from Kalwall range in size from 4 feet by 4 feet to 5 feet by 20 feet.[297] For this estimate we examine the smallest model of standard skylight, with a light transmission value of 20% and an insulation U-value of 0.05.

Kalwall is composed of a hydrophobic aerogel insulation composed of 95% air sandwiched between two fiberglass-reinforced polyester panels.[298] Aerogel appears to be environmentally safe, with no significant hazardous waste created during production, no toxins emitted during use, and a quick and harmless disposal.[299] Fiberglass is a potential carcinogen, but only during installation when cutting or sanding exposes fibers to the air.[300] Polyester has significant environmental effects during production, since it is a petroleum product. Kalwall is manufactured in New Hampshire, and therefore transportation would be fairly local. Compared to the other two alternatives, Kalwall would require the least distance traveled from its manufacturing source.

The largest foreseeable problem with Kalwall or regular skylight installation would be the buildup of snow during the winter. Because Kalwall has such a low thermal heat loss value, snow would not melt off of the skylight. Unless the angle of the skylight was large enough to dislodge snow build-up, passive solar lighting through Kalwall would be dramatically reduced during the winter.

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[296] "Standard Skylights," Kalwall, http://www.kalwall.com/pdfs/skylights.pdf Accessed March 18, 2009.
[297] "Standard Skylights," Kalwall, http://www.kalwall.com/pdfs/skylights.pdf Accessed March 18, 2009.
[298] Lloyd Alter, "Kalwall with Nanogel: The Light Stuff," Treehugger, http://www.treehugger.com/files/2007/06/kalwall_with_na.php Accessed March 20, 2009.
[299] "Use of Silica Aerogels," Microstructured Materials Group: Lawrence Berkeley National Laboratory, http://eetd.lbl.gov/ecs/aerogels/mmg.html Accessed March 20, 2009.
[300] "Environmental Health Sheet: Fiberglass," Illinois Department of Health, http://www.idph.state.il.us/envhealth/factsheets/fiberglass.htm Accessed Marc 20, 2009.

Solatube 21-0

The Solatube 21-O is the largest diameter solar tube light offered by the California based Solatube International. The Solatube 21-O has an acrylic dome with a diameter of 21 inches that is placed on the exterior of a building. As sunlight enters the dome, it is reflected off the mirror-like finish on the inside of the tubing attached to the dome. The tube, which can turn and travel up to fifty feet away from the lighting source, carries sunlight into the building to where it is eventually emitted through a diffuser lens.

Materials used in Solatube construction include the aluminum tube, steel fasteners, acrylic dome, nylon clips, and various sealants.[301] Of all the components, the sealants are the only hazardous materials. Aluminum production causes environmental damage from metal extraction as well as greenhouse gas emissions from smelting.[302] Aluminum, however, is a commonly recycled metal. Beyond production, the primary source of carbon emissions and environmental damage would probably be transportation of the solar tubes from California to Massachusetts. There are, however, local producers of solar tube lights who could be used in place of Solatubes.

Parans SP2 L1

The Parans fiber optic lighting system works by connecting a solar panel on the roof to a lighting fixture inside the building by means of fiber optic cables. The Parans solar panel is made of 62 Fresnel lenses that uniformly track sunlight throughout the day and concentrate that light into a bundle of optical fibers.[303] Inside the optical fibers, light can be transported a maximum of 20 meters from the light source to a solar fixture, at a light transmission of 95.6% per meter. [304]

The principle materials used in a Parans system include plastic optical fibers made of polymethylmethacrylate, solar panels composed of aluminum and glass, and acrylic lighting fixtures. Polymethylmethacrylate, or PMMA, has good environmental stability, and is non-toxic enough to have been implanted into the human body. PMMA is a petroleum derivative, however, and therefore creation of PMMA has the resultant environmentally detrimental effects of resource extraction and greenhouse gas emission. Glass also has considerable environmental impacts, both from sand extraction for silica and heat energy used to fire glass.[305] This environmental damage is countered by the high potential for recycling and the long

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[301] "MDDS: Product Materials Specification," Solatube, http://www.solatube.com/commercial/technical_resources.php Accessed March 20, 2009.
[302] "Aluminum," Environmental Literacy Council, http://www.enviroliteracy.org/article.php/1013.php Accessed March 20, 2009.
[303] "Parans SP2 Details," Parans, http://parans.production.llr.se/ParansProducts/ParansProductLine/ParansSolarPanel/ParansSP2Details/tabid/911/Default.aspx Accessed March 15, 2009.
[304] "Parans OC Details," Parans, http://parans.production.llr.se/ParansProducts/ParansProductLine/ParansOpticalCable/ParansOCDetails/tabid/918/Default.aspx Accessed March 15, 2009.
[305] "Ecotip: Glass-What's the Environmental Impact," Treehugger, http://www.treehugger.com/files/2004/11/ecotip_glass_a.php. Accessed March 19, 2009.

lifespan of glass products. Transportation again is a key factor in the life-cycle assessment, since Parans fixtures would have to travel from Sweden to Massachusetts.

Passive Solar Recommendations

Kalwall skylights would be the best option for the KSC if roofing space were not an issue. Because of the thermal insulation and broad, controlled light transmission, Kalwall would be well suited to the Keohane Sports Center. If, however, passive solar lighting must compete with green roofs or other solar installations for space, solar tube lights would make more sense, with their small diameters and large concentrated light output. In addition, solar tube lights would have the advantage of height above any snow that would accumulate on the roof, possibly creating larger amounts of solar light during the winter compared to skylights. Passive solar lighting is definitely becoming more popular, and, as a result, less expensive as time goes by. Certain technologies, like fiber optic solar lighting and special thermal glazed windows, will probably improve in the next decade and come down in cost, making them more financially viable for common use.

Figure 40. Passive Solar Lighting Cost Analysis

Alternative	Initial Cost of Unit Purchase ($)	Initial Cost of Installation ($)	Operation Costs ($/annum)	Maintenance costs ($/annum)	Estimated Lifetime (years)	End of life Cost ($)
1	640	200	0	10	30	24
2	489	100	0	10	30	3
3	12328	50	0	10	30	5

Most of the cost analysis behind initial purchase price is estimated. Both the Parans and Solatube systems would require minimum installation costs. The main installation with the Parans system would be loading the solar collector onto the roof, although depending upon where the lighting fixtures were placed, additional wiring could be needed. Solatubes were designed for easy installation within 3 to 4 hours by almost anyone with a basic knowledge of roofs. Kalwall would be the most expensive to install, because of shear size, but even so, a Kalwall skylight would already be assembled and ready for installation upon delivery.

None of the passive solar lighting systems would require any operation costs, since they do not use energy. Maintenance would also be minimal, since they are, for the most part, self-cleaning and self-regulating systems. The only maintenance would be an occasional cleaning if the solar collectors, skylights or solar tube domes got dirty, although all are designed to self-clean in the rain. Lifetime for the Parans system is estimated at 30 years, and is the building lifetime for the Kalwall skylights and Solatubes. At the end of their lifetimes, parts of the unit could be recycled, and parts would have to be disposed of at a dump.

Considering that the Keohane Sports Center uses 5,968,114 kWh of energy per year, lighting accounts for 35% of the building's energy use, and that passive solar lighting could replace 50% of all lighting, passive solar lighting could reduce energy demand at the Keohane Sports Center by 1,004,420 kWh per year.

Bulbs

Incandescent

Incandescent lights currently supply about 85% of household illumination. Lights are comprised of a tungsten filament in a noble gas medium encased by a glass bulb.[306] The filaments—a type of electrical resistor—heats up until it glows when an electrical current is passed through them. In the process, energy is lost to the surroundings in the form of heat. Incandescent light bulbs are thus an inefficient method of generating light and restricts their lifetime to a range of 750-2500 hours. The energy efficiency of incandescent light bulbs increases with wattage in a non-linear fashion and ranges from 10-17 lumens/watt. The advantageous of incandescent lights, include the appealing color composition of their light and their quick light up times.

Halogen

Halogen lights differ from incandescent lights only in their gaseous medium. In halogen lights, halogen gases such as chloride and bromine are added to the noble gas medium surrounding the filament.[307] This allows higher filament temperatures, increasing the energy efficiency (lumens/watt) by about 10% to 12-22 lumens/watt and more than doubles the lifetime of halogen lights compared to incandescent ones. [308] Apart from energy efficiency and lifetime considerations, halogen lights have the same advantages and disadvantages as incandescent lights due to their similar design.

Compact Fluorescent Lights (CFLs)

Compact Fluorescent Lights (CFLs) were once heralded as the environmentally friendly replacement for traditional incandescent lights due to their high energy efficiency. They are composed of liquid mercury suspended in a noble gas medium within a glass bulb whose inner surface is coated with a phosphor lining (typically transition metal based).[309] When stimulated with electrical current, the mercury emits UV light which excites the phosphor coating, inducing it to fluoresce in the visible range. A wide range of wavelength

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[306] Incandescent Lighting. US DOE Energy Efficiency and Renewable Energy. 2009. http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=12120. Accessed March 21, 2009.
[307]General Electric. Halogen FAQs. http://www.gelighting.com/na/business_lighting/faqs/halogen.htm#4. Accessed March 20, 2009.
[308] How does a halogen light bulb work? http://www.gelighting.com/na/business_lighting/faqs/halogen.htm#4. Accessed March 25, 2009.
[309] Light Bulbs Explained. Lighting Directory. 2008. http://www.lightingdirectory.com/company-news/article/187. Accessed March 20, 2009.

compositions is available in CFLs employing different phosphor compositions. CFLs have an energy efficiency of 60-72 lumens/watt and, hence, use only 66% of the electricity consumed by incandescent lights to produce the same effective lighting (lumens).[310] Because they contain mercury, however, they are currently regarded as hazardous waste at the end of their lifetimes. In addition, CFLs can often be slow to light up.[311]

Light Emitting Diodes (LEDs)

Light Emitting Diodes (LEDs) are a relatively new lighting technology employing semiconductor diodes that emit light when stimulated by electrical current. The color of emitted light is dependent on the semiconductor band gap. LEDs light-up much faster than other lights, have the longest lifetime, and use 90% less energy than incandescent lights with an energy efficiency of 30-160 lumens/watt.[312] Their initial cost, however, is much higher than that of other electrical lighting options.

Current Sports Center Lighting Scenario

A recent inventory of the KSC's electrical appliances found 1,183 CFLs and 92 halogen lights, and is listed in Appendix B. Collectively they cost Wellesley $30,000 to operate in any given year assuming an electricity cost of $0.10/kWh.

Alternative Lighting Scenarios

Phasing out current bulbs

If the current metal halide lamps in the field house were replaced by either CFLs or LEDs, many more light bulbs would be required to achieve the same apparent amount of light (lumens), which would incur significant expenses.

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[310] Light Bulb Facts. Iowa Waste Reduction Center. http://www.iwrc.org/downloads/pdf/LightBulbFacts.pdf. Accessed March 20, 2009.
[311] Turner, WC. Energy Management Handbook, 5th Ed. CRC Press: 2004.
[312] Kreith, F. Goswami, Y. Handbook of Energy Efficiency and Renewable Energy. CRC Press: 2007.; Schubert, Fred. Light Emitting Diodes, Rensselaer University. http://www.ecse.rpi.edu/~schubert/Light-Emitting-Diodes-dot-org. Accessed March 29, 2009.

Figure 41. Replacing Field House/Pool Metal Halide Lights with CFLs or LEDs

Alternative Sports Center Lighting	kW	Lumens	h/a	kWh/year	Total kWh/Year	# of Lights	Lifetime Hours	Initial Cost ($)	Operation Cost assuming $0.10/kWh
CFL	0.2	30,000	3,650	730	179,580	246	10000	4,818	17,958
LED	0.02	33,000	3,650	55	98,769	1,804	45000	135,282	9,877

With the current metal halide usage scenario of 3,650 hours per annum, the lifetime of these LEDs would be 12 years while that of CFLs and metal halides would be 3 and 4 years respectively. Projecting costs over a twelve year period, halide lamps would need to be replaced 2 times (excluding the current lights), CFLs four times, and LEDs once. Even with this projection, the current scenario is much more cost effective than the CFL and LED scenarios. Although end of life costs are not included, they are not likely to bridge the cost gap between the current metal halides and the LED scenario. In terms of environmental impact, LEDs produce the fewest carbon dioxide equivalents during the twelve year period.

Figure 42. Twelve Year Costs of Changing to Improved Lighting Alternatives

Light Type	Lifetime (years)	CO_2eq (tonnes)	kWh Used	# of replacements required	Cost of Bulbs and Replacements ($)	12 year Operating Costs ($)	Total 12 year costs ($)
Current Halides	4	8.56	17,520	164 (246)	4,764	143,664	148,428
CFL	3	4.28	8,760	984	19,270	215,496	234,766
LED	12	0.32	657	1,804	135,282	118,523	253,805

The KSC currently contains 1,183 CFLs, each containing approximately 4.5mg of mercury. Collectively, this sums to more than 5 grams of mercury that would be considered hazardous waste when retired. Given that CFLs already decrease the climate change impact of the Sports Centers' lights compared to incandescent lights and taking into consideration the cost and environmental impact of replacing these lights, continuing to use CFLs until the end of their lifetimes is recommended. At the end of CFL life-time, however, it would be both cost effective and environmentally beneficial to switch to LEDs, especially for hallway lighting (Figure 6).

Figure 43. CFL versus LED Comparison over 11 year lifespan of LEDs

Light Type	Lifetime (years)	CO2eq (tonnes)	kWh Used	# of replacements required	Cost of Bulbs and Replacements ($)	11 year Operating Costs ($)	Total 11 year costs ($)
CFL (Hallways)	2.3	849	788.4	4790	29123.2	143664	172,787
LED (Halway)	11	778	723	958	70652.5	69234.66	139,887

Controlled Lighting

Leaving lights on when they are unneeded is one of the most common ways energy is wasted in buildings. The College could invest in a number of different lighting control strategies to decrease the Sports Center's electrical lighting consumption and energy costs. Automatic controls switch or dim lighting based on time, occupancy, lighting levels or a combination of all three. These help mitigate unnecessary electrical lighting use, ensuring that lights are not left on longer than needed and are not used in unoccupied areas or when sufficient daylight exists.[314] There are a number of different control strategies and equipment options available to help achieve proper lighting and avoid unnecessary energy use.

Figure 44. Lighting control strategies and equipment[315]

Strategy	Equipment
Occupancy Sensing	Occupancy sensors — infrared, ultrasonic, dual technology
Scheduling	Timed switches, energy management systems
Tuning	Continuous dimming, bi-level switching
Daylight Harvesting	Continuous dimming, bi-level switching, photosensors
Demand Response	Voluntary or automatic — utility signals, dimmers, switches
Adaptive Compensation	Dimming, switching, timers, photocells

Occupancy Sensors

[314] "Buildings and Plants: Lighting," ENERGY STAR, <http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#SS_6_7_1>. Accessed April 3, 2009.
[315] "Buildings and Plants: Lighting," ENERGY STAR, <http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#SS_6_7_1>. Accessed April 3, 2009.

Occupancy sensors reduce energy consumption in building spaces by automatically turning the lights off when they do not sense the presence of an individual. They are most effective in spaces where people move in and out in unpredictable patterns and less effective in areas where one or more people may be present throughout the day.[316] The three most common types of occupancy sensors are passive infrared (PIR), ultrasonic, and dual devices that combine the two technologies. Each of these technologies can be individually mounted or installed as switches.

The proper placement of sensors is critical to their ability to operate effectively.[317] Wall-mounted devices are considered suitable in smaller areas that are intermittently occupied, while ceiling-mounted sensors are recommended for larger areas with higher lighting loads.

Figure 45. Occupancy Sensor Applications[318]

Type of Sensor	Applications
Ceiling Mount	Open partitioned areas, small open offices, file rooms, copy rooms, conference rooms, restrooms, garages
Corner Mount/Wide View	Large office spaces, conference rooms
Walls Switch	Private offices, copy rooms, closets
Narrow View	Hallways, corridors, aisles
High Mount/Narrow View	Warehouse aisles

Passive Infrared

Passive infrared devices detect heat emitted by occupants and are triggered by changes in infrared signals when people move in and of view.[319] These devices are fairly resistant to false triggering, but are best used within only a 15-foot radius.

[316] "Buildings and Plants: Lighting," ENERGY STAR, <http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#SS_6_7_1>. Accessed April 3, 2009.
[317] "Buildings and Plants: Lighting," ENERGY STAR, <http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#SS_6_7_1>. Accessed April 3, 2009.
[318] "Buildings and Plants: Lighting," ENERGY STAR, <http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#SS_6_7_1>. Accessed April 3, 2009.
[319] "Commercial Buildings: Lighting and Daylighting." U.S. Department of Energy: Energy Efficiency and Renewable Energy, <http://www1.eere.energy.gov/buildings/commercial/lighting.html>. Accessed April 3, 2009.

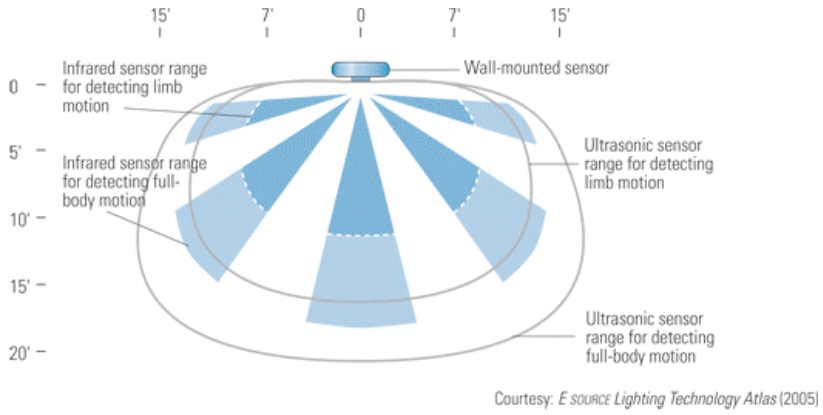

Figure 46. Occupancy Sensor Coverage Patterns[320]

Ultrasonic Sensors

Ultrasonic devices operate by emitting an inaudible sound pattern at high frequency and use a sensor to detect a change in the frequency of the reflected sound.[321] They are more expensive than passive infrared sensors, but they are much more sensitive and are generally capable of covering a larger area. The primary disadvantage to using these devices is that they are more prone to false triggering, often being triggered by air currents produced by a person running past an open door, moving curtains, or the on-off cycle of HVAC system.

Dual Technology Sensors

Some occupancy sensing devices use both passive infrared and ultrasonic technologies to increase their accuracy and flexibility. Dual technology devices take advantage of the resistance to false triggering provided by PIR devices and the higher sensitivity of the ultrasonic sensors.[322] The dual capability of this device makes them the most expensive option with regard to both mounted occupancy sensors and occupancy sensor switches.

Mounted Occupancy Sensors

We examine three types of mounted occupancy sensors: Passive Infrared (PSI), Ultrasonic (US), and Dual PSI/US. A passive infrared occupancy system that would provide coverage for all of the 158,000 ft² of the Sports Center's building space would be comprised of about 264 sensors. The system would cost $26,664

[320] "Buildings and Plants: Lighting," ENERGY STAR, <http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#SS_6_7_1>. Accessed April 3, 2009.
[321] "Commercial Buildings: Lighting and Daylighting." U.S. Department of Energy: Energy Efficiency and Renewable Energy, <http://www1.eere.energy.gov/buildings/commercial/lighting.html>. Accessed April 3, 2009.
[322] "Commercial Buildings: Lighting and Daylighting." U.S. Department of Energy: Energy Efficiency and Renewable Energy, <http://www1.eere.energy.gov/buildings/commercial/lighting.html>. Accessed April 3, 2009.

for acquisition and approximately $3,960 for installation, totaling $30,624. This estimate assumes that it would take one electrician about one half hour to install an occupancy sensor at a labor rate of $30 per hour. An ultrasonic occupancy system that can provide complete coverage of the Sports Center would consist of 79 sensors. At a rate of $158 each, the system would cost an estimated $13,667 with acquisition and installation. A dual occupancy system that would provide complete coverage for the sports center would cost the college approximately $14,062. The total cost of acquisition for this system would be around $12,062, and the total for installation of the 79-unit sensor system would be an estimated $1,185, assuming an installation cost of $15 each.

Figure 47. Mounted Occupancy Sensors

Model/Identifier	Physical Size Specifications	Coverage (ft²)	Initial Cost ($)	Installation Cost ($)	Estimated Lifetime
PSI occupancy sensor	4.5" Diameter, 1.5" High	60	$101.00	$15.00	10yrs
US occupancy sensors	4.5" Diameter, 1.5" High	2,000	$158.00	$15.00	10yrs
Dual PSI/US occupancy sensors	4.5" Diameter, 1.5" High	2,000	$163.00	$15.00	10yrs

Dimming Controls

When used in conjunction with photosensors, dimming controls can measure the quality of the indoor light and adjust electrical lighting outputs to account for incoming daylight. Dimming may be accomplished using dimming ballasts in either a stepped or continuous manner. These ballasts are used to reduce electrical lighting consumption whenever daylight is available and to decrease lighting loads.[323] It is important to note that not all ballasts are compatible with dimmers. Some systems utilize photosensors based on ambient daylight and lumen depreciation.

Step-dimming Ballasts

Step-dimming ballasts offer controlled lighting and energy savings. They can reduce lighting levels during non-critical hours and shed peak demand in commonly used areas. They typically offer 2 or 3 lighting levels and can be used in conjunction with occupancy sensors.[324] These devices are also useful for high

[323] "Buildings and Plants: Lighting," ENERGY STAR, <http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#SS_6_7_1>. Accessed April 3, 2009.
[30] "Buildings and Plants: Lighting," ENERGY STAR, <http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#SS_6_7_1>. Accessed April 3, 2009.

intensity discharge lights (HID) such as metal halide lamps, with extended warm-up times, due to their ability to switch them between low and high power.[325]

Figure 48. Dimming Control Equipment

Alternative	Lighting Application	Initial Cost of Unit Purchase ($)	Initial Cost of Installation ($)	Estimated Lifetime
Step-dimming ballast	HID	$368.00	$15.00	12+
Photosensor	Fluorescent	$188.30	$15.00	10

Step-dimming Ballasts for HID Lights using Photosensors

To replace the ballasts that currently operate the 74 HID lights in the pool area and field house with step-dimming ballasts, it would cost an estimated $28,232 including acquisition and installation. Photosensors would cost an additional $406.60, for a total of $28,635. This estimate assumes that it would take one electrician about 30 minutes to replace ballasts and to install a photosensor at a labor rate of $30 per hour. It also assumes that the photosensor is capable of controlling all the dimming ballasts in each area.

Recommendations

We recommend that passive solar technologies be installed in the KSC due to their ability to reduce the energy costs of lighting by one half. Installing both skylights and solar tubes are suggested, but incorporating skylights into the building is highly recommended. Since lighting accounts for 35% of the KSC's electricity needs, adding skylights and more windows to the space could reduce the sports centers annual electricity usage by 15%.

We also suggest that the metal halide lamp ballasts be replaced with step-dimming ballasts, and that photosensors be installed to measure the amount of natural light present. These installations would allow less energy to be used when spaces have adequate natural light. In addition, all fluorescent lights should be replaced with LED lights, at the end of their lifetime, due to the comparable energy efficiency of LED lights and drawback that CFL bulbs contain hazardous waste in the form of mercury.

Adding mounted infrared occupancy sensors to control lighting in hallways (which account for the majority of lighting being used due to consistent bulb burning in these areas) is also recommended. Since lumens can be increased at a minimal cost, the data shows that a slow phase-out of CFL lighting plus added light sensors will reduce energy costs for the College as well as improve the quality of light in the Sports Center.

[325] "Buildings and Plants: Lighting," ENERGY STAR, <http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#SS_6_7_1>. Date Accessed: April 3, 2009.

VI. WATER

SUMMARY

Water conservation and reuse are important and often overlooked opportunities for saving money and decreasing the College's impact on the environment. This report discusses two methods of approaching water use reduction in the Keohane Sports Center (KSC): first, through changing to more water-efficient appliances and second, through the addition of greywater and rainwater collection systems. Replacing appliances has the potential to make a great impact on water use at a relatively low cost. The addition of a greywater system, with its huge impacts on water use, would require an overhaul of the plumbing system in the Sports Center. For these reasons, we recommend that the College pursue the addition of a rainwater catchment system for irrigation purposes and the replacement of water inefficient appliances.

Introduction

Water is a deceivingly abundant resource. More than 70.9% of the Earth's surface is covered in water,[326] but of that, only 3% is fresh water. Of all of the fresh water in the world, approximately 69% is frozen in ice and glaciers; another 30% is groundwater and less than 0.3% is available in streams, lakes and swamps.[327] Wellesley College provides its own water through wells located on site. While Massachusetts is not a state at high risk of drought, and it is therefore unlikely that Wellesley's wells will ever run dry, there are several factors to consider before dismissing the importance of water conservation on campus.

In order to be used in sinks, showers and washing machines, water must be heated. Heating water requires energy. Conserving water for these appliances can save up to $0.01/gallon.[329] While this amount may not sound like much, consider that the average shower using a normal-flow shower head uses 34.4-13.4 gallons of water, whereas a low-flow shower uses 29.9-11.3 gallons of water (a potential savings of $0.02 - $0.04 per shower for heating water alone).[330] Similarly, all water used on campus for non-irrigation purposes must be treated before it can be used. This too carries its own energy, maintenance, and chemical costs.

While Wellesley has many water treatment and catchment systems in place, sewer systems can become overloaded during intense rainstorms and overflow, inundating nearby streams and lakes with untreated water. As the college continues to grow, it may find that costly expansions need to be made to the sewage system. By reducing water use or collecting this additional water, the college will avoid some of these added costs.

To understand how to conserve water in the Keohane Sports Center, the current water use must be determined. In order to estimate this number, we divided the annual campus-wide water use for 2007[331] by the total campus building square footage. This average annual water use per square foot was then multiplied by the total square footage of the KSC. This number was then divided by 365.25 to determine the Sports Center's average daily water use. The final number indicated that the KSC uses 16,117 gallons of water per day. The actual water use is certain to be larger than this, particularly when considering the differences in uses for water in different buildings (e.g. most academic buildings do not have showers, a pool or washing machines). Seemingly minor changes to the way water is used and recycled could make an enormous difference in total water use for the KSC.

Water Conservation

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[326]The CIA World Fact Book, "World," Central Intelligence Agency, https://www.cia.gov/library/publications/the-world-factbook/geos/xx.html#Geo. Accessed April 14, 2009.
[327] US Geological Survey Water Science for Schools, "Earth's Water Distribution," US Geological Survey, http://ga.water.usgs.gov/edu/waterdistribution.html. Accessed April 14, 2009.
[329] Wellesley College Sustainability, "Water Conservation," Wellesley College: Sustainability, http://www.wellesley.edu/AdminandPlanning/Sustainability/waterconservation.html. Accessed April 14, 2009.
[330] Boulder Area Sustainability Information Network, "Nature of Residential Water Use and Effectiveness of Conservation Programs," Boulder Area Sustainability Information Network, http://bcn.boulder.co.us/basin/local/wateruse.html. Accessed April 14, 2009.
[331] Wellesley College: Sustainability, "Water Conservation," Wellesley College: Sustainability, http://www.wellesley.edu/AdminandPlanning/Sustainability/waterconservation.html. Accessed April 14, 2009.

The first step to water conservation is ensuring that the systems currently in place are as efficient as possible. Toilets, sinks, showers, and other fixtures throughout the building should be checked for leaks. A small drip from a faucet can waste 20 gallons of water a day.[332] Behavioral changes should also be attempted, and are addressed in the Energy Efficiency chapter.

Toilets

Toilet flushing accounts for the highest water use in commercial and residential buildings.[333] The KSC has 23 toilets that are in constant use, all low flow (1.6 gallon), high power flush toilets. To further improve water conservation the College should install dual flush toilets. Dual flush toilets offer the option of a smaller 0.8 gallon flush as well as a larger 1.6 gallon flush. At the KSC, switching to dual flush toilets could result in tens of thousands of gallons in reduced water use.

Another often-overlooked KSC bathroom fixture is the urinal. While there are not many men who use the KSC, there are some male faculty, residents of the town of Wellesley, and visitors for athletic events who do. Like toilets, urinals are available in low-flow options, one gallon per flush, as well as waterless options. Using a waterless urinal would save three gallons of water per flush and despite the fact that urinals might receive less use than toilets the water savings would be significant.[334] Waterless urinals use a cartridge that contains a liquid sealant. The urinals are found to be cleaner, easier to maintain, and cause fewer odor complaints.[335]

A more radical option for reducing water use with toilet appliances would be composting toilets that use little to no water, little to no electricity, and turn waste into usable compost. Composting toilets can be installed in most buildings, including commercial buildings and even skyscrapers.[336] There are two main types of composting toilets, batch systems and continual process systems, and many smaller variations within the two categories. In a batch system all composting takes place within a sealed container that is filled and replaced as necessary. In a continual process system waste is constantly being added and composted and can be removed 6-12 months after being deposited.[337]

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[332] Eartheasy, "25 Ways to Conserve Water at Home," Eartheasy, http://www.eartheasy.com/live_water_saving.htm. Accessed April 13, 2009.
[333] Building Green.com, "Green Products," Building Green, http://www.buildinggreen.com/auth/productsByCsiSection.cfm?SubBuilderCategoryID=3430. Accessed April 14, 2009.
[334] Air Delights, "WaterFree Urinals and Cartridges," Air Delights, http://www.airdelights.com/waterfree_urinal.html. Accessed April 14, 2009.
[335] Facilitiesnet. "Making Waterless Work," Facilitiesnet, http://www.facilitiesnet.com/plumbingrestrooms/article/Making-Waterless-Work--2442. Accessed May 5, 2009.
[336] Green Building Encyclopedia, "Water Conservation in Buildings," Green Building Encyclopedia, http://www.whygreenbuildings.com/water_conservation.php. Accessed April 13, 2009.
[337] Composting Toilet World, "What is a Composting Toilet?," Composting Toilet World, http://compostingtoilet.org/compost_toilets_explained/what_is_a_composting_toilet/index.php. Accessed April 13, 2009.

In both systems the waste is treated by composting, worm processing, micro- and macro-breakdown, and dehydration and evaporation of moisture.[338] Composting toilets can reduce a household's water use between 20 and 50%.[339] Composting ensures a complete cycle of energy and waste, by turning human waste back into nutrient rich fertilizer that can be used in landscaping and gardening. Most composting toilets use suction air flow, eliminating toilet and bathroom odor.[340] Composting toilets do pose a significant initial cost and may be better used in new construction where avoiding the price of connecting to the sewer system or installing a septic system results is great savings. A composting toilet system can be 25-75% less expensive than a septic system depending on local prices.[341] Also, composting toilets are meant to be used only a certain number of times a day. This limitation could prove to be a problem in high traffic areas, such as locker rooms, which see high influxes of use especially during competitions and tournaments.

Figure 49. Water Reductions with Toilets

Alternatives	Water Use	Electricity Use	Cost	Benefits
Dual Flush Toilets	0.8 – 1.6 gallons	None	$1289.45 for entire toilet $222.00 for dual flush tank, can be fit to multiple bowls	Allows for small and large flush, more savings than 1.6 gallon per flush toilets
WaterFree Urinal	None	None	$319.00	No water use, less odor, less cleaning product required
Composting Toilets	Little - None	Little - None	$2,000	Water use reduction, usable end product, reduce possible pollution

Sinks/Faucets

Typical sinks expel a large amount of water very quickly, although that much water is often not necessary. Installing aerators in sink faucets can reduce a typical 2.75 gallons per minute faucet to a 1.5 gallon per minute faucet. For an average household of four this change could result in approximately 14,700 gallons

[338] Composting Toilet World, "What is a Composting Toilet?," Composting Toilet World, http://compostingtoilet.org/compost_toilets_explained/what_is_a_composting_toilet/index.php. Accessed April 13, 2009.
[339] Composting Toilet World, "The Benefits of Composting Toilets," Composting Toilet World, http://compostingtoilet.org/compost_toilets_explained/the_benefits_of_composting_toilets/index.php. Accessed April 13, 2009.
[340] Composting Toilet World, "The Benefits of Composting Toilets," Composting Toilet World, http://compostingtoilet.org/compost_toilets_explained/the_benefits_of_composting_toilets/index.php. Accessed April 13, 2009.
[341] Composting Toilet World, "FAQ," Composting Toilet World, http://compostingtoilet.org/faq/index.php. Accessed April 13, 2009.

of water saved each year, or about a 16% reduction in the household water use.[342] For the KSC, this change could result in similar water savings, and in a high water use building like the KSC a 16% reduction would be a lot of water. Aerators are extremely inexpensive, costing between $5-10, and can add up to 50% water savings.[343] Aerators can also be added to existing faucets without replacing the faucet hardware.

Showers

Showers account for 22% of individual water use in North America,[344] and we assume that they account for at least that much at the KSC. Gallons of water are wasted each day while users wait for water to heat. The addition of insulation to pipes allows water to heat faster and avoids wasting water as users wait for the water to heat. Long, hot showers can use 5 to 10 gallons every unneeded minute.[345] Showerstart, a device that can be attached to a showerhead, automatically becomes a trickle until the shower water heats up to 95° F, saving almost all the hot water that might be wasted while users wait for shower water to heat. New showerheads are required to flow at 2.5 gallons per minute or less, but older showerheads often flow at four gallons per minute. This means that two minutes of hot water in an older shower wastes five to eight gallons.

In addition to not wasting water while it is heated, it is possible to reduce the amount of water that flows out of the showerhead. Showerheads come in many different varieties. The lowest water per minute options seem to be about 1.8 to 2 gallons per minute. As well as helping earn points towards LEED certification low flow showerheads promise up to 20% water use reduction without sacrificing performance.[346] Also, just encouraging shorter showers could help save water, as a 4 minute shower uses approximately 20 to 40 gallons of water.[347]

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[342] Kohler, "Faucets," Kohler, http://www.us.kohler.com/savewater/how/bathroom/faucets.htm. Accessed April 14, 2009.
[343] Eartheasy, "Low-Flow Aerators/Showerheads," Eartheasy, http://www.eartheasy.com/live_lowflow_aerators.htm. Accessed April 14, 2009.
[344] Eartheasy, "Low-Flow Aerators/Showerheads," Eartheasy, http://www.eartheasy.com/live_lowflow_aerators.htm. Accessed April 14, 2009.
[345] Eartheasy, "25 Ways to Conserve Water at Home," Eartheasy, http://www.eartheasy.com/live_water_saving.htm. Accessed April 13, 2009.
[346] Kohler, "Showerhead and Handshowers," Kohler, http://www.us.kohler.com/savewater/how/bathroom/showerheads/detail.htm?productNumber=8544&business=KPNA&resultPageKey=504153519-0. Accessed April 14, 2009.
[347] Eartheasy, "25 Ways to Conserve Water at Home," Eartheasy, http://www.eartheasy.com/live_water_saving.htm. Accessed April 13, 2009.

Figure 50. Water Reduction from Showerheads

Alternative	Water Use	Cost
Low Flow Showerhead	1.8 – 2.0 Gallons/minute	$5.95-$105.30
Showerstart System	Restricts flow after water is hot, so water is not wasted waiting for it to heat	$28.99 (Just for Showerstart system, not showerhead)

Washing Machines & Dishwashers

The KSC staff does many loads of laundry each day to keep up with the use of towels, uniforms, and practice clothes. Water conservation tips recommend only doing laundry when the washer is full, which seems achievable due to the volume of laundry produced by the users of the KSC. Some of the washers at the KSC are Energy Star rated, but some are not. Energy Star washers uses 35-50% less water (and 50% less energy) per load than a typical washing machine.[348] Also, front load washers use 33% less water, heat energy, and detergent that top-loading washers.[349]

There is one dishwasher in the Athletic Training room, which is run a few times a day to cleanse water bottles and other small containers. By replacing a dishwasher purchased before 1994 with an Energy-Star model one can save $30 in utility costs per year.[350] In addition, new front-loading dishwashers use 30-50% less water than older models, as detailed in Appendix C.

Water Reuse

While the installation of water-saving appliances in the KSC could reduce water use, the college will inevitably continue to use and dispose of large amounts of water. Therefore, in addition to installing water-saving appliances, the college should consider potential ways to reuse water on campus. Water reuse in general has the benefit of reducing overall water consumption, cutting the amount of sewage or runoff generated by the college and permitting increased aquifer recharge. Here, we focus on two specific ways of reusing water on campus: greywater reuse and rainwater harvesting.

Greywater is non-potable wastewater drained from showers, laundry machines, and bathroom sinks.[351] It accounts for approximately 60-65% of indoor household water use, and does not include water

[348] Eartheasy, "25 Ways to Conserve Water at Home," Eartheasy, http://www.eartheasy.com/live_water_saving.htm. Accessed April 13, 2009.
[349] The Daily Green, "Get a Front-Loading Washing Machine," The Daily Green, http://www.thedailygreen.com/going-green/tips/front-loading-washing-machine-460303. Accessed April 14, 2009.
[350] Energy Star, "Dishwashers for Consumers," Energy Star, http://www.energystar.gov/index.cfm?c=dishwash.pr_dishwashers. Accessed April 14, 2009.
[351] Sustainable Village, "Frequently Asked Questions: Greywater," Sustainable Village, http://www.sustainablevillage.com/resources/faq/greywater.html. Accessed April 10, 2009.

from toilets.[352] Unlike blackwater, or toilet sewage, greywater contains low levels of nitrogen, toxic chemicals, and pathogens, and can be directly reused for irrigation or treated for flushing toilets and washing laundry.[353] Greywater systems range from the basic—run the hose from the laundry machine out the window—to the complex—constructed wetlands and sand filtration beds.[354] All greywater systems, however, rely on the same basic principles: do not store water for longer than 24 hours, minimize direct human contact, and make sure if greywater is used outside it infiltrates the ground near the surface without pooling or runoff.[355]

Rainwater harvesting involves collecting, storing, and sometimes treating rainwater runoff for irrigation or indoor water use. Like greywater, rainwater can be used untreated for irrigation, doing laundry and flushing toilets, and in many of these cases greywater and collected rainwater can be combined. Rainwater can also be filtered through a mix of mechanical systems including sand filtration and lava filter systems, and biological systems, such as constructed wetlands and treatment ponds.[356] Unlike greywater, rainwater can be treated to potable levels, and therefore used for drinking, showering, and washing hands.

Water Savings

Given current campus wide water use, approximately 3.826 million gallons of greywater a year could be reused from the Sports Center. This estimate is likely lower than the actual value, since the sports center almost certainly consumes more water per square foot than academic or administrative buildings on campus. Installation of water saving appliances such as low flow toilets and sinks would reduce total water use, and therefore greywater as a percentage of total water use.

Figure 51. Annual Water Usage and Potential Greywater Volumes

College Annual Water Usage (mil. gal.)	College GSF	Annual Water Use (mil. gal.)/Sq. Ft	Sports Center GSF	KSC Annual Water Usage (mil. gal.)	KSC Annual Greywater (65%)
94.688[357]	2543100[358]	3.72333E-05	158100[359]	5.887	3.826

[352] Sustainable Village, "Frequently Asked Questions: Greywater," Sustainable Village, http://www.sustainablevillage.com/resources/faq/greywater.html. Accessed April 10, 2009
[353] Carl Lindstrom, "Greywater: what it is…how to treat it…how to use it," Greywater, http://www.greywater.com/index.htm. Accessed April 10, 2009.
[354] Art Ludwig, "Recycling Water the Greywater Guerillas' Way," The Greywater Guerillas, http://www.greywaterguerrillas.com/greywater.html. Accessed April 14, 2009.
[355] Art Ludwig, "Recycling Water the Greywater Guerillas' Way," The Greywater Guerillas, http://www.greywaterguerrillas.com/greywater.html. Accessed April 14, 2009.
[356] Wikipedia, "Greywater," Wikipedia, http://en.wikipedia.org/wiki/Greywater. Accessed April 10, 2009.
[357] Wellesley College Sustainability, "Water Conservation," Wellesley College Sustainability, http://www.wellesley.edu/AdminandPlanning/Sustainability/waterconservation.html. Accessed April 14, 2009.

Meanwhile, the amount of rainwater collected depends upon the area of collection, annual rainfall and the roofing material used. Currently, if all runoff from the Sports Center roofs were collected, the college would harvest approximately 2.878 million gallons of rainwater per year. Installation of a green roof, which retains water, would reduce that value. Any water reclaimed either as runoff or greywater would most likely go towards irrigation of the sports center fields, which are currently irrigated using water from Lake Waban.[361]

Figure 52. Average Annual Runoff

	Footprint (sq. ft)	Annual Rainfall (inches)	Total Runoff (cubic feet)	Total Runoff (gallons)
Keohane Sports Center	95656[362]	48.28[363]	384900	2878900

Greywater System Costs

Greywater systems vary dramatically in size, complexity, and cost. For this estimate, we have chosen to look at systems at both ends of the size/cost spectrum.

The Earthstar® 55 Gallon Greywater Filter System could easily be hooked up to the laundry machines inside the sports center. Given that energy efficient front-loading washers use 18 to 25 gallons of water per load,[364] and that the KSC does at least three to four loads of laundry per day, the Earthstar System could provide greywater irrigation to landscaping around the KSC buildings.

On the larger end, Wellesley could install dual pipe plumbing system within the sports center to separate out greywater, run greywater through a backwashing sand filter or constructed wetland system and use the treated water in a sub-surface drip irrigation system for the athletic fields. Dual piping would be necessary to prevent contamination between grey and black water, while a sub-surface drip irrigation system would be necessary to prevent contamination to the athletes who play on the fields.[365]

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[358] Eva Klein & Associates, Harvey H. Kasier Associates and Symmes Maini McKee Associates, "Wellesley College Comprehensive Facilities Plan: Building and Capital Project Data," Wellesley College, https://services.wellesley.edu/planning/PDF/IVBuildingProjectData.pdf. Date Accessed: April 14, 2009.
[359] Eva Klein & Associates, Harvey H. Kasier Associates and Symmes Maini McKee Associates, "Wellesley College Comprehensive Facilities Plan: Building and Capital Project Data," Wellesley College, https://services.wellesley.edu/planning/PDF/IVBuildingProjectData.pdf. Accessed April 14, 2009.
[361] Wellesley College: Sustainability, "Water Conservation," Wellesley College: Sustainability, http://www.wellesley.edu/AdminandPlanning/Sustainability/waterconservation.html. Accessed April 14, 2009.
[362] Eva Klein & Associates, Harvey H. Kasier Associates and Symmes Maini McKee Associates, "Wellesley College Comprehensive Facilities Plan: Building and Capital Project Data," Wellesley College, https://services.wellesley.edu/planning/PDF/IVBuildingProjectData.pdf. Accessed April 14, 2009.
[363] CNNMoney.com "Best Places to Live: Wellesley, MA," CNNMoney.com, http://money.cnn.com/magazines/moneymag/bplive/2008/snapshots/PL2574210.html. Accessed April 10, 2009.
[364] Slipper Rock University of Pennsylvania, "Energy Star Washing Machine," Slipper Rock University of Pennsylvania, http://www.sru.edu/pages/6732.asp. Date Accessed: April 14, 2009.
[365] Art Ludwig, "Common Greywater Errors and Preferred Practices," Oasis Design, http://oasisdesign.net/greywater/misinfo/index.htm. Accessed April 14, 2009.

For a rainwater harvesting system, Wellesley would need to install a cistern in order to collect and store rainwater, whether for indoor or outdoor use. In Wellesley, annual precipitation averages 48.28 inches, and average monthly precipitation is a little over 4 inches.[366] Assuming that Wellesley's two soccer fields and one recreation club field are all covered in Kentucky bluegrass, it would take approximately 605,880 gallons of water per month to irrigate those three fields.[367] This is likely an overestimate of irrigation, since Wellesley's irrigation system is synchronized with local weather conditions,[368] and therefore shuts off during rainy periods.

The high cost of the constructed wetland greywater system is largely due to its complexity. Not only would new plumbing have to be installed in the KSC, but subsurface drip irrigation would have to be added to the athletic fields, and somewhere ten acres would have to be set aside for a new constructed wetland.

Figure 53. Cost Estimates and Projected Water Reduction for Three Greywater Alternatives

Alternative	Cost	Water Capacity (Gallons)
Earthstar Greywater Filter System	$1,199	55
Constructed Wetland Greywater System	$609,000	3,258,514
Plexiglass cistern	$10,000	10,000

Water Reuse and the Pool

Pool water recycling might be promising, but wastewater restrictions in the town of Wellesley prohibit the reuse of pool water for irrigation purposes or the re-release of pool water into the sewage system, even after being used in greywater appliances.[369] While the process of refilling the pool is water-intensive, the pool is only drained once every five years or so.[370] Similarly, efforts during the building of the pool limit current pool water loss. High humidity in the pool area prevents water from being lost to evaporation. Pool water loss does occur through "splash out", the water that drips from swimmers bodies as they exit the pool and water splashed out of the pool, as well as backwash that occurs when the pool filter is cleaned. Because the Chandler pool already has very high splash guards and a relatively low water level and is an indoor pool that requires less-frequent filter cleanings, there is little else that can be done to prevent these types of water loss.

[366] Idcide.com, "Wellesley, MA Weather," Idcide.com, http://www.idcide.com/weather/ma/wellesley.htm. Accessed April 14, 2009.
[367] This estimate is based on square footage of the fields and 1.2 inch weekly irrigation needs from: Brad S. Fresenburg and John H. Dunn, "Home Lawn Watering Guide," University of Missouri Extension, http://extension.missouri.edu/xplor/agguides/hort/g06720.htm. Accessed April 15, 2009.
[368] Wellesley College: Sustainability, "Water Conservation," Wellesley College: Sustainability, http://www.wellesley.edu/AdminandPlanning/Sustainability/waterconservation.html. Accessed April 14, 2009.
[369] Interview with Martha Dietrick, February 4, 2009.
[370] Email Correspondence with Martha Dietrick, April 10, 2009.

Recommendations

Important strides in water conservation cannot be monitored or appraised without the complete understanding of total water use that can only be provided by adding a KSC-specific water meter. In addition to new, clear data that would be provided by such a meter, meter readings can be posted to a website so that students can monitor and learn from water use in the sports center.

Small changes throughout the KSC may combine to make a large difference for water use. Installing aerators in all the faucets and showerheads may have a water savings of 30%. As washing machines and dishwashers are replaced throughout the building they should be swapped for water and energy efficient models. Dual flush toilets and waterless urinals would save the most water across the board. Therefore, as toilets and urinals are replaced, they too should be replaced with water efficient models. These small changes will make a large difference in the amount of water the KSC uses.

For water reuse, Wellesley should install a cistern to collect rainwater at the Sports Center in the short term. A cistern would not only decrease runoff and storm drain loads, it would also reduce the extraction of water from Lake Waban for irrigation, allowing more water to be left in the natural watershed. In the longer term, Wellesley should consider the possibility of including a constructed wetland greywater system somewhere near the sports center. Such a wetland would not only reduce sewage loads and increase the amount of water fed back into the watershed, it would also provide increased wetlands habitat and scenic landscaping. Wellesley should also consider installing dual plumbing for reuse of greywater in all future building retrofits.

VII. COOLING

Summary

Steadily climbing average temperatures over the past century combined with a shift to year-round usage of the KSC have highlighted the need to improve methods of cooling the facility. In this section we review three major types of cooling technologies: passive cooling, active cooling with thermal gradients and active cooling with evaporation. We recommend at least one option within each type of technology to provide decision-makers with a variety of options. We also rank our recommended options by a variety of criteria likely to be important in renovation considerations and conclude that solar screens and cool roofs are the most desirable options, followed by upgrading the ventilation system, adding directed landscaping, and adding an absorption chiller.

Background

The reasons for ensuring that the system for cooling the Sports Center is appropriate and energy efficient are plentiful. When the Keohane Sports Center was first built, its intended purpose was to house only activities that occurred during the academic year. In recent decades, however, the facilities have been used increasingly in the summer months.[371] While students, who aren't generally living at Wellesley in the summer, had no real complaints about the cooling system, faculty and staff who use the Sports Center from June to August have complained that the offices become unbearably hot. Students, as well as Sports Center faculty, have raised concerns about air quality within the building. Having an adequate cooling system is important to the quality of the air in the Sports Center because the cool air will inhibit the growth of mold and the spread of bacteria, which can cause the building to smell and feel stuffy. Athletic trainers have also expressed concern that student athletes suffering from heat stress have no adequate place to recuperate. Heat stress can cause dehydration and even more severe problems.

Commercially-available cooling systems are becoming increasingly innovative. As global temperatures rise, the need to cool buildings increases as well. Three categories of cooling systems exist: passive cooling, active cooling with thermal gradients, and active cooling with evaporative heat loss. Passive cooling could be considered "no cooling," because it doesn't involve technology as we think of it; rather, it uses natural cooling mechanisms such as shade. Active cooling with thermal gradients includes geothermal cooling options and technologies that take advantage of differences in air temperature between the inside and outside of buildings. Active cooling with evaporative heat loss includes conventional air-conditioning as well as more energy efficient systems that also take advantage of heat loss through evaporation of a liquid. The cogeneration power plant on Wellesley's campus currently operates an evaporative cooling system, which is used to control temperatures in the Davis Museum, Science Center, and Clapp Library year-round.[372] It would be possible to connect the KSC to the pre-existing cooling from the power plant, but the cost would be prohibitive. A stand-alone cooling system at the KSC would be more cost-effective.[373]

Passive Cooling: Alternatives and Costs

Passive cooling requires no energy investment, and relies on daily temperature and relative humidity fluctuations. Although considered to be an alternative form of cooling compared with mechanically-based technologies, more people utilize passive cooling than is commonly perceived; each time you open a window to allow a breeze through a room you are in fact employing a simple passive cooling technique.

There are three major strategies for passive cooling within the building's structure: natural ventilation, high thermal mass cooling, and green or cool roofing.[374] Some of these cooling methods are climate-dependent; some would work better in more humid climates, while others work better in drier climates.

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[371] Martha Dietrick, personal communication, February 18, 2009.
[372] Michael Dawley, personal communication, February 25, 2009.
[373] Patrick Willoughby, personal communication, April 3, 2009.
[374] Energy Source Builder, Passive Cooling Strategies, Which Passive Cooling Strategy is Right for You? http://www.oikos.com/esb/51/passivecooling.html#passive%20cooling. Accessed April 1, 2009.

Natural ventilation

Natural ventilation is defined as using air movements to cool areas. One example would be opening windows on opposite sides of a room, to create cross-ventilation driven by a breeze. Natural ventilation is inherently related to structural design of the building, which means windows need to be placed in areas that would most effectively ventilate the building. The major disadvantage to relying heavily on natural ventilation is that you can't control when the wind will blow. Architects can incorporate tall spaces within buildings, called stacks, which have openings near the roof to allow warm air to escape.[375] Natural ventilation is dependent on physical location. If an area is usually very calm, natural ventilation may not be the principal cooling component, but can still be integrated into the larger cooling scheme. Air moving at speeds of only 1.1 mph can cool the air in a building by 5.4°F.[376]

High thermal mass

High thermal mass building materials can absorb large amounts of heat throughout the day, and then slowly release that heat at night when the ambient temperature is cooler. In general, any material that has a high heat capacity, gives off heat easily (high emissivity), and is moderately conductive can be used to provide thermal mass in a building.[377] An effectively designed high thermal mass building will need to have three square feet of exposed mass (absorption materials) for every square foot of floor area.[378] Adding night ventilation helps a high thermal mass system to release heat at night. By slowing the transfer of heat from the outside to the inside of a building, high thermal mass can keep indoor temperatures more stable. One study found a six-fold decrease in daily temperature fluctuations in a building with high thermal mass.[379] The incorporation of absorptive brick walls would be one way to integrate high thermal mass into the existing KSC building. This type of passive cooling is more challenging and structurally-dependent, and is not likely to be a large part of the Sports Center's cooling regime.

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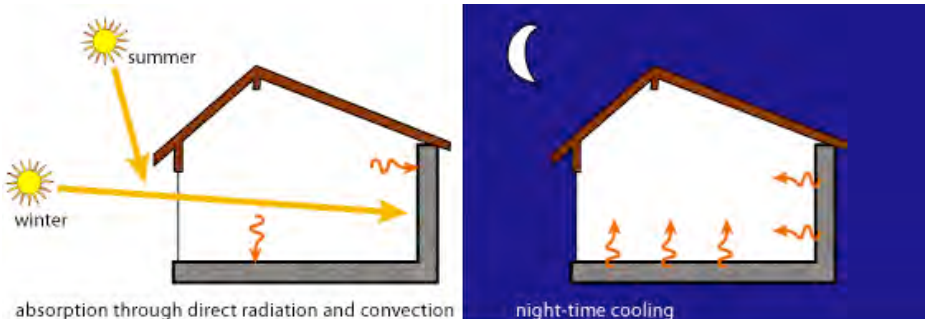
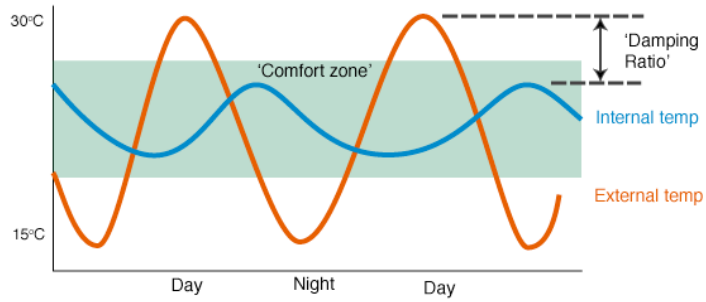
[375] Energy Source Builder: Passive Cooling Strategies, Which Passive Cooling Strategy is Right for You? http://www.oikos.com/esb/51/passivecooling.html#passive%20cooling. Accessed April 1, 2009.
[376] Chris Reardon and Dick Clarke, "Passive Cooling," Your Home Technical Manual, http://www.yourhome.gov.au/technical/fs46.html#air. Accessed May 4, 2009.
[377] National Green Specification, "The Low-Carbon House: Thermal Mass," GreenSpec, http://www.greenspec.co.uk/html/lowcarbon/lowcarbonthermalmass.html. Accessed May 2, 2009.
[378] Energy Source Builder, Passive Cooling Strategies, Which Passive Cooling Strategy is Right for You? http://www.oikos.com/esb/51/passivecooling.html#passive%20cooling. Accessed April , 2009.
[379] Bruce Baccei, "Peak Electric Savings Raise the Importance of Increased Thermal Mass and Passive Solar," Building Industry Research Alliance, http://www.bira.ws/projects/files/Peak_Interest_Thermal_Mass.pdf. Accessed May 4, 2009.



(a)



(b)

Figure 54. How high thermal mass (a) cools a building and (b) stabilizes internal temperatures[380]

Green Roofs and Cool Roofs

The roofing on the KSC plays a key role in determining the temperature within the building. An efficient and well-constructed roof will insulate the air inside the building, and retain heat in the winter and cool air in the summer. The Roof chapter discusses in detail two types of roofs—green roofs and cool roofs—that could significantly reduce summer temperatures inside the KSC.

Non-structural Passive Cooling Techniques

Passive cooling techniques also include landscaping and solar screens. These techniques will be more easily incorporated into the existing Sports Center because they don't require heavy construction and alteration of the existing structure, compared with the previously mentioned cooling practices.

Landscaping

An effectively designed landscape can provide numerous benefits in addition to the obvious aesthetic value it is usually intended to serve. These benefits include reductions in water consumption, pesticides, and fuel for landscaping and lawn maintenance, control of noise and air pollution, protection from winter wind

[380] National Green Specification, "The Low-Carbon House: Thermal Mass," GreenSpec, http://www.greenspec.co.uk/html/lowcarbon/lowcarbonthermalmass.html. Accessed May 2, 2009.

and summer sun, and decreasing energy costs overall.[382] Shading and evapotranspiration from vegetation can reduce surrounding air temperatures by as much as 9°F.[383] Since Wellesley is in a temperate climate, landscaping strategies should aim to maximize warming effects of the sun in the winter and cooling effects of shade in the summer, in addition to funneling summer breezes towards the building.[384] In particular, the south and west walls of the field house and pool, respectively, have no landscaping, and these walls are the most exposed to the sun. Because there is not much space along these walls, shrubby conifers such as balsam fir (*Abies balsamea*) and red cedar (*Juniperus virginiana*) would be good species to plant. Deciduous trees or shrubs to the west of the building would provide shade from the sun in summer and allow the sun's warmth to penetrate in winter. Possible species for this location include red maple (*Acer rubrum*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*).

Because the south wall of the field house and west wall of the pool lie along a playing field, emergency vehicle access must be considered in designing a landscaping strategy.[385] One possibility is to tear up the asphalt that currently runs along the building and move it away from the building to allow some space for planting shrubs in between the pathway and the building itself. If this solution is not practical, some trees or shrubs could still be planted at the west end of the field house.

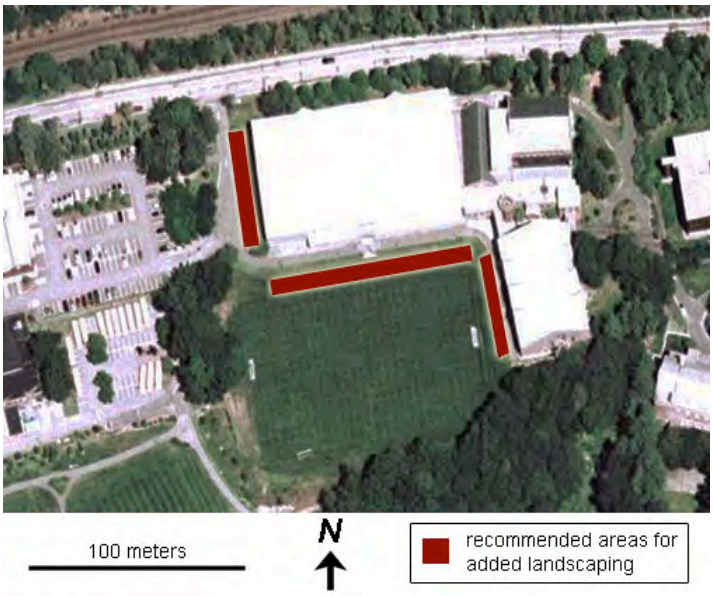


Figure 55. Recommended locations for added landscaping at the KSC, to increase passive cooling

[382] South Carolina Energy Office. Energy Briefs Landscaping for energy efficiency. p. 1. Accessed April 1, 2009.http://www.builditsolar.com/Projects/Cooling/Shading/EB%20Landscaping%20for%20energy%20efficiency.pdf
[383] South Carolina Energy Office. Energy Briefs Landscaping for energy efficiency. p. 1. Accessed April 1, 2009.http://www.builditsolar.com/Projects/Cooling/Shading/EB%20Landscaping%20for%20energy%20efficiency.pdf
[384] South Carolina Energy Office. Energy Briefs Landscaping for energy efficiency. p. 2. Accessed April 1, 2009. Accessed April 1, 2009.
[385] Patrick Willoughby, personal communication, February 11, 2009.

Solar screens

To defray the heating effects of sunlight, window tints, window films, or solar screens can be installed into pre-existing windows. These generally operate on the principle of deflecting the sun's glare and heat prior to entering the building. Window tints or films are applied directly to the window surface, and permanently attached. There are several disadvantages with the tint and film options: they may wear off over time, window cleaning may damage them, they typically void all window manufacturer's warranties, can cause thermal shock fracture of insulated windows, and don't block as much visible light heat as solar screens, and these typically cost 30 to 50% more than solar screens.[386]

Solar screens deflect light before it hits the windows, and block the visible sunlight, heat, and UV rays that are responsible for 44% of the heat gain in an office.[387] Solar screens are also removable, to allow for passive heating during the winter months, and easy maintenance without the worry of damaging passive solar window treatments, and do not decrease the amount of light in a room the way blinds or shades would. There are a variety of solar screen products to choose from including exterior sun control, solar skylight shades, exterior roll-down shades, exterior window shutters, interior sun control, interior window shades and shutters, and overhangs.[388]

Figure 56. A solar screen blocks heat from hitting window glass (left), but does not block the view from inside the building (right) [389]

[386] Sun Blox, Solar window screens, 2007. http://www.sunbloxsolarscreens.com/#. Accessed April 1, 2009.
[387] Sun Blox, Solar window screens, 2007. http://www.sunbloxsolarscreens.com/#. Accessed April 1, 2009.
[388] Sun Blox. Solar screen solutions. 2007. http://www.sunbloxsolarscreens.com/solar-screens/solar-screen-solutions.html. Date Accessed: April 1, 2009.
[389] Pike Awning Company, "Solar screens block the HEAT, not the view," http://www.pikeawning.com/Solar_screens.html. Accessed May 1, 2009.

Figure 57. Comparison of passive cooling alternatives

	Alternative	Degree of cooling	Costs	Life span	Energy use in operation	Life cycle environmental impacts	Air quality effects
Structural	Natural ventilation	less than 10°F	none	lifespan of building	none	low	increased airflow from outdoors
	High thermal mass	lessens daily temperature fluctuations up to six-fold	4% more than standard construction[390]	lifespan of building	none	low	none
	Green roof	up to 20°F cooler than buildings with conventional roofs	up to $20 per sq. ft.	50-100 years	none	low	improved air quality, carbon sink
	Cool roof	up to 4°F cooler than ambient temperature	up to $3.75 per sq. ft.	12-50 years	none	low to moderate	none
Non-structural	Land-scaping	up to 9°F cooler outside of building	Variable prices	varies with plant and tree species used	none	low	improved air quality, carbon sink
	Solar screens[391]	10-15°F cooler than ambient temperature	less than $100 per screen	20+ years	none	low	reduced airflow from outdoors

Active Cooling Using Thermal Gradients: Alternatives and Costs

There are three main types of cooling technologies that would take advantage of outside temperature to cool the KSC with a low energy input. These three options are a geothermal heat pump system, a lake water cooling system, and night-time ventilation.

[390] Pacific Southwest Concrete Alliance, "Concrete Homes" http://www.concreteresources.net/categories/4BAC1BFB-94D2-AA1E-C17A69D468F41929/concrete_homes.htm. Accessed April 6, 2009.
[391] Quality Screen Co, LLC, "Types of Solar Screen Material," Quality Solar Screen Co., http://www.qualitysolarscreen.com/product_solar_screens.html. Accessed April 6, 2009.

Geothermal Heat Pump & lake Water Cooling

As discussed in the Energy chapter subsection on geothermal energy potential at Wellesley College, geothermal heat pumps take advantage of stable temperatures below ground, which vary between 45 and 75°F according to latitude. The geothermal subsection of the Energy chapter also discusses the advantages and disadvantages of lake water cooling at Wellesley.

Earth tubes

Earth tubes are a technology similar to geothermal heat pumps that could be installed at the Sports Center without a major construction undertaking. Earth tubes use underground metal or plastic pipes with air running through them. The air then releases its heat to the surrounding soil, and re-enters the building as cooler air.[394] Earth tubes are either configured with an open- or closed-loop system. Open-loop systems draw air from outside and deliver it directly into the building which could require additional dehumidification while providing ventilation. In closed-loop systems, the interior air is re-circulated through the earth tubes, making them more efficient than open-loop systems.[395] Earth tubes are typically an expensive cooling alternative and may not be economically justifiable at Wellesley College. They have been successfully installed in places such as the Platinum LEED-certified Aldo Leopold Legacy Center in Baraboo, Wisconsin.[396]

Night-time Ventilation

Ventilation systems can take the form of exhaust ventilation, supply ventilation, or balanced ventilation. An exhaust ventilation system uses a fan to push air out of the building, lowering the pressure inside the building so that outside air flows in. A supply ventilation system works in the opposite way, by pushing outdoor air into the building so that pressure builds up and hot indoor air is pushed out. A balanced ventilation system uses both an exhaust fan and a supply fan, so that there are no changes in building pressure but fresh outdoor air still flows through the rooms. A balanced ventilation system is appropriate for Keohane Sports Center because having both supply and exhaust fans would make it easier for rooms in the lower levels of the building to be ventilated. By running the ventilation system at night, cool nighttime air can be drawn into the building to flush out hot air that has accumulated in the building over the course of the day. The chosen ventilation system should not include heat recovery, or should allow heat recovery to be turned off, so that heat is allowed to leave the building. [397]

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[394] United States Department of Energy. 2008. Energy Savers: Earth Cooling Tubes. http://www.sunbloxsolarscreens.com/solar-screens/solar-screen-solutions.html. Accessed April 1, 2009.
[395] United States Department of Energy. 2008. Energy Savers: Earth Cooling Tubes. http://www.sunbloxsolarscreens.com/solar-screens/solar-screen-solutions.html. Accessed April 1, 2009.
[396] Leopold Legacy Center. http://www.aldoleopold.org/LandEthicCampaign/earth%20tubes.pdf. Accessed April 1, 2009.
[397] U.S. Department of Energy, "Whole-House Ventilation Systems," Building Technologies Program, http://www.ornl.gov/sci/roofs+walls/insulation/fact%20sheets/whole%20house%20ventilation%20systems.pdf. Accessed April 5, 2009.

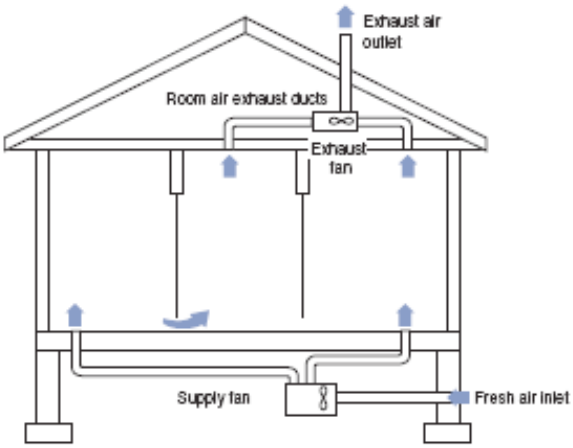

Figure 58. A balanced ventilation system[398]

Figure 59. Comparison of alternatives employing thermal gradient active cooling

Alternative	Degree of cooling	Costs	Life span	Energy use	Life cycle environmental impacts	Air quality effects
Geothermal heat pump	full (replaces conventional AC)	$10,000-$30,000 for drilling, $717,500 for equipment ($2,500/ton capacity)	25-30 years for indoor parts, 50+ years for underground parts	low	moderate	none
Earth tubes	full (replaces conventional AC)	not cost-effective[399]	20+ years	none	low	potentially increased airflow from outdoors
Lake water cooling	full	under $1 million	75-100 years	low	moderate	none
Night-time ventilation	cools to night-time air	$60,000	20+ years	low	moderate	increased airflow

[398] U.S. Department of Energy, "Whole-House Ventilation Systems," Building Technologies Program, http://www.ornl.gov/sci/roofs+walls/insulation/fact%20sheets/whole%20house%20ventilation%20systems.pdf. Accessed April 5, 2009.
[399] U.S. Department of Energy, "Earth Cooling Tubes," Energy Savers, http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12460. Accessed April 6, 2009.

Active Cooling Using Evaporative Heat Loss: Alternatives and Costs

This section examines what most people refer to as the "conventional" method of cooling – central air conditioning - as well as absorption chillers and evaporative coolers (swamp coolers). Over the course of the twentieth century the cost of cooling technologies declined while average temperatures simultaneously kept climbing. As such the rate at which U.S. consumers installed active air-conditioning increased nearly substantially.[400] It is now estimated that nearly 50% of all U.S. homes have air-conditioning.[401] The three alternatives in this section all cool the building substantially, while those discussed earlier do not.

Central Air Conditioners

Central air conditioners extract heat from indoor air and transfer it outside though a system of supply and return ducts.[402] There are two main types of central air-conditioning units: split systems or packaged unit systems. Most central air conditioners are called split systems because there is an outdoor unit (condenser) and an indoor unit (evaporator coil).[403] The compressor in the outdoor unit changes a gaseous refrigerant into a high temperature, high pressure gas that loses heat as it flows through the outdoor coil. That makes the refrigerant condense into a high temperature, high pressure liquid that flows through copper tubing into the evaporator coil located in your fan coil unit or attached to your furnace.[404] Packaged air conditioners combine the condensing unit and the evaporator coil into one outdoor unit. They are commonly installed for small commercial buildings as they are out of the way and therefore quieter than split systems.

[406] If sized correctly, both split system and packaged unit air conditioners can efficiently provide the desired level of cooling. Central air-conditioning units are rated according to their Seasonal Energy Efficiency Ratio (SEER). SEER ratings today range from 13 to 23, with higher numbers indicating more efficient units that offer the greatest energy savings.[407] The minimum SEER rating that earns an Energy Star label is 14. The energy used by central air-conditioning systems depends greatly upon their efficiency (as determined by their SEER rating). The best models today use 30 to 50% less energy than air conditioners made in the 1970s.[408]

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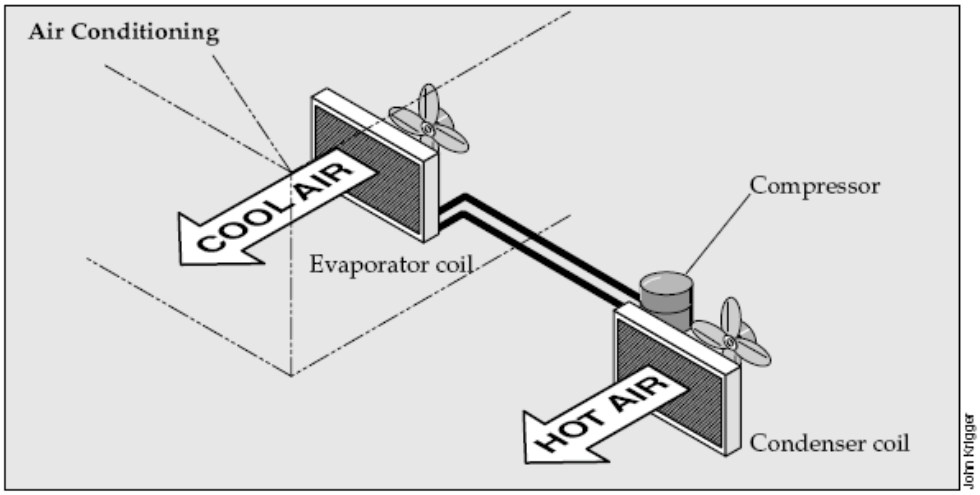
[400] Richard Hayter "The Future of HVAC: The Perspective of One American" (presented at the 40th Anniversary of the Netherlands Technical Association for Building Services, Amsterdam, the Netherlands, June 11, 1999)
[401] Richard Hayter "The Future of HVAC: The Perspective of One American" (presented at the 40th Anniversary of the Netherlands Technical Association for Building Services, Amsterdam, the Netherlands, June 11, 1999)
[402] United States Department of Energy, Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy – Central Air Conditioners" http://energysavers.gov/. Accessed April 4, 2009.
[403] California Energy Commission, Consumer Energy Center "Central HVAC" California Energy Commission. http://consumerenergycenter.org/. Accessed March 31, 2009.
[404] California Energy Commission, Consumer Energy Center "Central HVAC" California Energy Commission. http://consumerenergycenter.org/. Accessed March 31, 2009.
[406] United States Department of Energy, Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy – Central Air Conditioners" http://energysavers.gov/. Accessed April 4, 2009.
[407] California Energy Commission. Consumer Energy Center "Central HVAC" California Energy Commission. http://consumerenergycenter.org/. Accessed March 31, 2009.
[408] United States Department of Energy, Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy – Central Air Conditioners" http://energysavers.gov/. Accessed April 3, 2009.



The fluid that collects heat at the evaporator and releases it at the condenser is called refrigerant. A pump, called the compressor, forces the refrigerant through the circuit of tubing and fins in the coils. Air moves through the tiny spaces between the fins and is cooled by the refrigerant in the coils.

Figure 60. How an air-conditioning system works[409]

Higher efficiency units generally have a higher initial purchase cost, but save money over the 15-20 year lifespan[410] of most units through reduced operating costs. The initial cost of central air-conditioning units varies greatly depending on the efficiency of the model and the size needed. Additionally, the installation cost depends entirely upon whether a functioning system of ducts exists and what condition it is in. Because we do not know the state of the duct system in the KSC we cannot provide specific cost estimates in this section.

The life cylce effects of central air-conditioning units depend on where they are manufactured, how far they are transported to their installed location, and what type of refrigerant they use. Most air-conditioners manufactured before the mid 1980's used either CFCs or HCFCs as their refrigerants, which have major implications for the stratospheric ozone layer.[411] Newer models use alternative non-ozone-depleting refrigerants and are therefore have fewer negative environmental consequences. The main effect of central air conditioners on indoor air is dehumidification, as cooler air can't hold as much moisture as warmer air. The extra moisture condenses on the outside of the coils and is carried away through a drain.[412] A

[409] Energy Efficiency and Renewable Energy Clearinghouse. "Energy-Efficient Air Conditioning" Consumer Energy Information: EREC Fact Sheet. June 1999.
[410] United States Department of Energy, Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy – Central Air Conditioners" http://energysavers.gov/. Accessed April 5, 2009.
[411] United States Environmental Protection Agency, "Stationary Refrigeration and Air Conditioning" Ozone Depletion – Regulatory Programs. http://www.epa.gov/ozone/title6/608/index.html Accessed April 5, 2009.
[412] California Energy Commission. Consumer Energy Center "Central HVAC" California Energy Commission. http://consumerenergycenter.org/. Accessed March 31, 2009.

common complaint about air conditioning units is that the air is sometimes 'stale' compared to other cooling methods (like swamp coolers) as air-conditioners keep recycling the same air.

Absorption Chillers

Absorption chillers have mainly been used in industrial and commercial settings[413] although smaller chillers are now being developed. One main advantage of absorption chillers is that they can make use of any heat source including solar and geothermal hot water.[414] Absorption chillers can also work in zoned heating systems like the KSC's. Absorption chillers use a thermo-chemical process involving two different fluids – a refrigerant and an absorbent. The high affinity of refrigerant for the absorbent causes the refrigerant to boil at a lower temperature and pressure than it normally would, thereby transferring heat from one place to another.[415]

Absorption chillers can achieve full cooling for a building like central air conditioning systems. Ammonia-water absorption coolers can achieve temperatures as low as -40°F, while lithium-bromide systems can achieve temps as low as -47°F,[416] either of which would be more than sufficient for use at the KSC. The initial cost of absorption chillers is usually greater than conventional air conditioning and most economic analyses favor models that would be larger than a model installed for the KSC.[417] An advantage of absorption chiller equipment is that it has very few moving parts and usually has a long service life (20 to 30 years).[418] Another advantage of absorption chillers is that electric energy is only needed for pumps, fans, and controls leading to lower lifetime operating costs than conventional AC.[419]

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[413] United States Department of Energy, Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy –Absorption Heat Pumps" http://energysavers.gov/. Accessed April 5, 2009.
[414] United States Department of Energy, Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy –Absorption Heat Pumps" http://energysavers.gov/. Accessed April 5, 2009.
[415] Energy Solutions Center: Plant and Building Utilities "Process Applications for Small Absorption Chillers" www.energysolutionscenter.org. Accessed March 31, 2009.
[416] Energy Solutions Center: Plant and Building Utilities "Process Applications for Small Absorption Chillers" www.energysolutionscenter.org. Accessed March 31, 2009.
[417] United States Department of Energy – Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy –Absorption Heat Pumps" http://energysavers.gov/. Accessed April 3, 2009.
[418] Energy Solutions Center: Plant and Building Utilities "Process Applications for Small Absorption Chillers" www.energysolutionscenter.org. Accessed March 31, 2009.
[419] Energy Solutions Center: Plant and Building Utilities "Process Applications for Small Absorption Chillers" www.energysolutionscenter.org. Accessed March 31, 2009.

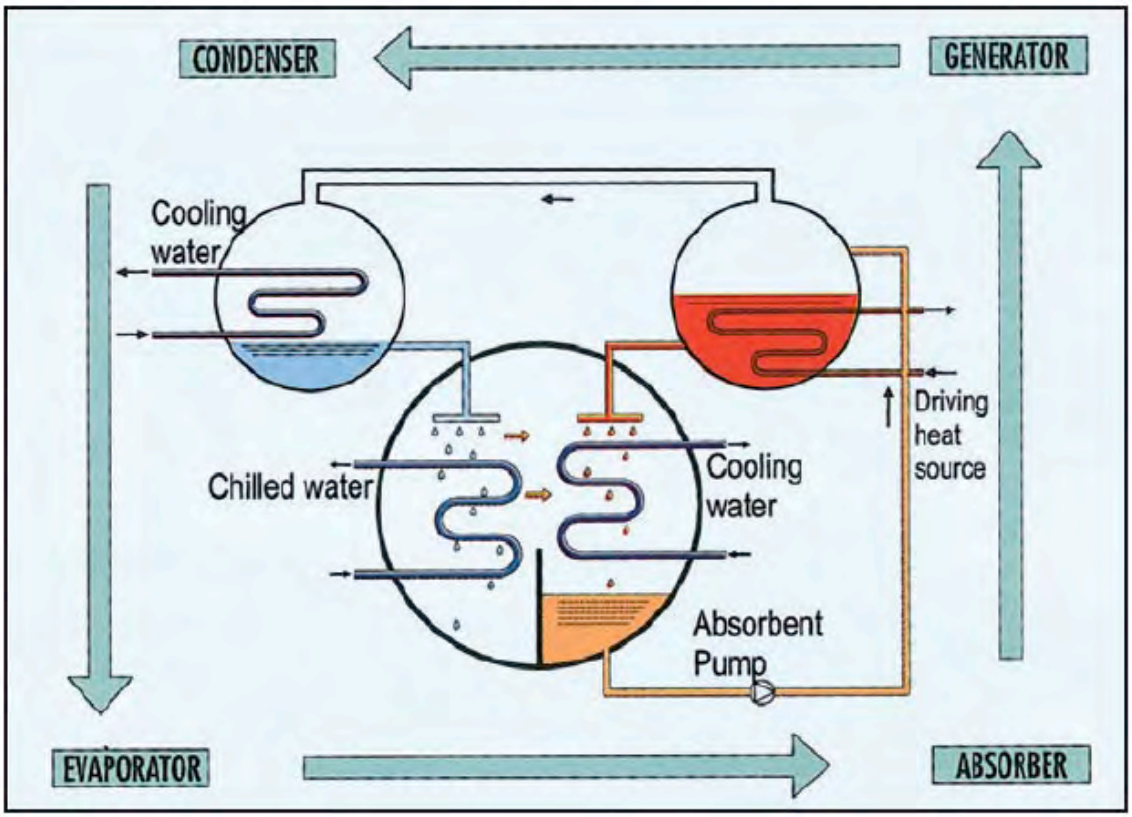

Figure 61. Basic operation cycle of an absorption chiller[420]

Evaporative Coolers

Evaporative coolers (also called swamp coolers) combine the natural process of water evaporation with a moving air system to produce cooler indoor temperatures.[421] In this system, warm outside air is passed through moist pads where it is cooled by evaporation and circulated through the building by a large blower.[422] Evaporative coolers are usually installed in one of two ways – the cooler either blows air into an open central location or connects to ductwork which then distributes the air throughout the rest of the building.[423] Units are commonly installed on roofs (as down-flow units) or on the ground (horizontal units). Evaporative

[420] Energy Solutions Center: Plant and Building Utilities "Process Applications for Small Absorption Chillers" www.energysolutionscenter.org. Accessed March 31, 2009.
[421] California Energy Commission, Consumer Energy Center "Evaporative Cooling" California Energy Commission. http://consumerenergycenter.org/. Accessed March 31, 2009.
[422] California Energy Commission, Consumer Energy Center "Evaporative Cooling" California Energy Commission. http://consumerenergycenter.org/. Accessed March 31, 2009.
[423] United States Department of Energy, Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy –Evaporative Coolers" http://energysavers.gov/. Accessed April 3, 2009.

coolers are rated by the cubic feet of air that they deliver to the building.[424] The size of cooler needed is determined using the amount of floor space (in cubic feet) divided by two.

Major advantages of evaporative coolers are that they cost less than half of what central AC does, use one-fourth as much energy as central AC, and continually provide fresh air (instead of recycled air).[425] Evaporative coolers are the only option of the three in this section that don't include chemical refrigerants.[426] The energy used can be provided by photovoltaic cells to make the process even greener.[427] Evaporative coolers usually cool the air by 27 to 72°F; while they cannot cool to a controlled temperature like air conditioners,[428] the amount of cooling they provide is likely to be sufficient for the KSC. The drawbacks of evaporative coolers include their more frequent maintenance requirements[429] and relatively short lifespan (10 to 20 years).[430] Furthermore, evaporative coolers are only suitable for areas with low humidity (as they add humidity to the air).[431] Evaporative coolers use 3 to 15 gallons of water per day.[432]

Figure 62. Comparison of alternatives employing active evaporative cooling

Alternative	Degree of cooling	Costs	Life span	Energy use	Life cycle environmental impacts	Air quality effects
Central air conditioning (AC)	full	varies	15-20 years	high, though more efficient units are now available	moderate (high for old models)	removes humidity but recycles same air
Absorption chiller	full	more than AC	10-25 years	low	moderate	none
Evaporative cooler	15-40°F cooler than ambient temperature	< than half cost of AC	10-20 years	low	moderate	constant new air, adds humidity

[424] California Energy Commission, Consumer Energy Center "Evaporative Cooling" California Energy Commission. http://consumerenergycenter.org/ . Accessed March 31, 2009.
[425] United States Department of Energy , Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy –Evaporative Coolers" http://energysavers.gov/. Date Accessed: April 3, 2009.
[426] California Energy Commission, Consumer Energy Center "Evaporative Cooling" California Energy Commission. http://consumerenergycenter.org/. Accessed March 31, 2009.
[427] California Energy Commission, Consumer Energy Center "Evaporative Cooling" California Energy Commission. http://consumerenergycenter.org./. Accessed March 31, 2009.
[428] United States Department of Energy , Energy Efficiency and Renewable Energy "A Consumer's Guide to Energy Efficiency and Renewable Energy –Evaporative Coolers" http://energysavers.gov/. Accessed April 3, 2009.
[429] United States Department of Energy, "Evaporative Coolers," Energy Efficiency and Renewable Energy, http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12360. Accessed April 3, 2009.
[430] U.S. Inspect, "FAQs: Home Inspection," U.S. Inspect, http://www.usinspect.com/resources-for-you/faqs/home-inspection. Accessed May 4, 2009.
[431] United States Department of Energy, "Evaporative Coolers," Energy Efficiency and Renewable Energy, http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12360. Accessed April 3, 2009.
[432] United States Department of Energy, "Evaporative Coolers," Energy Efficiency and Renewable Energy, http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12360. Accessed April 3, 2009.

Recommendations

In this section we reviewed three major types of cooling technologies: passive cooling, active cooling with thermal gradients and active cooling with evaporation. We recommend at least one option within each type of technology to provide decision-makers with a variety of options. Within passive cooling we determined landscaping and solar screens to be highly attractive options. Active cooling using thermal gradients is largely unfeasible at Wellesley College; however, we concluded that improving the ventilation system would greatly aid cooling and could potentially improve indoor air quality. From the conventional active cooling options, we suggest absorption chillers because of the potential to power the system with solar photovoltaic cells (a recommended roof option) and because it can accommodate zoned heating systems (which the KSC currently possesses).

We can also rank these recommended options by a variety of criteria likely to be important in renovation considerations. These criteria are the degree of cooling provided, initial cost, energy use in operation, environmental and air quality impacts, and ease of integrating within the current building structure (ranked from 1 to 5 with 1 being easiest and 5 being the most difficult). Using these criteria, solar screens and cool roofs emerged as the most desirable options as they are relatively inexpensive, easy to install, have low to moderate environmental impact, and could make a noticeable difference in indoor air temperature (4 to 15°F cooler than ambient temperature). Upgrading the current ventilation system is the next highest priority. The framework for this system currently exists and it is the only option that increases airflow from outdoors, which has beneficial effects for indoor air quality. Although landscaping is easier to implement than improving the ventilation system, we propose it as the third recommended option due to its lower cooling potential, highly variable cost, and longer time period before the advantages are realized. We only suggest adding an absorption chiller if the above options don't cool the building sufficiently and if serious renovations are being considered, as adding this option would require major structural changes. Additionally, absorption chillers have a relatively high initial cost and a shorter lifetime than the higher-priority passive cooling techniques.

Figure 63. Comparison of recommended cooling options, in order of preference for implementation

Alternative	Degree of cooling	Costs	Life span	Energy use in operation	Life cycle environmental impacts	Air quality effects	Ease of integration
Solar screens	10-15°F cooler than ambient temperature	less than $100 per screen	20+ years	none	low	reduced airflow from outdoors	1
Cool roof	up to 4°F cooler than ambient temperature	up to $3.75 per sq. ft.	12-50 years	none	low to moderate	none	2
Night-time ventilation	cools to night-time air temperature	$60,000	20+ years	low	moderate	increased airflow from outdoors	4
Landscaping	up to 9°F cooler outside of building	variable	varies with species used	none	low	improved air quality, carbon sink	3
Absorption chiller	full	more than AC	10-25 years	low	moderate	none	5

VIII. Air Quality

Summary

Poor indoor air quality can have adverse health effects on building occupants. Pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems. To reduce contaminants in the KSC, it is recommended that low emitting building materials and cleaning products be used. It is also recommended that the KSC be equipped with a displaced ventilation system that would bring in outdoor air to dilute emissions from indoor sources and provide conditioned air at floor levels. Using air purification devices mounted in the current HVAC system's ductwork would be a less expensive option that would still help decrease contaminants and increase indoor air quality.

Background

The presence of indoor air contaminants in buildings is a major environmental health risk.[433] Pollutants that can have adverse affects on the quality of indoor air include both particulate and gaseous contaminants. Particulate matter includes dust, smoke, pollen, and particles associated with organisms such as dust mites, mold, bacteria, and viruses.[434] Gaseous pollutants are generated from combustion processes and by emissions from building materials, furnishings, and products such as adhesives, paints, varnishing, cleaning products, and pesticides.[435]

The U.S. Environmental Protection Agency has developed three main strategies for reducing indoor air pollutants: source control, ventilation, and air cleaning.[436] Source control aims to eliminate specific sources of pollutants within a space to reduce emissions of volatile compounds and can be accomplished by making informed product purchasing decisions. Unfortunately, not all pollutant sources can be identified and means beyond source control must be pursued to help mitigate indoor air contaminants. Ventilating buildings efficiently with clean outdoor air can help minimize deleterious indoor air pollutants, and utilizing indoor air cleaning devices or air purifying units can remove contaminants from indoor air.

Source control

Building Materials and Cleaning Products

Cleaning products and building materials that emit high levels of Volatile Organic Compounds (VOCs) can be extremely toxic, posing health risks to people including nose and lung irritation, headaches, nausea, rashes and asthma.[437] Using industrial cleaning products and building materials that emit low levels of VOCs is essential for the protection of staff, students, and faculty. More information about the impacts of building materials can be found in the Materials Chapter.

Moisture Management

Moisture management is particularly important inside the KSC. If there is too much moisture in the air, mold can develop and cause health problems like allergies and asthma.[439] Mold does not require standing

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[433] "Guide to Air Cleaners in the Home," U.S. Environmental Protection Agency. http://www.epa.gov/iedweb00/pubs/airclean.html#Indoor%20Air%20Pollutants. Accessed 13 April, 2009.
[434] "Guide to Air Cleaners in the Home," U.S. Environmental Protection Agency. http://www.epa.gov/iedweb00/pubs/airclean.html#Indoor%20Air%20Pollutants. Accessed 13 April, 2009.
[435] "Guide to Air Cleaners in the Home," U.S. Environmental Protection Agency. http://www.epa.gov/iedweb00/pubs/airclean.html#Indoor%20Air%20Pollutants. Accessed 13 April, 2009.
[436] Greenbiz, "Interiors Backgrounder," http://www.greenerbuildings.com/resources/resource/interiors-backgrounder. Accessed April 9, 2009.
[437] Green Seal. "Floor Care Products: Finishes and Strippers." Green Seal's Choose Green Report. Washington, DC. June, 2004. (4)
[439] EPA. "IAQ Reference Guide." http://www.epa.gov/iaq/schools/tfs/guideh.html#Condensation,%20Relative%20Humidity,%20and%20Vapor%20Pressure Accessed April 14, 2009.

water in order to grow. It can cultivate in un-vented bathrooms, locker rooms, showers, gyms, leaky roofs or any other area where there may be an excess of moisture.[440] There are several areas in the KSC where mold is likely to develop. To prevent moisture buildup, the relative humidity near the surface of the floor must be kept below the dew point,[441] which can be achieved by reducing the moisture level of the air (either by the use of vents or dehumidifiers), or by increasing the flow of air at the surface with improved ventilation and air circulation.[442]

HVAC

A Heating, Ventilation, and Air Conditioning (HVAC) system not only regulates a building's temperature, but also its air exchange rate and thus its air quality relative to outside air. As these factors greatly impact the health and comfort of occupants, choosing an appropriate HVAC system is one of the most important aspects of building design.

Heating

The Sports center currently uses waste heat from the cogeneration plant as well as additional natural gas energy to maintain comfortable temperatures during the cold New England winters. Heating the KSC requires 4,227,404 kWh of energy per year, nearly 71% of its total energy consumption.[443] A displacement ventilation system would allow heat energy to be utilized more effectively. Displacement ventilation is an energy efficient space heating and ventilation option and has been employed in the subfloor at Harvard's state of the art Landmark Center.[444] These systems introduce conditioned air at the floor level and avoid the use of noisy, high pressure systems.[445] They are most effective when air is circulated at or above outside temperatures because natural convective circulation of air occurs.[446]

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[440] EPA. "IAQ Reference Guide." http://www.epa.gov/iaq/schools/tfs/guideh.html#Condensation,%20Relative%20Humidity,%20and%20Vapor%20Pressure Accessed April 14, 2009.
[441] EPA. "IAQ Reference Guide." http://www.epa.gov/iaq/schools/tfs/guideh.html#Condensation,%20Relative%20Humidity,%20and%20Vapor%20Pressure. Accessed April 14, 2009.
[442] EPA. "IAQ Reference Guide." http://www.epa.gov/iaq/schools/tfs/guideh.html#Condensation,%20Relative%20Humidity,%20and%20Vapor%20Pressure. Accessed April 14, 2009.
[443] Based on top-down estimate described in Energy Chapter of this report.
[444] Schmidt, C. The Greening of the Crimson Campus. 2005. http://www.greencampus.harvard.edu/lgci/documents/hsphreview_greening_000.pdf
[445] MIT Department of Architecture Renovation. Green Engineer. 1999. http://www.greenengineer.com/ideas/mitb10.htm
[446] Kozanoglu, B. Ferrero, F. Munoz, M. Arnaldos, J. Casal, Joaquim. Velocity of convective currents in boilover. Chemical Engineering Science [2006] 61 (8): 2550-2556.

Ventilation

Ventilation is defined as the exchange of indoor air with outdoor air. The KSCs current HVAC system was designed by Collaborative Engineers and employs an overhead forced ventilation system.[448] This type of system is energy intensive because it requires high pressures to force air circulation. Displacement ventilation systems (as described above) are a good solution for most spaces. The pool house, however, presents a more difficult ventilation scenario. Indoor commercial pools can put up to 500 lbs of corrosive chlorinated water vapor into the air every hour.[449] To prevent structural damage and occupant discomfort, these conditions require that air circulate through the area at a rate of 0.48 ft^3 of air volume per square foot of pool and window surface area every minute to prevent unwanted condensation.

Air Conditioning

Supplying cool air to the entire building during the summer would be cost would be extremely expensive. If improved ventilation combined with air displacement by standing fans is not sufficient, a chiller capable of servicing portions of the KSC in rotation is an attractive option. Such a system would allow cooling of the field house during events. It has been installed at the world's first LEED Gold certified athletic center at Haverford College.[450]

Air Cleaning

Air purification systems may be employed to help achieve additional pollutant reductions. These systems are designed to remove unwanted or harmful pollutants by relying on sorbents, ultraviolet radiation, filtration systems or the attraction of charged particles for their removal. Their effectiveness in removing pollutants depends on both the efficiency of the device (e.g., the percentage of the pollutants removed as it goes through the device) and the amount of air the device is capable of handling.[451]

Mechanical Filters

Mechanical filters typically consist of coarse glass fibers, animal hair, vegetable fibers or synthetic fibers that are coated with a viscous substance capable of acting as an adhesive to trap particulate matter.[452] While these purifiers can be effective in removing small particles suspended in air, there is controversy as to their efficiency in removing larger particles that settle rapidly such as pollen and dust allergens.

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[448] Design Experience. The Collaborative Engineering. http://www.collaborativeengineers.com/college.html
[449] Steinbach, P. Dry Runnings. Athletic Business. 2007
http://athleticbusiness.com/articles/article.aspx?articleid=1667&zoneid=10
[450] A Gold-en Opportunity. School Construction News. 2006. http://www.schoolconstructionnews.com/
[451] "Residential Air Cleaning Devices," U.S. Environmental Protection Agency.
http://www.epa.gov/iaq/pdfs/residential_air_cleaning_devices.pdf. Accessed April 13, 2009.
[452] "Residential Air Cleaning Devices," U.S. Environmental Protection Agency.
http://www.epa.gov/iaq/pdfs/residential_air_cleaning_devices.pdf. Accessed April 13, 2009.

Figure 64. Air Cleaning Technologies[453]

Air Cleaning Technologies		Pollutants Addressed	Limitations
Filtration	Air Filters	Particles	Ineffective in removing larger particles because most settle from the air quickly and never reach filters.
	Gas-phase filters	Gases	Used much less frequently in homes than particle air filters. The lifetime for removing pollutants may be short.
Other Air Cleaners	UVGI	Biologicals	Bacterial and mold spores tend to be resistant to UV radiation and require more light or longer time of exposure, or both, to be killed.
	PCO	Gases	Application for homes is limited because currently available catalysts are ineffective in destroying gaseous pollutants from indoor air.
	Ozone generators	Particles, gases, biologicals	Sold as air cleaners, they are not always safe and effective in removing pollutants. By design, they produce ozone, a lung irritant.

Electronic Air Cleaners

Electronic air cleaners use a process called electrostatic attraction to trap charged particles, drawing air through an ionization instrument where particles receive electrical charges.[455] These charged particles then accumulate on a collector, a series of flat plates with opposite charges.[456] One of the potential disadvantages of using this device is it can produce excess amounts of ozone if it is not properly installed or maintained. Electronic air cleaners can be installed in ducts or may be used as portable devices that utilize fans to circulate air through the system.

Recommendations

To increase the air quality in the Sports Center, we recommend that the College take preventative measures to reduce pollutants by purchasing building materials and continuing to use cleaning products that emit low amounts of VOCs. We also suggest a displaced ventilation system that is more efficient at supplying quality air at floor levels. A small chiller could be added if the ventilation system proves to be insufficient at circulating cooler air during summer months.

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[453] "Residential Air Cleaning Devices," U.S. Environmental Protection Agency. http://www.epa.gov/iaq/pdfs/residential_air_cleaning_devices.pdf. Accessed April 13, 2009.
[455] "Guide to Air Cleaners in the Home," U.S. Environmental Protection Agency. http://www.epa.gov/iedweb00/pubs/airclean.html#Indoor%20Air%20Pollutants. Accessed 13 April, 2009.
[456] "Guide to Air Cleaners in the Home," U.S. Environmental Protection Agency. http://www.epa.gov/iedweb00/pubs/airclean.html#Indoor%20Air%20Pollutants. Accessed 13 April, 2009.

A less expensive alternative to replacing the current ventilation system would be to purchase an air purification system that can be installed in the existing HVAC ductwork. Testing the Sports Center for the types of pollutants in the building would help determine which type of purification system would be most effective.

IX. ROOF

Summary

The Keohane Sports Center has recently experienced problems with the Dorothy Towne field house and Chandler pool roofs. Due to extensive leaking, these roofs have been designated for replacement in the near future. This section will examine the following potential options for new roofs: photovoltaic roofing systems, cool roofs, and green roofs. Photovoltaic roofing systems are similar to standard roofs with the added benefit of solar energy generation. Cool roofs minimize the absorption of solar energy to reduce cooling loads inside buildings. Extensive green roofs have multiple environmental and economic benefits, including controlling storm water run off, reduced energy costs, and improved roof insulation. Considering the benefits of each of these roofing options we recommend the use of green roofs if structurally compatible with the existing facility, but provide information about the benefits and problems of all these options.

Introduction

Roofs are often wasted space. Many people may look at these vast expanses and see nothing but a money sink. Environmental designers, however, see these surfaces as opportunities. They see the opportunity to create power with PV panels, PV roofing systems, small wind turbines and solar collectors for hot water. They see opportunities to improve the "green aesthetic" and education value of the building through the addition of highly visible green roofs and power generating devices. They also see opportunities for increased interior lighting through the addition of skylights and light harvesters. They consider reflectivity, emittance and insulation as they think about reduced heating and cooling costs. Environmental designers weigh each of these features against the realities of costs of installation, end of life and maintenance, estimated lifetime of the roofing, structural capacity and load limits and runoff issues.

Roofs can also contribute to urban heat islands. Urban heat islands occur because paved, dry urban environments tend to absorb and retain more heat than surrounding fields or other natural landscapes. As a result, cities stand out thermally against their natural backgrounds, with increased temperatures resulting from the re-radiation of thermal energy from buildings and pavements, leading to smog and increased energy use.[457] We examine the extent to which the roofs we evaluate contribute to, or prevent, this problem.

Here, we weigh the benefits and drawbacks of each of three types of roofing: PV roofing, cool roofs, and extensive green roofs. What follows is a general introduction to each of these options, their benefits and drawbacks, and their feasibility on the Wellesley College campus.

For each type of roof we consider solar reflectivity, thermal emittance, insulation, and weight. Solar reflectivity, also known as albedo, is the "percentage of solar energy reflected by a surface".[458] The higher a roof's reflectivity, the less solar energy is absorbed, reducing cooling costs in summer and potentially increasing heating costs in winter. Similarly, thermal emittance dictates how readily a surface will give up heat, and the temperature at which a surface will reach thermal equilibrium.[459] The higher a building's thermal emittance, the more it radiates back absorbed heat, and the cooler the temperature at which the surface will stabilize. Insulation is the protective layer between the interior building and the exterior roof. Better insulation reduces the amount of warm or cool air the building loses, and decreases the electricity costs of altering the indoor environment. Finally, the potential weight of any additions to a standard roof is important to consider, and to examine in light of the weight the walls on which it rests can support.

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[457] U.S. EPA, "Heat Island Effect: Basic Information," http://www.epa.gov/heatisland/about/index.htm. Accessed April 2, 2009.
[458] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in *Reducing Urban Heat Islands: Compendium of Strategies*, 3, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.
[459] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in *Reducing Urban Heat Islands: Compendium of Strategies*, 3, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.

Figure 65. Characteristics of Roofing Options

Alternative	Reflectivity	Insulation	Emittance	Load/Weight Specifications	Runoff Benfits
Green Roof (Extensive)	Moderate 0.25	Very high	Low (cools by evapotransporation)	29-69 lbs per sq. ft.	Controlled and filtered
Cool Roof Replace	Moderate 0.25	0	High 0.83	0.5-1.5 lbs per sq. ft.	None
Cool Roof Spray	Moderate 0.25	0	High 0.83	0	None
PV Shingles	Low	Low	Low	< 1lb per sq. ft.[460]	None
Galvanized Standing Seam Steel Roof	Low	Low	Low	1.5 lbs per sq. ft.[461]	None

Photovoltaic Roofs

In our discussion in the Energy Chapter, we recommend that the College pursue thin film photovoltaic (PV) technology for alternative energy generation. If used, these panels would be installed on one or more of the roofs at the Sports Center. Here we examine more deeply solar roofing options. Solar roofs intentionally avoid reflectivity in the service of energy generation. They are designed to capture solar energy. Though fine metal films or thin glass encapsulates many units, the amount of reflected sunlight is designed to be minimal. They do have the potential to cause emittance problems, since solar cells are designed to capture solar energy, including thermal energy. This energy is slowly released following capture and therefore has the potential to contribute to the urban heat island effect.

Both insulation and additional weight from solar roofs are minimal. As with standard roofing, solar roofing requires insulation to be added by the user prior to installation and offers no added insulation benefits on its own. When considering more practical concerns, load and weight requirements of solar shingles are only slightly higher than those of standard roofing shingles. In the case of solar laminates, the weight is

[460] Stephen Heckeroth, "California Triple-Junction Photovoltaic Manufacturing Proposal", Ovonic Solar, http://www.frbsf.org/community/resources/files/OvonicSolar.pdf. Accessed April 5, 2009.
[461] ReRoof America, Inc. "Standing Seam Roof," ReRoof America, Inc., http://www.reroof-america.com/standseam.html. Accessed April 6, 2009.

approximately 0.7 lbs/ft^2,[462] not significant enough to require major structural changes. As a flat, smooth surface, PV shingles offer few runoff benefits.

PV roofing installation costs are high, while maintenance costs are low and life span is long (estimated 20-30 years[463]). PV has the added benefit of being able to provide electricity for free, perhaps recovering some of its initial costs. Mounting large scale solar roofing systems often requires the employment of a master electrician in addition to standard roofing contractors. For a 4,900 ft^2 laminate install (on a pre-existing steel roof) at MagCo Inc. in California, the cost of the laminate thin film PV strips plus installation costs was approximately $43 per square foot.[464]

The cost of recycling PV shingles is generally covered by the manufacturer.[465] Maintenance costs are low and consist of yearly inspections to test the security of electrical connections and to check for leaks.[466] In the event that rainfall is not sufficient to keep the shingles clean of debris, manufacturers also recommend using a hose and sponge to gently remove excess dirt from the tiles.[467]

Cool Roofs

A cool roof is a roof system made of solar reflecting, thermal emitting materials that reduce the amount of solar energy absorbed by a building, preventing thermal heat gain within the building and urban heat islands around it.[468] Because of the high albedo (high solar reflectance) of the materials used, cool roofs absorb less incoming solar radiation than typical roofs. A high degree of thermal emittance then ensures that whatever solar energy is absorbed is quickly radiated off, cooling the roof.[469] During the hottest, brightest days of summer, cool roofs can remain 50 to 60ºF cooler than conventional roofs.[470] This cooling in turn translates to less energy used for air conditioning within a building, and less heat being radiated from the

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[462] Stephen Heckeroth, "California Triple-Junction Photovoltaic Manufacturing Proposal", Ovonic Solar, http://www.frbsf.org/community/resources/files/OvonicSolar.pdf. Accessed April 5, 2009.
[463] Jeffrey Landreth, "Photovoltaic Roof Systems," GreenBuild Tech Bulletin, February 2005.
[464] Michelle Bennett, "A Thin-Film Solar Installation," CleanTechnica.com, http://cleantechnica.com/2008/05/24/a-thin-film-solar-panel-installation/. Accessed April 5, 2009.
[465] US Department of Energy: Solar Energy Technologies Program, "PV Panel Disposal and Recycling," US Department of Energy, http://www1.eere.energy.gov/solar/panel_disposal.html. Accessed April 5, 2009.
[466] Solar World, "Quick Guide for Users Solar World Solar Technologies," Solar World, http://www.solarworld.de/fileadmin/content_for_all/pdf/sunmodule/2008/11/benutzer_user_info_en.pdf. Accessed April 5, 2009.
[467] Solar World, "Quick Guide for Users Solar World Solar Technologies," Solar World, http://www.solarworld.de/fileadmin/content_for_all/pdf/sunmodule/2008/11/benutzer_user_info_en.pdf. Accessed April 5, 2009.
[468] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in Reducing Urban Heat Islands: Compendium of Strategies, 1-3, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.
[469] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in Reducing Urban Heat Islands: Compendium of Strategies, 3, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.
[470] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in Reducing Urban Heat Islands: Compendium of Strategies, 1, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.

building into the surrounding environment. Cool roofs have already been installed on several newer buildings on the Wellesley College campus, including the Davis Parking Facility and the distribution center.

Since the field house roof is slated for replacement in the next year or two, one option would be to replace the roof with an entirely new cool roof. For a cool roof replacement, metal roofs similar to the standing seam steel currently used atop the field house and pool[471] should be considered with the slight modification that "cool" colors with high reflectivity and emittance values should be used. While there are cool roofs available in asphalt, tile, and other mediums, metal roofs are lightweight and high in recycled content. They also have a long lifespan and low end of life costs.[472]

Environmentally, cool roofs reduce urban heat islands. It is estimated that if all the roofs and pavements of the world's 100 largest cities were painted white, the net reduction in thermal absorption would be equal to cutting 44 billion tons of carbon dioxide emissions per year, which would have a measurable impact on climate change.[473] By installing a cool roof on Wellesley's Sports Center, the college could contribute to that goal.

Cool roofs are available in a variety of reflectivity levels, ranging from approximately 0.25 up to 0.90.[474] The higher the reflectivity, the less solar energy is initially absorbed. Because the Sports Center has no air conditioning, the reduced absorption of solar energy in summer resulting from a cool roof would not lead to decreased energy usage. Installation of a cool roof at the sports center would instead lead to a net increase in spending, because more heat would be used to make up for decreased solar energy absorption during the winter than could be made up through potential energy savings in the summer. Additionally, Wellesley is positioned almost at the geographic border for cost-effectiveness of cool-roofing,[475] with far more days of the year spent on warming than on cooling.

Types of Cool Roofs

There are two basic categories of cool roofs: those designed for low-sloped roofs (< 2:12 inch pitch) and those designed for steeply sloped roofs (>2:12 inch pitch).[476] Wellesley's Keohane Sports Center has

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[471] E-mail correspondence with Patrick Willoughby, April 2, 2009.
[472] "Metal Roofing: Advantages & Benefits," Don Vandervort's HomeTips.com, http://www.hometips.com/buying-guides/metal-roofing-advantages.html. Accessed April 5, 2009.
[473] Justin Berton, "Hashem Akbari's Cool Anti-global-warming Plan," San Francisco Chronicle, February 20, 2009, F-1, http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2009/02/20/DDTL15VQAG.DTL. Date Accessed: April 2, 2009.
[474] "Directory of Rated Products," Cool Roof Rating Council, http://www.coolroofs.org/products/search.php. Accessed April 2, 2009.
[475] James L. Hoff, "The Economics of Cool Roofing: A Local and Regional Approach," (paper presented at the Cool Roofing Symposium, Atlanta, Georgia, May 2005), http://www.roofingcenter.org/syncshow/uploaded_media/Documents/The%20Economics%20of%20Cool%20Roofing%20-%20A%20Local%20and%20Regional%20Approach.PDF. Accessed April 6, 2009.
[476] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in Reducing Urban Heat Islands: Compendium of Strategies, 5, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.

roofs in both categories, with low-sloped roofs on parts of the main administrative building, and steeply sloped roofs atop the Chandler Pool and Dorothy Towne Field House. Existing low-sloped roofs in reasonably good shape can be made into "cool roofs" with the application of paint-like cool coatings to the exterior surface. The fastening of single-ply prefabricated membrane sheets may be applied to existing roofs in need of repairs. Cool roof options for steeply sloped roofs include specially designed asphalt shingles, tiles, and cool colored metal roofs[477] although sprays are now also being marketed in the steep roof sector. Of the different cool roof options, coatings have the best solar reflectance, at 65% or higher, while metal roofs can range from just 20% reflectance up to 90%. Cool colored Energy Star tiles are the next best option, ranging from 25-75% solar reflectance, followed by Energy Star asphalt shingles at 25-65% reflectance.[478] Within the two categories of low-sloped and steeply sloped roofs, cool roof coating and cool colored metal roofs are likely the least expensive and most feasible.

Another alternative within the cool roof sector is an elastomeric spray that could be applied to any existing roof, either steep or low sloped. Cool roof sprays have the benefit of cooling, reducing thermal shock and adding waterproofing to existing roofs in good condition, without requiring expensive roof replacements. Elastomeric sprays add no measurable load on the existing roof, and can easily be overlain after ten or fifteen years[479] with another layer of cool roof spray if desired. While cool roof coatings aid in waterproofing roofs, they have no added benefits in terms of reducing rooftop run-off. Cool roof spray does not add to the insulation levels of the underlying roof. A newly installed cool metal roof would rely on insulation added under the roof, similar to the current field house and pool roofs, since the metal itself serves as a poor insulator. Since cool roof spray adds minimal load to a roof, additional insulation may be added without concern for the weight-bearing capacity of the building.

Cool Roof Costs

Despite the fact that a cool roof would lead to no net decrease in spending, installation of a cool roof could still be useful. Overheating, especially during the summer, is of concern at the Sports Center. Installation of a cool roof could potentially create enough cooling to offset the need to install an expensive air conditioning system in the future. A cool roof could make the sports center a more pleasant work and recreation environment during the summer months for students, faculty, and staff.

Because there is no current financial benefit from installing a cool roof at the KSC, the best option of cool roof for the sports center would be one with the lowest possible reflectivity that still meets Energy Star efficiency standards. Currently, Energy Star requires an initial reflectivity value of 0.25 for steep slope

[477] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in Reducing Urban Heat Islands: Compendium of Strategies, 5-7, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.
[478] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in Reducing Urban Heat Islands: Compendium of Strategies, 6-7, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.
[479] "Henry Cool Roof: Metal," Henry Building Systems, http://www.henry.com/Metal.221.0.html. Accessed April 6, 2009.

roofs like those found over the majority of the sports center.[480] A roof with 0.25 reflectivity could provide much needed cooling during the summer while minimizing increased heating costs for the College during the rest of the year. Should we eventually decide to install air conditioning at the KSC, Energy Star's Roofing Calculator estimates the College could save over $21,000 annually by installing a cool roof with reflectivity values of 0.95 over the Sports Center.[481]

Financially, cool roofs can help by increasing roofing lifespan and reducing building cooling costs. Because cool roofs do not gain as much solar heat as conventional roofing, the dramatic thermal variations that expand, contract, and eventually deteriorate roofs don't happen to "cool roofs" with the same severity.[482] Both cool roof options are designed to be waterproof which may lengthen the lives of the existing roofs, and absorb and retain less heat than conventional roofs, reducing thermal pollution of runoff.

Installation of a metal cool roof is no more expensive than that of a conventional metal roof system.[483] Metal cool roofs have estimated lifespan of fifty years,[484] approximately twenty years longer than conventional metal roofs. Metal roofing can also be applied directly on top of old roofing, which would result in no end of life costs. If the metal roof is removed, it can be recycled, which could result in very low end of life costs.

Cool roof sprays have minimal installation costs, and can generally be applied to a roofing surface by non-professionals, provided the right safety precautions related to roof work are taken considered. Cool roof elastomeric coatings can last up to 15 years before needing reapplication.[485] Maintenance on both cool roof replacements and cool roof sprays involve cleaning the surface to maintain high reflectivity and emittance values. Maintenance costs are low, and consistent with normal rooftop care. Elastomeric sprays have no end-of-life costs, because new coatings can be applied directly over old ones.

Green Roofs

A green roof is a roof partially or fully covered by some sort of vegetation. There are many different forms of green roofs around the world, some dating back thousands of years, such as the Hanging Gardens

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[480] Energy Star, "Roof Products Key Product Criteria," U.S. Department of Energy, http://www.energystar.gov/index.cfm?c=roof_prods.pr_crit_roof_products. Accessed April 6, 2009.
[481] "Energy Star Roofing Calculator," U.S. Department of Energy, http://www.roofcalc.com/RoofCalcBuildingInput.aspx. Accessed April 5, 2009.
[482] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in Reducing Urban Heat Islands: Compendium of Strategies, 20, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.
[483] U.S. EPA, Climate Protection Partnership Division, "Cool Roofs," in *Reducing Urban Heat Islands: Compendium of Strategies*, 13, http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf. Accessed April 2, 2009.
[484] "Cool Metal Roofing: The Energy Efficient Choice," Cool Metal Roofing Coalition, http://www.steelroofing.com/energy_efficient_choice.pdf. Accessed April 6, 2009.
[485] "A Long, Cool Life for Roofs Starts with Duracool," Duracool: Thermal Control Roof Coating, http://www.duracoolinc.com/. Accessed April 6, 2009.

of Babylon[486] and the sod-roofed homes of the Vikings.[487] Green roofs have gained popularity recently for their economic, environmental, and aesthetic benefits. Germany has become a leader in green roof use and promotion with approximately 14% of all flat roofs covered by vegetation. In the state of Nordrhein-Westfalen the government will pay 15 Euros per square meter of green roof to individuals who install them.[488] Green roofs are beginning gain popularity in the Untied States especially because of promotion from the government and non-profit organizations like the United States Green Building Council. More governmental agencies are utilizing or researching the use of green roofs.[489] The Chicago City Hall roof has become an example for others to emulate.

Green roofs provide economic, environmental, and aesthetic benefits. Soil and plants insulate a building's roof, regulating temperature fluctuations and maintaining current building temperatures with less air conditioning or heating. These insulating properties reduce energy costs and the amount of greenhouse gases emitted because of that energy use. Evapotranspiration from plants on the roof also cools the surface of the roof and the interior of the building much like sweat cools a human body. Green roofs also increase the life of a roof, often doubling the lifespan.[490] The plants can provide habitat for many animals, especially vulnerable ground nesting birds, as well as help counter the affects of pollution. The vegetation helps absorb noise, trap dust, intake carbon dioxide, release oxygen, and break down many gaseous pollutants.[491] Green roofs have relatively high reflectivity (up to 2.5) which helps reduce the effects of the urban heat island and filter and slow storm runoff.

Figure 66. Green Roof on Chicago City Hall[492]

[486] Edmund C. Snodgrass and Lucie L. Snodgrass, Green Roof Plants, (Portland: Timber Press, 2006), 15.
[487] Larocque, Cody, "Mom, Do I Really Have to Mow the Roof?," MSN.com, http://green.sympatico.msn.ca/article.aspx?cp-documentid=582283. Date Accessed: April 2009.
[488] Edmund C. Snodgrass and Lucie L. Snodgrass, Green Roof Plants, (Portland: Timber Press, 2006), 15-16
[489] Edmund C. Snodgrass and Lucie L. Snodgrass, Green Roof Plants, (Portland: Timber Press, 2006), 19.
[490] Nigel Dunnett and Noël Kingsbury, Planting Green Roofs and Living Walls, (Portland: Timber Press, 2004), 32.
[491] Nigel Dunnett and Noël Kingsbury, Planting Green Roofs and Living Walls, (Portland: Timber Press, 2004), 7.
[492] World Business Chicago, "Economic Focus: Urbs in Horto," Volume 23, September 2006, http://www.worldbusinesschicago.com/newsletters/email.Sept06.htm. Accessed April 5, 2009.

Many college and university buildings including Carleton College, Duke University, Williams College, and Temple University, already have existing green roofs among.[493] Carnegie Mellon currently has four buildings on campus with green roofs. The University has monitored the green roofs compared to similar roofs to compare the advantages and disadvantages. One building with a green roof, the Posner Center, is home to "one of the top five private collections of rare art and books in the world."[494] It is essential that this collection is kept dry, and the University is certain that a green roof will not hinder the waterproof qualities of the roof.

Wellesley has several green roofs on campus; one is on the fourth floor of the Lulu Chow Wang Campus Center, another covers the area in front of the Physical Plant, and a third is in the Botanic Gardens. When a new well pump building was being built Kristina Jones, Director of the Botanical Gardens, spearheaded a project to incorporate a green roof into the design. She used the roof as an experiment to see what type of plants and substrate material would be viable on campus. Researchers from the greenhouses planted 28 different species and found 26 of them to be successful in establishing themselves on the roof. These species are listed in Appendix D.

Types of Green Roofs

There are two main categories of green roofs: extensive and intensive. Extensive roofs require little to no maintenance and use less than six inches of mostly inorganic substrate. Intensive roofs use deeper, more organic substrate and often require more maintenance. Extensive varieties are often full blown rooftop gardens that require weeding, fertilization, and irrigation.[495]

Vegetation must be picked carefully for both extensive and intensive green roofs considering budget, maintenance, roof accessibility, exposure, humidity, temperature fluctuations, substrate depth and composition, and irrigation.[496] Generally, successful roof plants are usually low growing, shallow rooted, perennial plants that are tolerant of heat, cold, sun, wind, drought, salt, insect, and disease. Ideally local plants will be used.[497]

Both extensive and intensive roofs have the same basic structure, which is pictured below. From the building surface up, a green roof requires roofing materials, like a typical roof, and then a completely sealed membrane to ensure no roots get through (choosing plants that lack tap roots will help prevent this problem).

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[493] Greenroofs.com, "The Green Roof Projects Database," http://www.greenroofs.com/projects/plist.php. Accessed April 4, 2009.
[494] Carnegie Mellon, "Green Practices: Posner Center," http://www.cmu.edu/greenpractices/greening-the-campus/green-roofs/Posner%20Center.html. Accessed April 4, 2009.
[495] Edmund C. Snodgrass and Lucie L. Snodgrass, Green Roof Plants, (Portland: Timber Press, 2006), 18.
[496] Edmund C. Snodgrass and Lucie L. Snodgrass, Green Roof Plants, (Portland: Timber Press, 2006), 47.
[497] Edmund C. Snodgrass and Lucie L. Snodgrass, Green Roof Plants, (Portland: Timber Press, 2006), 48.

Typically some sort of insulation and water storage and drainage layer come next. Then, at the top of these layers is the actual growing substrate and vegetation.

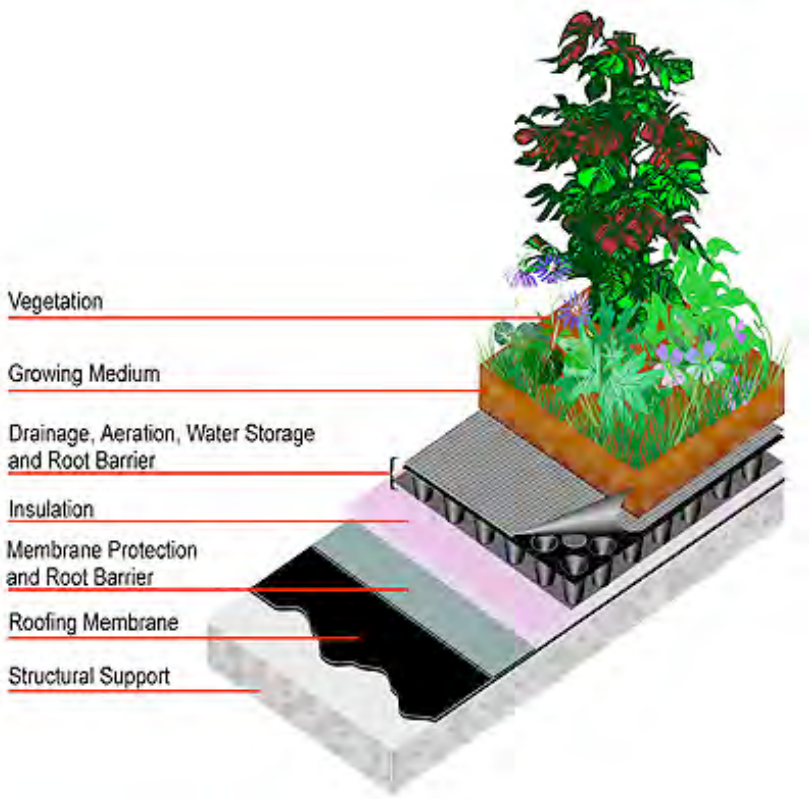

Figure 67. Typical Green Roofing Layers[498]

Green Roof Costs

The main disadvantage of green roofs is the additional weight associated with the inches of soil and plants. Between 2 and 6 inches of lightweight substrate usually increases the roof's load by 14 to 35 pounds per square foot, and an intensive roof can add 59 to 199 pounds per square foot.[499] The roof must also be able to support the load of soil when completely saturated, which can add 15 to 25 pounds per square foot, above the weight of the soil and plants.[500] It may be difficult for some buildings to be retrofitted for a green roof, if the structure was not built to withstand significant weight on the roof.

[498] Erika Tokarz, "CEER Green Roof Project," Department of Civil and Environmental Engineering of Villanova University, May 2006, http://egrfaculty.villanova.edu/public/Civil_Environmental/WREE/VUSP_Web_Folder/GR_web_folder/GR_paper.html. Accessed April 5, 2009.
[499] Edmund C. Snodgrass and Lucie L. Snodgrass, Green Roof Plants, (Portland: Timber Press, 2006), 37.
[500] Edmund C. Snodgrass and Lucie L. Snodgrass, Green Roof Plants, (Portland: Timber Press, 2006), 37.

Another concern is the pitch of the roof used for a green roof. Many green roofs are built on flat rooftops, where there is no concern for slippage. Pitched roofs require slope stabilization measures, and green roofs are not ideal for slopes steeper than 2:12, or about a 9.5° slope.[501] For roofs steeper than that horizontal strapping, laths, battens, or grids make it possible to plant a green roof on pitches up to 7:12 or 30 degrees.[502] It is still possible to build on steeper pitches, but special substrate mixes must be used.[503]

These concerns make extensive green roofs large investments, with the cost per square foot being estimated at $10 to 20 (in USD 2002 prices).[504] Installing a green roof may be costly, especially if retrofitting an existing building. Part of the cost is in hiring either an engineer or architect to determine if the project is possible and how to design the roof. In this analysis installation costs and general costs are combined.

Maintenance is minimal on extensive roofs throughout the roof's lifetime. Some additional maintenance may be required to assure that the plants are properly established such as direct irrigation, but this is not always necessary. The Great Lakes Water Institute (GLWI) estimated that extensive green roofs would only need minimal maintenance for two years. These costs were low especially because the GLWI assumed the roof could be accessed by ladder, eliminating the need for specialized machinery for maintenance.[505]

A green roof can actually double the lifetime of a roof, so any additional costs incurred may be mitigated by the extended lifetime of the roof.[506] Traditional roofing products are constantly exposed to harsh UV rays that slowly break down the materials. If the UV rays are absorbed by vegetation and the roof membrane is protected, it will last much longer. The Derry and Toms department store in London has had a roof top garden since 1938, and the roof membrane is still in good condition.[507]

Potential Combination

In addition to the aforementioned roofing options, various energy saving/generating technologies should be considered as additions to the Sports Center roof. The potential for combination varies with each of the roofing systems discussed.

Photovoltaic roofs rely on direct access to sunlight. Therefore any roofing additions that would block sunlight would reduce electricity-generating efficiency. As with traditional roofing options, passive solar could be integrated into a solar photovoltaic roof.

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[501] Nigel Dunnett and Noël Kingsbury, Planting Green Roofs and Living Walls, (Portland: Timber Press, 2004), 62.
[502] Nigel Dunnett and Noël Kingsbury, Planting Green Roofs and Living Walls, (Portland: Timber Press, 2004), 62.
[503] Nigel Dunnett and Noël Kingsbury, Planting Green Roofs and Living Walls, (Portland: Timber Press, 2004), 62.
[504] Nigel Dunnett and Noël Kingsbury, Planting Green Roofs and Living Walls, (Portland: Timber Press, 2004), 32.
[505] Great Lakes WATER Institute, "Green Roof Installation," http://www.glwi.uwm.edu/research/genomics/ecoli/greenroof/roofinstall.php. Accessed April 6, 2009.
[506] Nigel Dunnett and Noël Kingsbury, Planting Green Roofs and Living Walls, (Portland: Timber Press, 2004), 32.
[507] Nigel Dunnett and Noël Kingsbury, Planting Green Roofs and Living Walls, (Portland: Timber Press, 2004), 32.

In the case of cool roofs, both of the options of photovoltaic panels and passive solar lighting would be compatible. Cool roofs have the added benefit of reducing dramatic thermal variations at the roof's surface, minimizing thermal wear and tear on photovoltaic panels and increasing their potential lifespan.

The same benefit applies to green roofs, which are even better at moderating rooftop temperatures than cool roofs. As long as the height of green roof vegetation is less than the height of solar photovoltaic panels or passive solar collectors, it is the best combination option, provided structural load bearing capacity is not an issue.

Figure 68. Associated Costs of Roofing Options

Alternative	Cost (Range)/sq ft	Cost of Installation	Cost of Maintenance	Estimated Lifetime	End of Life Costs
Green Roof Extensive	$10-20 per sq. ft.	N/A	Low to none $1.25-2.00 per sq. ft. for 1st 2 years	50-100 years	Minimal
Cool Roof Replace	$1.80-$3.75 per sq. ft	$5.50 per sq. ft	Low $0.20-$0.30/ sq. ft	30-50 years	Low
Cool Roof Spray	$0.60-0.80 per sq. ft	$0.50 per sq. ft	Low $0.20-$0.30/ sq. ft	12-15 years	None
PV Shingles	<$50 per sq. ft [508]	$43 per sq. ft. (cost of roofing and installation)	Low to None	20-30 years	Moderate to High
Galvanized Standing Seam Steel Roofing	$7.15 per sq. ft (cost of roofing and installation)[509]		None[510]	20+ years[511]	Low

[508] Stephen Heckeroth, "California Triple-Junction Photovoltaic Manufacturing Proposal", Ovonic Solar, http://www.frbsf.org/community/resources/files/OvonicSolar.pdf. Accessed April 5, 2009.
[509] ReRoof America, Inc. "Standing Seam Roof," ReRoof America, Inc., http://www.reroof-america.com/standseam.html. Accessed April 6, 2009.
[510] ReRoof America, Inc. "Standing Seam Roof," ReRoof America, Inc., http://www.reroof-america.com/standseam.html. Accessed April 6, 2009.
[511] ReRoof America, Inc. "Standing Seam Roof," ReRoof America, Inc., http://www.reroof-america.com/standseam.html. Accessed April 6, 2009.

Recommendations

When considering roofing options, the ideals of long lifespan, high recycled content, and local manufacturing should be prioritized. Considering the anticipated rise in the cost of energy and the increasing challenges of global climate change, we should also commit to roofing options with small carbon footprints and long-term energy conservation benefits across their lifespan. Taking these ideals into account, we recommend that extensive green roofing replace at least some of the roofing covering the Keohane Sports Center.

In the short term, if the field house roof is to be replaced within the next two years, we recommend that it be replaced with extensive green roofing, permitting that the structural weight-bearing capacity is high enough to support such a change. The roofing over the Chandler pool and administrative areas should be sprayed with cool roofing elastomeric coating in order to improve cooling capacity during the hot summer season and to add a protective layer to the roofs until such time as they can be replaced.

As each of these sections of roofing is replaced, we recommend that extensive green roofing be put in place, structurally permitting, most likely in combination with either passive solar or PV panels, or both. Photovoltaic roofing systems should be considered in the future as this technology continues to become more efficient and cost effective. PV panels should be a priority due to their high energy output and low cost.

X. AESTHETICS

Summary

One of PERA's stated goals is to increase student participation in athletics and physical activity on campus by increasing use of the Keohane Sports Center. Improvements in lighting, signage, entrances, and art could be easily achieved and would make the KSC a more inviting and desirable place to visit. More indoor plants could also add to the "green" state of mind that is driving our renovations, and add color, life and beauty. More community lounge space with computers and music will invite visitors to linger in the space. We also suggest expanding the exhibit dedicated to Wellesley's athletic history to include a broader history of women in athletics.

Introduction

PERA hopes to increase use of the Sports Center to 60% of the student body.[512] One way to encourage students to come to the KSC more often would be to improve the overall aesthetics of the building. These improvements could begin with the addition of clear signage directing users to the correct entrance to the building, and continue inside with the addition of a newly-situated front desk closer to the doors, more art, better lighting, and an open, inviting lounge-area with eco-friendly furniture. More signage directing users around inside the building, including new labels on all classrooms and multi-purpose rooms, could aid students and other visitors in getting around the KSC in general, and the updated lounge area and art could make them more likely to return on a more frequent basis.

Exterior Entryway

The current entryway to the KSC is uninviting and confusing. Visitors from outside the college community are often perplexed as to how to get *inside* the large, brick building, and even students and staff are often misled into thinking the first door, the handicapped accessible entrance tucked underneath the walkway, will be open, when it is not. How could people feel comfortable coming to work-out if they cannot even get into the building? Both the exterior and interior entryway to the KSC should be renovated to become more welcoming, informative, and clear – clear as in where the actual entrance to the main part of the building is and how it will be possible to get from that point within the building to any other.

The outside of the entrance should be eye-catching and inviting enough that students or staff who are not regular sports center users should feel intrigued and interested into seeing what's going on inside. Ideally, the overhead walkways leading to the pool would be relocated, but if such a major reconstruction were not to take place, an addition as simple as adequate signage would greatly improve the exterior entryway. A large, truly visible, welcoming plaque off to the right of the pavement, right before going under the overpassing walkway explicitly stating: "Welcome to the Keohane Sports Center. Main entrance this way, up the stairs and to the right" would be a great improvement.

Additionally, more landscaping could add aesthetic appeal as well as work in conjunction with the our recommendation for the addition of trees as a natural way to moderate the KSC's indoor temperature. Although it is difficult to maintain a colorful plant bed in New England winters, another way to add color would be through a mural on the wall where students lock their bikes. This artwork could be done by current Wellesley students, which would also help to include a wider community of people working to renovate the KSC.

Interior Entryway

The interior of the Sports Center could also benefit from clear signage, beginning at the front desk. The front desk should allow KSC visitors to see right away where they could go to ask for assistance. At

[512] Bridget Belgiovine, personal communication, February 2009.

present, when someone walks into the KSC he or she is usually unsure where the front desk is, as it is set back from the doors and up several steps. The rough brick exterior can also appear an intimidating barrier between the person at the desk and the visitor. Relocating the front desk to the right of the doors as suggested in the new floorplan would help to alleviate this problem.

Working from the new location, the front desk person's main priority would be signing in visitors, offering assistance on explaining anything about the KSC and its facilities, and issuing rental equipment. Within this new space of the front desk, artwork could be added around the walls in-line with what already exists in this lounge area: pictures of current and recently-graduated alumnae playing sports. These photos are a wonderful way to introduce visitors to the importance Wellesley places on physical activity.

The main aesthetic goal of the interior to the KSC should be to make sure that a visitor never feels lost, and one of the easiest ways to do that would be to outfit the interior entryway with adequate signage: to locker rooms (visitor's, Wellesley, staff, men's), field house, weight/cardio room, and the pool. The over-arching aesthetic of the KSC should be one of welcome and support.

Figure 69. Example of an aesthetically pleasing entryway

Informational Signs

Informational signage or "wayfinding" are terms that describe all of the ways used to help individuals orient to a physical space and takes into account the size, scale, and structure of a building.[513] Informational

[513] Andrew Light and Aurora Wallace, "Not Out of the Woods: Preserving the Human in Environmental Architecture," Environmental Values 14 (2005), p. 15.

signs will help users and visitors find their way to and around the fitness center's facilities. Even though the renovation project is specific to the Sports Center, it is important to include the outdoor fitness amenities (such as the playing fields) and to incorporate the location and purpose of each amenity in the new signage system. Signs in the KSC should not only lead to the building, but should also present information on the size, number of spaces, and the purpose of each space. They should include written text, graphic symbols, and systems using words, colors, and aids for the physically challenged that will help point toward the facilities and physical spaces and explain the proper use of the equipment.[514] Also, more signs could be added detailing the history of the KSC, including its environmental innovations, and any other information regarding Wellesley's athletic community.

Figure 70. Example of sport signage

Signs and symbols used for wayfinding should reflect the purpose, environment, and aesthetic of the Sports Center. For example, signs and symbols that point to the tennis courts would not only read "Tennis Courts," but also symbolize its purpose with pictures of tennis rackets or some ther sign to denote the game, and possibly other cues to assist the physically challenged. Outdoor signage could serve not only to direct, but also to facilitate exercise activities and instruct about the history of the Wellesley's amenities. Informational signage was popularized as a result of the Americans with Disabilities Act of 1990;[515] collaboration with the Wellesley Disability Services to ascertain the most important needs of all students, faculty, and staff with visual and physical disabilities is paramount.

Inside the KSC, other signs and symbols should explain the administrative guidelines and Sports Center regulations, procedures for check-in, and borrowing of equipment, and give directions to the classroom or exercise spaces. The general layout of each floor of the KSC should be made available. It is also

[514] Andrew Light and Aurora Wallace, "Not Out of the Woods: Preserving the Human in Environmental Architecture," Environmental Values 14 (2005), p. 15.
[515] Turning Point Signs and Designs. http://www.tpsigns.com/pages/glossary.html. Accessed April 2009.

recommended that room numbers and names be assigned to all exercise and classroom spaces to further aid in helping people orient to the Sports Center.

First Floor Lounge

The Keohane Sports Center has two common spaces for users. As our recommendations the physical space of the KSC include the conversion of one of these lounges into a new front desk area,[516] special attention must be paid to the remaining area. As patrons enter the field house, main stairwell, or fitness center, they pass through the lounge. Currently, it contains a pool table, couch, two paintings, and pictures of Wellesley athletics and former Athletic Directors. Athletes and casual users use this lounge as a meeting space and is the only seating area of its kind in the KSC. As such it has great potential to become a space in which users will want to linger, chat with friends, or simply pause as they use the facility.

First, lighting changes must be implemented to lend softer, more natural light to the area. To assist lighting improvements, the walls should be painted and the flooring replaced to reflect ambient light. The furniture and pool table should be replaced by eco-friendly lounges and sofas, complete with low tables for setting down book-bags and equipment. Many companies now sell organic and sustainable furniture and some of the options are introduced in the figures below. These modifications, along with any computer or sound installation, could transform the neglected space into a green, light-filled lounge for all KSC visitors.

Figure 71. Couch made from organic and recycled materials

[516] See Physical Space Chapter

Figure 72. Sustainable Furniture Options for the KSC student lounge

Manufacturer	Organic Materials	Eco-Adhesives	Recycled Materials	Cost[517]
Greener Lifestyles[518]	Yes	Yes	Yes	$4600
Bean Organic Furniture[519]	Yes	Yes	No	$5200
Vivavi	Yes	Yes	Yes	$5600

The first floor lounge currently contains an exhibit on rowing history at Wellesley, complete with photographs and an old oar from the class of 1896. This section could be easily expanded to reflect Wellesley's proud athletics history. The Clapp Library contains an exhibit on athletics at Wellesley, and a similar project at KSC could be modeled on this approach. Because Wellesley College is a women's institution with a broader investment in women's history and rights, the KSC would be the perfect host of an exhibit on Title IX in the United States. This exhibit would be housed in the hallway that leads from the front desk to the field house, and would be a source of pride for Wellesley students, much like the hallway of Alumnae Award recipients in the Diana Chapman Walsh Alumnae Hall.

Technology and Media

Wellesley makes access to information, knowledge, and resources a core component of its mission to educate women as exemplified by the many and varied technology resources in academic, art, and social spaces. This commitment could be replicated in providing state-of-the-art technology and social spaces in the KSC as in other buildings. The addition of technology and media in the form of computer stations, flat screen televisions, and audio equipment would connect the sports center to this mission, greatly enhance a user's experience, and most likely increase not only participation, but also the duration of the user's visit. Space should be allocated for new computer stations in the newly renovated, open, visible, and well-lit lounge area. Additionally, assuming that students will enjoy the new renovations enough to arrive early or stay later, campus communication that details the extent of the added wireless service would be helpful. Fulfilling this recommendation would ensure that the Sports Center becomes a more integrated resource on campus that serves to enhance the PERA curriculum as well as educate students and other visitors to the KSC.

Television with cable service and audio equipment in the classrooms, multipurpose fitness room, the field house and one dance studio, would prove popular with students. In the classroom, this equipment could enhance the PERA curriculum, increase course offerings, and enrollment. Coaches could use this

[517] Cost of a three-seat sofa.
[518] Greener Lifestyles Sustainable Furniture. Catalogue available at http://www.greenerlifestyles.com/index.html. Accessed March 12, 2009.
[519] Bean Products. Catalogue available at http://www.beanproducts.com/. Accessed March 12, 2009.

equipment to train and educate varsity athletes. With the addition of exercise and training videodisks in the dance studios, users could have more exercise options from which to choose and could use a dance studio in place of weights, cardio machines, or swimming. Also, student organizations would have the equipment needed for practices and other group activities.

A sound system wired throughout the KSC with a main control at the reception desk and individual controls in strategic places would complete the new technology setup. Quality sound is necessary in a large fitness center due to the competing sounds from users and equipment. A complete audio setup would include the ability to individually operate the system to make general and emergency announcements, listen to music, or broadcast an indoor game. The depth of this system would enhance the College's emergency response system to reach students and the community who may not have access to their cell phones. Wiring and equipment would be necessary in the main spaces—fieldhouse, pool area, indoor courts, and all exercise spaces. Additionally, speakers for announcements and music should be installed in the locker rooms. The integration of music could also create a social atmosphere between users who normally use a personal MP3 and those that do not own one.

Art

The proposed new fitness area is a blank slate and therefore has great potential to be made into a space that would be both motivational and fun. There may be many large-scale changes made in the field house, and the addition of some aesthetically pleasing touches could make the final product even more astounding. Simple and mostly small-scale alterations throughout these areas could make a significant improvement to the overall aesthetic of the KSC.

Art is an integral part of the liberal arts education inside and outside of the classroom at Wellesley. The Sports Center presents another unique opportunity to connect with the campus community by incorporating and installing a variety of art forms in collaboration with the Art Department, the Davis Museum, and interested students. To fulfill the mission of providing a liberal arts education, students could incorporate an art or photography class project with a sports theme for an in-class presentation and/or a Sports Center installation. Student works with a common focus on the human body, form and exercise could be showcased, along with visiting works of art, and also photographic representations. For example, the current display on the wall adjacent to the front desk of photographs from former rowers from the 1950s and 1960s could inspire a student to create a modern representation of the college's crew teams to illustrate how much Wellesley has changed over time.

The placement of all art forms—wall art, photography, or sculpture— is important to consider for aesthetic and practical reasons, and should convey a message or story through the art form or its location. Art should decorate most bare walls and empty floor spaces and corners. Specifically, art should be in every administrative space, the locker rooms, along the walls and hallways, as well as the exercise rooms and field house. The proposed new fitness area, a larger space with more machines, would represent the sports center administration's continued support of active and healthy women. To further improve the experience of using such a new facility, a fun and energetic wall color should be added, in conjunction with artwork of Wellesley

students using the KSC facilities. We also propose major renovations to the field house that would dramatically improve the space. Minor artistic touches, such as the addition of color to the walls, designs to the courts, pictures of sports teams and banners celebrating sports team's successes, would all add greatly to the attractiveness of the space. Art need not convey a sports theme in every instance, to allow space for differing aesthetic sensibilities and art forms. The goal should be to enliven the Sports Center with images and representations that tell stories and convey empowering messages.

Recommendations

Several simple and inexpensive modifications could be made to the Keohane Sports Center to improve its aesthetics. Of these, we recommend improvements to the entryway, lounge, signage, and addition of color to the interior of the KSC take priority. Lighting changes suggested in an earlier section could also make the Sports Center more welcoming. These changes would heighten the accessibility of the building in many ways: a more user-friendly entrance would invite visitors, signage would assist users in navigating the new parts of the facility, a new lounge would build community, and new paint themes would improve general lighting and aesthetic characteristics.

X. MATERIALS

Summary

Renovations require new materials and generate waste materials. In choosing which materials to bring in and how to dispose of unwanted materials, a green renovation must consider the environmental impacts of these materials before, during and after they are used. The environmental degradation caused by the extraction and processing of new materials should be considered when choosing materials to bring in to the building. Materials that are brought in should also be evaluated in terms of their effects on indoor environmental quality. Finally, disposal methods for waste materials, with an emphasis on reusing, salvaging, and recycling, should be considered carefully to minimize environmental impacts at the end of the product's life cycle. This section of the report cannot make specific recommendations about materials in the KSC because the extent of the renovations is unknown; yet we offer recommendations on the reuse and recycling of certain types of materials.

Introduction

It is important to be mindful of the products and furnishings used during a renovation of an existing structure as many building materials can be extremely damaging to the environment and the health of occupants. The Keohane Sports Center provides Wellesley College with an opportunity to mitigate its negative environmental impacts and sources of indoor air pollutants. Inattention to the building materials and furnishings may also result in greater environmental destruction and exposure to higher concentrations of contaminants. It is important to evaluate new materials to understand the processes involved, such as the manufacturing process, durability, and whether these products have the potential to emit high levels of air pollutants.

Health Impacts

Many building materials and furnishings are major contributors of air contaminants, with the level of contribution determined by how much of a given pollutant is emitted and the known level of hazard such pollutants pose. For example, some materials can release contaminants continuously, resulting in high concentrations in the air for long periods of time.[520] Common building materials that emit large quantities of volatile organic compounds (VOCs) include carpet, paints, and adhesives that can be extremely harmful to occupants.[521]

The health effects of indoor air pollutants can either be experienced relatively soon following exposure or years later. Short-term immediate effects can resemble colds or other viral diseases and can be commonly misdiagnosed. Symptoms include irritation of the eyes, nose and throat, as well as headaches, dizziness and fatigue.[522] Effects that could be experienced years later can include respiratory diseases, heart disease and cancer.[523] The most effective way for the college to decrease air contaminants and prevent student, faculty, and staff from its harmful effects is to purchase low-emitting products to eliminate the sources of pollution.

Product History

New materials that minimize environmental degradation should also be considered for the renovation of the sports center. It is important to be aware of what materials are used in constructing products and the manufacturing process involved. Newly installed materials may not immediately pose a threat to the environment once in use but have the potential to cause damage earlier due to the

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[520] U.S. Environmental Protection Agency, "The Inside Story: A Guide to Indoor Air Quality," http://www.epa.gov/iaq/pubs/insidest.html#Look11. Accessed April 18, 2009.
[521] U.S. Environmental Protection Agency, "The Inside Story: A Guide to Indoor Air Quality," http://www.epa.gov/iaq/pubs/insidest.html#Look11. Accessed April 18, 2009.
[522] U.S. Environmental Protection Agency, "The Inside Story: A Guide to Indoor Air Quality," http://www.epa.gov/iaq/pubs/insidest.html#Look11. Accessed April 18, 2009.
[523] U.S. Environmental Protection Agency, "The Inside Story: A Guide to Indoor Air Quality," http://www.epa.gov/iaq/pubs/insidest.html#Look11. Accessed April 18, 2009.

manufacturing process. Environmental degradation can occur during the mining or harvesting of basic materials used in products or from pollution linked to the production process.

Knowing where a product comes from can also be beneficial to mitigating negative environmental impacts. Utilizing wood products that have been certified by the Forest Stewardship Council (FSC) can help ensure that the College is not putting pressure on forests, as the FSC certifies wood products from well-managed locations.[524] Additionally, building materials should be durable to prevent the need for their frequent replacement and disposal, and they should be purchased locally to reduce carbon dioxide emissions from fossil fuels used in shipping.

Materials Disposal

When materials and appliances reach the end of their useful life, they have not yet reached the end of their life in terms of environmental impact. The chosen method of disposal may result in further environmental effects including greenhouse gas emissions, ozone depletion, and the release of toxic materials.[525] There are four ways waste materials can be disposed of, which vary in environmental impact: donation to another party for reuse, salvage, recycling, or trash disposal (incineration or landfill dumping).

Reuse

Reuse of an object has the least environmental impact out of the four possible disposal methods, because the object is used for the same or a similar purpose as before and no energy is required to change the object into a different form.[526] Among the items for which removal or replacement is recommended within this report, the lounge furniture is probably the best candidate for donation to another party for reuse because it is still in decent condition. Other equipment, such as computers and refrigerators, are sometimes donated to charities that distribute the materials within the United States or abroad. If the computer is in good working condition but too old to be useful at Wellesley, donation may be a good option for disposal. The refrigerators currently used at the KSC are not good candidates for donation, however, because they use vast amounts of energy (3500 kWh/a), and the best outcome environmentally is to dispose of them immediately.[527]

In the case of both refrigerators and computers, it is important to know their ultimate fate before donating it to avoid unsafe disposal of the hazardous materials inside them. Computers may contain lead or

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[524] Forest Stewardship Council, "About the Forest Stewardship Council," http://www.fsc.org/about-fsc.html. Accessed April 18, 2009.
[525] NY Wa$teMatch, "Building Materials Reuse Calculator," NY Wa$teMatch, http://www.wastematch.org/calculator/calculator.htm. Accessed April 18, 2009.
[526] California Integrated Waste Management Board, "Waste Prevention Terms and Definitions," Reduce Waste, http://www.ciwmb.ca.gov/Wpw/Define.htm. Accessed April 18, 2009.
[527] Hyung Chul Kim, Gregory A. Keoleian, and Yuhta A. Horie, "Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost," Energy Policy 34, no. 15 (2006): 2310-2323.

mercury depending on the type of monitor, as well as brominated flame retardants.[528] Refrigerators manufactured before 2005 may contain ozone-depleting substances (CFCs and HCFCs) as coolants.[529] If these items are exported to countries with few environmental regulations, the hazardous materials may not be disposed of properly and can threaten human and environmental health.[530]

Salvage

Salvage is a disposal option that falls somewhere between reuse and recycling. Salvaged materials are not transformed into completely new products, but they may change shape or use. Thus, salvage has a smaller impact on the environment through energy and resource use than recycling, but more of an impact than reuse of the material in its current form. The potentially salvageable materials in the KSC include the field house and dance studio flooring and the metal roof. If the renovation includes tearing down any walls as in the Physical Space Chapter, we recommend careful deconstruction because there may be pipes, metal framing, insulation, or wood beams in the walls that can be salvaged for reuse within the KSC or on another building project.[532]

Recycling

The potential for recycling and the amount of recycled waste has grown rapidly in the last thirty years.[533] By recycling 85 million tons of municipal solid waste annually, the United States prevents the release of 193 million metric tons of carbon dioxide equivalents into the atmosphere.[534] With the growth of recycling, it is not surprising that almost all of the materials and major appliances to be discarded from the KSC can be recycled. Recycling should be considered as a disposal option only if reuse or salvage is impractical. Recycling one product to generate a completely new one involves collecting, transporting, cleaning, sorting, and transforming the materials, then marketing the new product. Recycling has a significantly greater impact on the environment than reuse or salvage.[535]

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[528] U.S. Environmental Protection Agency, "Frequent Questions," eCycling, http://www.epa.gov/epawaste/conserve/materials/ecycling/faq.htm. Accessed April 18, 2009.
[529] U.S. Environmental Protection Agency, "Safe Disposal of Refrigerated Household Appliances: Frequently Asked Questions (FAQ)," Ozone Layer Depletion – Regulatory Programs, http://www.epa.gov/ozone/title6/608/disposal/household.html. Accessed April 18, 2009.
[530] Chris Carrol, "High-Tech Trash," National Geographic, January 2008, http://ngm.nationalgeographic.com/2008/01/high-tech-trash/carroll-text. Accessed April 12, 2009.
[532] U.S. Environmental Protection Agency, "Deconstruction: New Opportunities for Salvage," Deconstruction and Reuse, http://www.epa.gov/region09/waste/solid/pdf/cd4.pdf. Accessed April 18, 2009.
[533] U.S. Environmental Protection Agency, "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2007," Municipal Solid Waste (MSW) in the United States, http://www.epa.gov/osw/nonhaz/municipal/pubs/msw07-fs.pdf. Accessed April 18, 2009.
[534] U.S. Environmental Protection Agency, "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2007," Municipal Solid Waste (MSW) in the United States, http://www.epa.gov/osw/nonhaz/municipal/pubs/msw07-fs.pdf. Accessed April 18, 2009.
[535] California Integrated Waste Management Board, "Waste Prevention Terms and Definitions," Reduce Waste, http://www.ciwmb.ca.gov/Wpw/Define.htm. Accessed April 18, 2009.

Recycling is a particularly good method of disposal for materials or appliances containing hazardous wastes. For instance, compact fluorescent (CFL) light bulbs contain approximately 5mg of mercury. If these bulbs are put into landfills or incinerated, the mercury inside them can leach into the soil or be released into the atmosphere, where it can cause serious human and environmental health problems. Recycling CFLs allows the mercury in the bulbs to be recovered and used again in other products, preventing the release of mercury into the environment.[536]

Trash Disposal

The EPA states that sending trash to an incinerator or landfill should be a last resort.[537] In the United States, landfills release more than 20% of human-related emissions of methane, a potent greenhouse gas.[538] Landfills also take up space and wildlife habitat, and they have to be monitored carefully so that no hazardous chemicals escape into the surrounding environment.[539] Incinerators release chemicals that pose major human health risks, such as dioxins, furans, and heavy metals, and technologies to prevent the release of these compounds are imperfect.[540] There are no items from the KSC for which trashing is the recommended disposal option.

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[536] U.S. Environmental Protection Agency, "Mercury Containing Light Bulb (Lamp) Basic Information," Mercury Containing Light Bulb (Lamp) Recycling, http://www.epa.gov/epawaste/hazard/wastetypes/universal/lamps/basic.htm. Accessed April 18, 2009.
[537] U.S. Environmental Protection Agency, "Mercury Containing Light Bulb (Lamp) Basic Information," Mercury Containing Light Bulb (Lamp) Recycling, http://www.epa.gov/epawaste/hazard/wastetypes/universal/lamps/basic.htm. Accessed April 18, 2009.
[538] U.S. Environmental Protection Agency, "Basic Information," Landfill Methane Outreach Program, http://www.epa.gov/outreach/lmop/overview.htm. Accessed April 18, 2009.
[539] U.S. Environmental Protection Agency, "Landfills," Municipal Solid Waste, http://epa.gov/osw/nonhaz/municipal/landfill.htm. Accessed April 18, 2009.
[540] Salman Zafar, "Negative Impacts of Incineration-based Waste-to-Energy Technology," Alternative Energy, http://www.alternative-energy-news.info/negative-impacts-waste-to-energy/. Accessed April 18, 2009.

Figure 73. Preferred disposal methods for materials and appliances in the KSC for which removal or replacement is recommended within this report

Disposal method	Material
Reuse	lounge furniture
	treadmills
	desktop computers
Salvage	field house flooring
	dance studio flooring
	pipes
	metal framing
	insulation
	wood beams
Recycle	CFL light bulbs
	gypsum drywall
	desktop computers
	refrigerators
	toilets
	washing machine
	dishwasher
	treadmills [541]

Cost Analysis

In addition to being the most environmentally friendly disposal option, reuse is also the most cost-effective disposal option. Donations of used appliances to charity can result in tax breaks, and the only cost is that of transporting the appliance to the charity. Salvage can be inexpensive or even financially beneficial, depending on the value of the materials that are salvaged.[542] Recycling is not prohibitively expense, either; the town of Wellesley charges only $20 to drop off an appliance at the Recycling and Disposal Facility.[543] Even

[541] e.g., City of Manchester Department of Public Works, "Recycling and Disposal of Everyday Items," Trash Collection, http://www.manchesternh.gov/website/Portals/2/Departments/public_works/highway/recycling/other_special_pickups_2008.pdf. Accessed April 18, 2009.
[542] U.S. Environmental Protection Agency, "Deconstruction: New Opportunities for Salvage," Deconstruction and Reuse, http://www.epa.gov/region09/waste/solid/pdf/cd4.pdf. Accessed April 18, 2009.
[543] Town of Wellesley Department of Public Works, "Appliances," Recycling and Disposal, http://www.wellesleyma.gov/Pages/WellesleyMA_DPW/rdf/Appliances. Accessed April 18, 2009.

though normal trash disposal is free to the general public, appliances or large volumes of material must often be removed by a paid contractor, driving up the cost of trash as a disposal option.

Conclusion

All of the materials and appliances that will be disposed of during the KSC renovation can avoid incineration or a future in a landfill through reuse, salvage, or recycling. Few materials can be directly reused, so any type of disposal will incur environmental costs through the energy and resource use of re-processing the materials. For appliances or materials that are currently operating at an acceptable level, the KSC should only replace them when they stop working or if the environmental benefits of replacement outweigh the environmental costs of disposal, as in the case of the KSC's refrigerators. Whether materials and appliances are donated, sold as salvage, or recycled, it is important to have a clear idea of what will happen to them after they leave the college's property, so that they are disposed of in an environmentally responsible manner.

XI. LEED

Summary

Leadership in Energy and Environmental Design, or LEED, is a process of certifying buildings as environmentally sustainable. One of the drawbacks of pursuing LEED certification is the cost associated with application, especially given the current economic crisis. However, the College is already planning to apply for LEED certification for the Lulu Chow Wang Campus Center, as well as the renovation to Alumnae Hall. Certifying the Sports Center as well would create a green corner of campus, garnering positive publicity for the College. Pursing certification also ensures that the College follows through on planned green steps in renovation. As the College plans to renovate the Sports Center, taking those renovations one step further and pursuing LEED certification is feasible; following the recommendations of this report will earn the College almost all of the necessary points.

LEED Certification

Leadership in Energy and Environmental Design (LEED) is a certification process developed by the United States Green Building Council (USGBC) in 1998. LEED ranks buildings on a four-tiered scale, ranging from standard certification to platinum based on the qualities of energy savings, water efficiency, indoor air quality, reduction of carbon dioxide emissions, and stewardship of resources. Other colleges in Massachusetts including Mount Holyoke College, Harvard University, Emerson College, Worcester Polytechnic Institute, Clark University, Boston University, and Suffolk University already have LEED certified buildings.[544] Mount Holyoke, one of Wellesley College's "sister schools," opened a new LEED-certified residence hall in the fall of 2008.[545] Though the project developers were only working to obtain a silver rating, they managed to acquire a gold rating, with the majority of its points coming from energy and water efficiency measures.

LEED for Existing Buildings

Because the KSC will not be built anew, as the Mount Holyoke building was, and would instead undergo a major renovation, the College would work within the parameters of the LEED for Existing Buildings standards. Meeting only 40 of a maximum of 110 possible points would earn the College basic certification; earning more points could secure an even more prestigious rating for the Sports Center. The majority of the points are in the Energy & Atmosphere section, with the Sustainable Sites section claiming second most. The three remaining sections, Water Efficiency, Materials & Resources, and Indoor Environmental Quality, total to about a third of the available points. Ten bonus points can be earned for Regional Priority and Innovation in Operations. By instating the recommendations outlined in this report, the renovated KSC will earn points from the Water Efficiency, Energy & Atmosphere, Indoor Environmental Quality, Materials & Resources, and Innovation in Operations categories. The KSC renovation would need to earn an average of less than ten points in each of these sections in order to earn a standard certification.

Advantages and Drawbacks of LEED

LEED certification for the KSC will provide many benefits for Wellesley College. LEED certification is a well-known concept and would help to enhance the College's image. Because a certain standard must be met in order to earn LEED certification, both people within and outside of the College community will recognize that the KSC was sustainably renovated and up to par with other green buildings. As prospective students and their parents take tours past the KSC, the guide will indicate the green attributes and LEED certification of the KSC. Additionally, after the renovation of the KSC, the College could have a

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[544] United States Green Building Council. "LEED Projects & Case Studies Directory.," "http://www.usgbc.org/LEED/Project/CertifiedProjectList.aspx?CMSPageID=247"http://www.usgbc.org/LEED/Project/CertifiedProjectList.aspx?CMSPageID=247. Accessed May 4, 2009.
[545] Mount Holyoke College, "New Residence Hall Turns Green to Gold.," "http://www.mtholyoke.edu/news/channels/22/stories/5681104"http://www.mtholyoke.edu/news/channels/22/stories/5681104. Accessed May 4, 2009.

reopening ceremony; in news coverage of the ceremony LEED certification will garner a great amount of positive publicity. Additionally, Wellesley is pursuing LEED certification for other buildings on campus, specifically the Lulu Chow Wang Campus Center and Alumnae Hall. Because both of these buildings are located close to the KSC, it would create a "green corner" of campus appealing to both current and prospective students. Pursuing LEED certification also ensures that the College fulfills its proposed green upgrades.

Although LEED certification has many benefits, there are a few drawbacks to pursuing certification. The primary negative aspect associated with pursuing LEED certification is the cost. Implementing LEED standards may force the College to conform with standards with which it did not originally want to comply. These standards would be costly to instate, and could be unnecessary if the College is simply trying to green one of its buildings. These downsides are easily mitigated; it is likely that the costs associated with pursuing LEED certification will be earned back through cost savings from better energy and water efficiency, as well as the public interest garnered by the certification.[546]

Conclusion

While LEED certification is not an absolutely necessary measure in the greening of the KSC, it will provide many advantages for the College. LEED certification will send the message that the College was seeking not only to establish its belief in green principles, but that it is willing to pursue an even higher standard. LEED certification is rather easy to achieve, and because the College is planning on implementing a green renovation of the KSC, it would not take much more work to push the renovation to LEED standards. For these reasons, we should most definitely seek to earn LEED certification for the Sports Center renovation.

[546] United States Green Building Council, "How to Achieve Certification," "http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1991" Accessed May 4, 2009.

CONCLUSION

This spring, the ES 300 class planned a sustainable renovation of the Keohane Sports Center. We narrowed our focus to ten specific areas of the building that need attention, with both practical (the leaking roof in the field house) and sustainable (reducing the carbon footprint of the Sports Center) concerns in mind. We prioritized our recommendations based on surveys and interviews with members of the community, the PERA Department, and the various constituencies that use the KSC. One of PERA's goals is to encourage as many students, staff and faculty of the Wellesley College community as possible to participate in physical activity each day, and we expect that our recommendations will further this goal.

To make the Keohane Sports Center more sustainable we recommend a combination of wind, solar, and human power to generate electricity for the KSC, and a host of other changes including: a cantilevered running track, centralized cardio and weight room, energy efficient treadmills, Energy Star appliances, improved insulation, skylights, infrared occupancy sensors, LED lights, landscaping, low VOC building materials and cleaning supplies, displaced ventilation, an extensive green roof, cool roof spray, a more welcoming entryway, and the pursuit of LEED certification.

Underpinning our recommendations is the belief that the goal of personal physical health is philosophically analogous to the goal of sustainability for our planet. Recreation and athletics should take place in a sustainably managed facility. In keeping with this approach, we evaluated the potential educational aspects of each option in addition to aspects of their cost, lifespan, and disposal. We received a Green Grant for a human-powered cardiovascular machine, which will show users the energy output of their workout by powering a TV or a computer. In the same way, many of our recommendations have educational potential for the broader community.

Because we are not engineers, electricians or architects, we provide our recommendations as a starting point for the College, from which experts and administrators can build more in-depth plans. Many of our values for energy and water consumption are rough estimations, emphasizing the need for better monitoring on campus. Increased metering will not only give the College a better idea of usage, but will also encourage life-long behavioral change.

If Wellesley hopes to live up to its motto of educating "women who will," we cannot afford to overlook our environmental impact. As an institution of higher education, Wellesley's actions both in and outside of the classroom serve as examples to its students and educational resources; an environmentally-conscious Keohane Sports Center would serve as both a recreational and an academic resource. The ES 300 class has started the renovation process by installing a human powered elliptical machine in the Sports Center through the Green Grant. We have taken action, and we can only hope that with our recommendations, the College will see fit to do the same.

Appendix A: Aesthetics

Figure 74. Cost Analysis for Dance Flooring

Company	Model	Notes	Permanent?	Price
Rosco	Roscoleum Classic	Linoleum for all types of studios	Yes	2m x 32m roll = $2242
Alvas	Matlay	Reversible - suited for all dance types, lightweight	Optional	$17.50/ square yard
Dance Equipment International	Arabesque	heavy-duty vinyl ideal for many dance types	Optional	$23.19/ square yard

Appendix B: Energy

Figure 75. Equations used to Calculate Top-Down Sports Center Energy Consumption

$$E_s = (E_w \times 10^6) \times (z/y) \quad (1)$$

Where:

E_s = *Electricity usage of Sports Center (Btu)*

E_w = *Electricity usage of Wellesley College (Btu)*

y = *GSF of Wellesley College (ft2) = 2,543,100 ft²*

z = *GSF Sports Center (ft2) = 158,100 ft²*

$$H_s = (H_w \times 10^6) \times (z/y) \times (0.000293) \quad (2)$$

Where:

H_s = *Heat energy usage of Sports Center (Btu)*

H_w = *Heat energy usage of Wellesley College (Btu)*

y = *GSF of Wellesley College (ft2) = 2,543,100 ft²*

z = *GSF Sports Center (ft2) = 158,100 ft²*

Figure 76. Sports Center Electrical Appliances General Inventory

Item Name	Number of Items	Energy Input/Item (kW/item)	Hours Used/day (h/d)	Energy Consumed (kWh/d)	Energy Consumed (kWh/a)
Pool Lights (400 watt metal halides)	32	0.4	12	153.6	56,064
Field House Lights	42	1	15	630	229,950
Fluorescent Lights	400	0.03	15	180	65,700
Incandescent Lights	100	0.06	15	90	32,850
Fillion Sand Pool filters	2	12.25	24	588	214,620
Pool Pump	2	0.38	24	18.24	6,658
Exercise Machines	25	1.5	5	187.5	68,438
Washing Machines	2	1.5	4	12	4,380
Dryers	2	1.75	4	14	5,110
Refrigerators	4	0.4	24	38.4	14,016
Microwaves	4	0.024	2	0.192	70
Ice Machine	1	1	24	24	8,760
Hand Dryers	10	2.2	1.67	36.74	13,410
Phones	30	0.025	2	1.5	548
Fans	10	0.025	5	1.25	456
TV's	2	0.15	2	0.6	219
Computers	30	0.225	8	54	19,710

Figure 77. Sports Center Heat Usage

Item Name	Number of Items	Energy Input/Item (kW/item)	Hours Used/day (h/d)	Energy Consumed (kWh/d)	Energy Consumed (kWh/a)
Dry Saunas	2	13.185	0.5	13.185	4,813
Pool Heating (gallons)	400,000	51	24	1234.838995	450,716
Space Heating					4,227,404

Figure 78. Energy Estimate Summary

SUMMARY

Top-Down Estimate

Electricity Consumption = 1,740,710 kWh/a

Heat Energy Consumption = 4,227,404 kWh/a

Total Energy Consumption = 5,968,114 kWh/a

Bottom-Up Estimate

Electricity Consumption = 740,958 kWh/a

Heat Energy Consumption = 4,682,933 kWh/a

Total Energy Consumption = 5,423,891 kWh/a

*Values are predicted to be underestimates

Figure 79. Photovoltaic Alternatives Feasible at Wellesley College

Alternative #	Model/Identifier	Physical Size Specifications (ft2)	Electrical Output (kWs)	Estimated Annual Output (kWh/panel/a)	Initial Cost ($/panel)
1	Roof Mounted Silicon Flat Panels	7	0.085	91.63	449.00
2	Roof Mounted Thin Film Flat Panels	23	0.128	137.98	640.64
3	Window Thin Film Panels (MST-43-LV)	8	0.043	46.354	202.00

Figure 80. Overview of Photovoltaic Unit Costs

Alternative #	Model/ Identifier	Initial Cost of Unit Purchase ($/panel)	Cost of Installation per Panel ($/panel)	Operation Costs ($/annum)	Maintenance costs ($/annum)	Estimated Lifetime (years)	End of life Cost ($/W)
1	Roof Mounted Silicon Flat Panel[547]	449.00	239	0	0	30	0.05
2	Roof Mounted Thin Film Flat Panels[548]	640.64	239	0	0	25	0.05
3	Window Thin Film Panels (MST-43-LV)	202	83.78	0	0	25	0.05

[547] Alternative Energy Store, "Kyocera KC85T 85W 12V Solar Panel," http://store.altestore.com/Solar-Panels/51-to-99-Watt-Solar-Panels/Kyocera-KC85T-85W-12V-Solar-Panel-with-J-Box/p725/. Accessed March 1, 2009.
[548] Alter Systems, "Uni-solar 12W PV Laminate Module," http://www.altersystems.com/catalog/unisolar-128-watt-pv-laminate-module-p-373.html. Accessed March 10, 2009.

Figure 81. Overview of Total Costs and Outputs of Photovoltaic Systems

Alternative #	Model/Identifier	Number of Panels	Electrical Output (kW)	Total Annual Output (kWh/system/a)	Total Initial Cost ($/system)	Total End of life Cost to Recycle ($)
1	Roof Mounted Silicon Flat Panel	7	238.17	256,825	1,926,590	10,718
2	Roof Mounted Thin Film Flat Panels	23	109.184	117,702	749,972	4,913
3	Window Thin Film Panels (MST-43-LV)	8	10.75	11,589	92,389	484

Figure 82. Carbon dioxide emissions in transport of wind turbine models from the manufacturer

Alternative	Turbine Model	Manufacturer Location	CO_2 emissions in transport (lbs)
1	Southwest Windpower Skystream® 3.7	Flagstaff, AZ	9400
2	Aerostar® 6 Meter	Westport Point, MA	250
3	Bergey EXCEL	Norman, OK	6300
4	ReDriven Power 10 kW / 20 kW	Iroquois, Ontario, Canada	1400
5	Northern Power Northwind 100™	Barre, VT	700

(Calculations assume $C0_2$ emissions of 22.2 lbs/gallon of diesel [549] and transport of the turbine in a single tractor-trailer with a fuel efficiency of 6 mpg.[550])

[549] US Environmental Protection Agency, "Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel," Overview: Pollutants and Programs, http://www.epa.gov/oms/climate/420f05001.htm. Accessed March 18, 2009.

[550] Union of Concerned Scientists, "Reducing Global Warming Pollution: Technology Options for Tractor-Trailers," Clean Vehicles, http://www.ucsusa.org/clean_vehicles/technologies_and_fuels/gasoline_and_diesel/technology-options-for.html. Accessed March 18, 2009.

Figure 83. Estimated Current Sports Center Lighting Scenario

Current Sports Center Lighting	kW	Lumens	h/day	days/year	kWh/a	# of Lights	Total kWh/a	Operation Cost (@ $0.10/kWh)
Lights 400 W Pool/Field House/MP Room (Metal Halides)	0.4	33000	10	365	1460	82	119720	11972
Lights 100 W Recessed (CFL)	0.1	6200	12	365	438	61	26718	2671.8
Lights 90 W Dance Studio Floor Lamps	0.09	5000	2	365	65.7	8	525.6	52.56
Lights 60 W Dance Studios (CFL)	0.06	3600	5	365	109.5	72	7884	788.4
Lights 34 W Hallways/Offices (CFLs)	0.03	2800	12	365	148.92	958	142665	14266.536
Lights 14? W Raquetball	0.01	750	2	365	10.22	84	858.48	85.848
Lights 30? W Hallogen Floor Lamps (Office)	0.03	360	15	365	164.25	10	1642.5	164.25

Appendix C: Water

Figure 84. Water Reduction from Washing Machines and Dishwashers

Alternative	Water Use	Energy Use	Cost	Capacity
Frigidaire Front Loading Washer	30-50% less than top load	50% less energy than non-energy rated	$499 after rebates	3.5 ft^3
LG Front Loading Washer	30-50% less than top load	50% less energy than non-energy rated	$712.49	3.6 ft^3
Energy-Star Dishwasher		41% more efficient than 2007 Federal standard	From $248.00	24 Inch (Standard)

Appendix D: Roofing

Figure 85. Successful Species on Wellesley College Experimental Green Roof

Species	Common Name
Allium cernuum	Nodding Onion
Allium stellatum	Prairie Onion
Andropogon scoparius	Little Bluestem grass
**Anemone caroliniana*	Carolina Anemone
Antennaria plantaginfolia	Pussytoes
Arctostaphylos urva-ursi	Bearberry
Aster divaricatus	White Woodland Aster
Aster laevis	Smooth Aster
Aster ptarmicoides	White Aster
Campanula rotindifolia	Harebell
Carex eburnea	Ivory Sedge
Carex pensylvanica	Common Oak Sedge
Dennstaedtia punctilobula	Hay-scented Fern
Fragaria virginiana	Wild Strawberry
Geum triflorum	Prairie Smoke
**Houstonia longifolia*	Longleaf Bluets
**Hypoxis hirsuta*	Yellow stargrass
Muhlenbergia cuspidata	Prairie Satin Grass
Sedum nevii	Stonecrop
Sedum ternatum	Wild Stonecrop
Silene virginica	Fire Pink
**Sisyrinchium albidum*	Common Blue-eyed Grass
Solidago sciaphila	Cliff goldenrod
Sporobolus heterolepis	Northern Dropseed
Vaccinium angustifolia	Lowbush Blueberry
Verbena stricta	Hoary Vervain
Viola pedata	Bird's Foot Violet

Appendix E: Green Grant

Proposal for Human Energy Pilot Program

Song-Song Xi '10, Taylor Harvey '10, Alex Warren '10, Beth DeSombre - Faculty, Jess Hunter - Environmental Studies Program Coordinator, and the Environmental Studies 300 Class

Spring 2009

Wellesley College uses an incredible amount of energy each year. Approximately 28,000,000 kW of electricity were used on campus in 2008. Many students think very little about their energy use or carbon footprints. It is easy for them to think of energy on campus as free and expendable because they do not receive utility bills that clearly define their energy usage. One way to put a "price" on electricity would be to help students understand the amount of work necessary to create electricity.

Our Project

We propose that exercise machines in the Keohane Sports Center be fitted with converter boxes that use motion to generate electricity. There are two options for storing this electricity. The machines could be directly connected to the electrical grid allowing, electricity to be used anywhere on the grid. Alternately, energy could be stored in a battery to power any device attached to the battery.

Nearly any exercise machine can be retrofitted to harness energy. Several gyms across the country use exercise machines to power their facilities. MIT's Alumni Gym is one such example, with an exercise bike that powers a laptop. At 100 watts per hour, elliptical trainers are the most efficient application of this technology. We recommend connecting two ellipticals to a battery to provide supply energy.

We recommend initially for this pilot program to connect the machines in the KSC to batteries that power an electrical device such as a television. The television or other device will not work if there is not enough electricity stored in the battery. Exercisers will quickly realize that they must keep moving to power the television. This will help students understand the amount of work required to power a simple device.

Why Human Power?

Human power obviously could not replace fossil fuels entirely as a campus energy source. One elliptical can generate only 135 kilowatts per year. With a display of how much electricity was produced during a workout or a television that will not function without enough electricity, an exerciser can begin to understand the price of electricity. With proper signage, this knowledge can foster both personal and institutional change.

Signs around exercise equipment will connect human work and electricity generation, making comparisons to energy use of common household devices. As part of a broader environmental education campaign, these machines will help to raise student awareness of their impact on campus energy use and climate change.

Costs

The cost of this pilot program is small compared to the possible savings it could initiate. A kit to retrofit an elliptical can be purchased from ReCardio, a company that specializes in retrofitting cardio exercise equipment, for $300. Typical car batteries can be used to store electricity. The price of the retrofitting kit, batteries, and television may be more than the cost of the energy saved through the use of these machines initially, although if the pilot program were successful and eventually expanded, it could eventually provide cost-effective energy in the KSC. Even with the pilot program advantages associated with increased awareness may lead to behavioral changes that significantly reduce campus-wide energy use. Resulting energy cost savings will quickly recover project costs and positively impact future energy budgets.

In addition, there are many unpriced costs associated with the use of fossil fuels for electricity generation; for example, the effects of burning fossil fuels on human health and environmental health are not factored into the price of electricity. While generating electricity from human motion has higher direct costs, it has the added benefit of avoiding fossil fuel use and greenhouse gas production. And, the education from the machine may result in energy reductions because users will understand the vast amount of energy necessary to produce electricity and may make behavioral changes such as reducing the amount of electricity they use. With even a small attitude shift across campus the price of installation could be recovered quickly, and the college could even save money from the reduction in energy use.

Cost Estimate

Equipment Needed	Electrical Capacity	Estimated Annual Output[551]	Quantity	Cost	Subtotal
Elliptical Retrofit by ReCardio	300 Watts/hour	135 kW/year	2	$300 and Battery Connection	$600
19" Hi-Def LCD Television with DVD	50-100 Watts/hour		1	$400	$400
Car Battery			1	$65	$65
Protective Battery Casing with Sign			1	$30	$30
Educational Signage			1	$50	$50
Wireless Headphones			6	$80 per pair, including transmitting station	$480
Energy Meter with LCD Display			1	$30-60	$60
TOTAL (assuming highest listed cost)					$1385

Possible Concerns

Introducing a television to the Sports Center may be an incentive for more students to use the facilities. This addition may not be desirable to all users and Sports Center staff. A compromise may be to limit television use to closed captioning and wireless headphones, eliminating sound that may disrupt other users. These headphones could be checked out from the front desk in the same manner as rental sports equipment and would be maintained by front desk staff.

We budgeted for a protective battery casing to protect all users from unlikely potential hazards. Batteries do

[551] Assumes machine would be used 270 days per year for 5 hours each day.

contain some toxic materials and should be recycled at the end of their life. Batteries must be replaced every three to five years depending on use and model specifications.

This system can easily be installed and maintained by existing experienced Facilities staff. After the initial installation, minimal maintenance will be required. The cost of any maintenance should be included in routine Facilities budgeting.

Publicity

To ensure optimal educational benefits, the advantages of human power must be made very public and obvious. Proper signs should be installed near exercise and television equipment explaining how it works and its connection to carbon emissions and fossil fuel use.

Since the exercise machines are connected to batteries, they may be transported to different parts of the campus to reach more students. A Tanner presentation in the fall would showcase the benefits of human powered equipment while explaining its link to energy production and inciting other student and staff behavioral changes. A temporary display of the elliptical and television system in the Campus Center at the start of the fall semester would allow visitors and students who do not frequent the Sports Center to see and experience this new technology. Similarly, we will highlight this system at the Fall Sports Picnic so that athletes can understand how the system works and experience the benefits of human power for themselves. As frequent users of the Sports Center, athletes could be our best ambassadors to the wider student community by spreading the word about energy conservation.

Proposed Timeline

Summer 2009- Installation of retrofitted exercise machine system in Keohane Sports Center.

Collaboration with Patrick Willoughby, Jess Hunter, Bridget Belgiovine, and Martha Dietrick

Fall 2009- Fall Sports Picnic Showcase, Lulu Chow Wang Campus Center Showcase, Tanner Presentation presented by non-graduating members of Spring 2009 Environmental Studies 300 class and Jessica Hunter and Beth DeSombre

This grant proposal was developed during the Environmental Studies 300 capstone course Environmental Decision Making as a part of a larger project to design a green renovation of the Sports Center. Alterative energy production was explored. Human power was heavily supported because of its environmental and educational benefits. We believe Wellesley should pursue this type of energy production because of the strong statement it sends about the college's commitment to green energy as well as the institutional change that human power could create. This grant offers the college an opportunity to invest in an experimental form of energy production during tough economic times without financial risk. With the help of this grant, the college can try human power and determine the feasibility of expanding the project.