PENNSTATE

architectural engineering thesis

[proposal update#1]

PHIPPS
center for sustainable landscapes

mechanical system redesign
January 13, 2012
thesis.joshwentz.net

option. mechanical
advisor. Dr. William Bahnfleth
building location. Pittsburgh, PA

by JOSHWENTZ








CONTENTS

TABLES

FIGURES

1.0 Executive Summary

Phipps Center for Sustainable Landscapes (CSL) is a new 24,350 square foot building in Pittsburgh, Pennsylvania. The building will be comprised of classrooms, offices, and conference rooms for Phipps employees and university researchers. The estimated date of construction completion is April 2012. Phipps strives for CSL to exceed the United State Green Building Council's highest certification, LEED(Leadership in Energy and Environmental Design) Platinum.

The **objective** of this proposal is to explain the scope of the redesign project, provide justification for the proposed project based on the existing conditions of the facility, and indicate in sufficient detail the tools and methods you will use to accomplish the work. **Sections discuss**: background, problem, depths, breadths, timeline, and preliminary research.

While the mechanical design is extremely high performing for an office building, there are several **maintainability issues** that are likely to occur due to the **complexity of the controls** that result from the use of highly new and progressive systems.

Proposed depth redesigns include:

- **Spray Cooled Roof**: Green roofs are an expensive initial cost and its energy savings through the thermal barrier that it creates is not proven over time. As a way to decrease costs, water sprayed on the roof, which acts as an ecologically sound cooling agent, could offer similar benefits at lower costs. In pursuit of figuring out which rooftop design would be the most energy conscious throughout its life, the green statement criterion of the owner will be relaxed.
- **Hybrid Geothermal System**: Ground source heat pumps have higher first costs than conventional systems making short-term economics unattractive. An alternative, lower cost approach for such applications can be use of a hybrid GHP design. In hybrid geothermal systems, the ground heat exchanger size is reduced and an auxiliary heat rejecter (e.g., a cooling tower or some other option) is used to handle the excess heat rejection loads during building cooling operation. This depth will analyze the function of life cycle costs vs. ground loop size.

Proposed breadth redesigns include:

- **Electrical, Direct Current Distribution**: To accommodate the controls system and eliminate PV inefficiency, it is proposed to study the alternative of a DC distribution system within the building. This was not to be considered as an alternative after completion but to be considered as an initial design consideration.
- **Construction Management, Bore Hole Optimization**: The installation of a hybrid geothermal system will dramatically affect the construction schedule, installation cost, and equipment. In particular bore hole depth and corresponding bore drilling costs will presumably be reduced due to the ground heat exchanger reduction. Bore hole optimization will be analyzed and weighted to see if the proposed hybrid geothermal system is worthwhile to the owner.

2.0 Background

The Center for Sustainable Landscapes is a 24,350 SF building in Pittsburgh, PA that was designed with a high performance mechanical system with the main objective of achieving LEED Platinum. As background into the building and problem, this section summarizes the building overview, mechanical system overview, and evaluation of the existing mechanical system.

2.1 Building Overview

<table>
<tr><td>Name</td><td>Phipps Conservatory, Center for Sustainable Landscapes (CSL)

Figure 1 Rendering & Location Map</td></tr>
<tr><td>Location</td><td>One Schenley Park Drive
Pittsburgh, PA 15213</td></tr>
<tr><td>Occupant</td><td>Phipps Employees / University Researchers
367 persons [1st: 140, 2nd: 112, 3rd: 115]</td></tr>
<tr><td>Function</td><td>Classroom / Office / Conference
Education / Administration / Research</td></tr>
<tr><td>Size</td><td>24,350 SF [1st: 11,209 SF, 2nd: 11,151 SF, 3rd: 1,990 SF]</td></tr>
<tr><td>Floors</td><td>3 stories</td></tr>
<tr><td>Construction</td><td>Dec. 2010 - Apr. 2012</td></tr>
<tr><td>Cost</td><td>$20 million</td></tr>
<tr><td>Team</td><td>Integrated Project Delivery (IPD) required by the owner</td></tr>
<tr><td>Sustainability Goals</td><td>1. LEED Platinum
2. Living Building Challenge
3. SITES Certification for landscapes</td></tr>
</table>

2.2 Mechanical System Overview

Objectives	The primary factor in the mechanical system design was Phipps' ambition to achieve the **three highest green standards**: the ILBI (International Living Building Institute) Living Building Challenge, LEED Platinum, and SITES Certification for landscapes (all of which were required by the owner in the building program). These standards are expected to be a way to emphasize more green and sustainable building practices and operations. Phipps' new center for education, research, and administration will **generate all of its own energy** and capture and treat all of its own water on site. Other compliance factors includedthe Uniform Construction Code of Pennsylvania 2006, International Building Code 2006, National Electric Code, and ASHRAE ventilation requirements.
Heating & Cooling	A **geothermalground-source closed-loop system** satisfies 70% of CSL's heating and cooling loads. Geothermal wells, bored into the ground sink, create a ground source heat exchanger by remaining at a consistent temperature of 57 °F.In winter, warmth stored over the course of the summer season is recovered from the wells to heat the building spaces. In summer, heat removed from the heat pump refrigeration cycle is absorbed by the water circulated in the wells and the cool ground. A 12,400 cfm capacity **rooftop energy recovery unit** supports the geothermal system in heating, cooling, ventilating, and dehumidification. A desiccant wheel in the energy recovery unit pre-cools and dehumidifies outside air to reduce cooling loads by removing the humidity from warmer incoming air. Air is distributed throughout the majority of the building (offices, classrooms, conference rooms) through an **underfloor air distribution**variable air volume (VAV) with baseboard diffusers. This system was chosen to reduce duct costs while accommodating for fluctuations in occupancies throughout the day. The large, three-story atrium/lobby is 100% passively cooled. Passive heating strategies are supplemented by **radiant floors** heated by an evacuated tube solar hot water system and heat from the upper campus conservatory and green house. To provide both insulation and thermal storage a **green roof** was added to CSL.
Ventilating	A **demand controlled ventilation system** (DCV) uses **CO_2 sensors** throughout the building to track building occupancy levels and tailors the ventilation rate to provide for the current occupancy level.**Ultraviolet duct lamps** were also added to increase the indoor air quality in response to the tighter, high performance envelope. A **natural ventilation sensor system** inside the building automatically notifies building occupants whenconditions are appropriate to open the operable windows. Through natural ventilation and humidity reduction, a comfort setpointof 78°F reduces the mechanical cooling load and HVAC system fan energy usage.
Controls	A **direct digital control (DDC) Building Management System** will monitor, control, and provide feedback to various building systems for optimal energy efficient operations. The DDC uses past historical weather patterns and current conditions to predict daily ambient temperatures, humidity swings and optimize building systems. **Energy data meters** will also provide building managers and occupants building operating profiles and trend data to monitor energy efficiency.

2.3 Evaluation of Existing System

As a response to the requirements of the building program, the mechanical systems of the Center for Sustainable Landscapes exceed standards in nearly every category, yet maintaining such new and complex systems may cause future issues. The evaluation for the as-designed existing mechanical systems for the Center for Sustainable Landscapes was conducted using seven categories and grades A through F.

Space: A

CSL mechanical systems including the 1st floor mechanical room, electrical room, rooftop energy recovery unit, and vertical duct shafts account for 835 SF of the 24,350 SF building, which equates to 3.5% of lost usable architectural space.Typically, the mechanical system space ranges from 8 to 15% of the total floor area. Thus, CSL mechanical systems were extremely space efficient.

Comfort: B

The geothermal system in conjunction with the rooftop energy recovery unit provides heating, cooling, ventilation, and dehumidification. Operable windows give occupants added control of their comfort. Increased daylighting within the space makes the open office a comfortable space to work. Yet, the minimally conditioned atrium with its roof being 100% glazing and its supplemental radiant floor systems potentially being cut due to end of project budget costs, has a small potential for comfort concerns.

Health & Indoor Air Quality: A

With its high performance envelope which creates a tight building with little infiltration, indoor air quality in CSL was an initial potential concern. But, the designers added five different air quality systems that are expected to combat unhealthy air. With an energy recovery ventilator with a 100% outdoor air mode, CO2 occupancy sensors, exhaust fans, natural ventilation with operable windows, and ultraviolet duct lights, indoor air quality in CSL should not be a concern.

Controls & Maintainability: D

The sequence of operations for the selected mechanical systems is extremely detailed and intricate. Systems are highly dependent upon each other and are even more dependent on the overarching Building Management System (BMS), WebCTRL by Automatic Logic. This BMS is to take in over 236 hardware and software points (some of which consists of continuous metering) from 5 different product manufacturers and make all of the information understandable and manageable to the facility manager and building owner. If each BMS point represents a potential maintainability issue, that equates to 236 potential controls problems. Due to these high risks and poor user interfaces of controls software, maintainability is likely to be very difficult.

Energy: A

CSL strives to exceed net-zero by generating more electricity than it uses with photovoltaic panels and an on-site wind turbine. Using Trane TRACE 700, it was simulated to consume 19,926 BTU/SF annually for electricity. Compared to otherbuildings of its size, function, and location from an Energy Information Administration study, CSL consumes an average of 75% less energy.

Costs: B

The mechanical system initial cost is $714,000 (approximately 3.6% of the total budget), and annual operating costs is $14,216. Typically, the mechanical system cost ranges from 15 to 20% of the total estimated construction budget. Thus, CSL's initial cost appears to be much lower than traditional designs at face value, yet could be misleading. In order to achieve LEED Platinum, Phipps hired 10 consultants (which increased initial services costs yet was not able to be captured in the up-front costs amount). Additionally, since the controls manufacturer and supplier was through a separate contract, the hundreds of intended building sensors are also excluded from the initial costs.Nevertheless, the mechanical system first cost and annual operating costs break down to $29.32 and $0.68 per square foot respectively. Both the system first cost and annual energy costs are below the building industry. New, progressive designs are not cheap, thus CSL has higher up-front yet lower costs throughout its life.

Sustainability: A

With a team of over 10 companies committed to achieving LEED Platinum, CSL is expected to earn 55 of the 69 available points for its Pittsburgh site. Well above the 52 points LEED Platinum threshold, it is highly likely that CSL will be awarded the highest rating given by the USGBC upon construction.

Opportunities for Improvement

After evaluating the Center for Sustainable Landscapes, its mechanical design is found to be extremely well rounded. Four of the selected seven categories received a perfect rating (including: space, health / indoor air quality, energy, and sustainability). Two categories received a near perfect rating (comfort and costs), while controls and maintainability fell short of an otherwise near flawless design.

3.0 Problem

Differing from most traditional buildings, great effort, time, and money has been invested into the Center for Sustainable Landscapes during of its life in order for it to ensure energy efficiency, comfort, and a healthy environment in years to come. CSL is designed to generate more energy than it produces with highly new mechanical systems that in theory are energy efficient. But, the people maintaining such systems have seemed to be left out of the equation. After construction is complete, the contractor and engineers have very little to do for the remaining 95% of the building's life. The owner and facility manager of CSL must understand how all of the building systems interact and be able to fix any problems that develop during the next 30+ years.Figure 2 shows that these people are responsible for 85% of the total costs of a building.

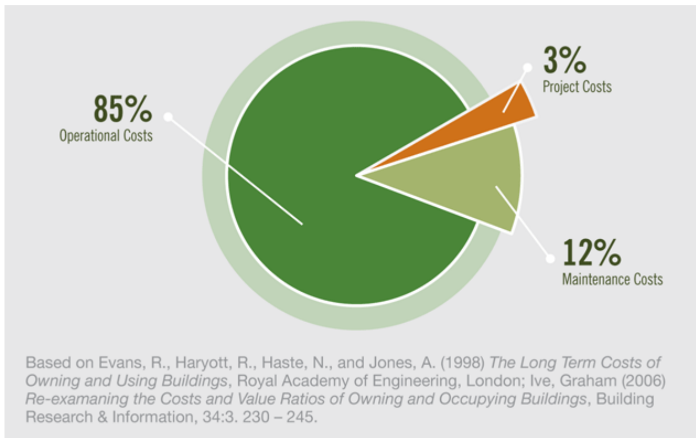

Figure 2 Life Cycle Costs of a Building

Without proper maintenance and upkeep by the existing Phipps campus operations staff, the building will not perform as designed. With its complex sequence of operations and mechanical system interdependencies, CSL's operations and maintainability is expected to be a large concern.

4.0 Depths

Mechanical system redesigns typically revolve around reducing energy and costs of a building, including adding: radiant slabs, dedicated outdoor air system (DOAS), enthalpy or heat or recovery wheel, geothermal ground source heat pump, solar / photovoltaic panels, raised floor under floor air distribution, rooftop energy recovery unit. But, the Center for Sustainable Landscapes has all of these systems within its existing design and in response was simulated to consume only 19,926 BTU/SF annually for electricity.

Alternatives considered included:

- **Green Roof Alternative**: Green roofs are an expensive initial cost and its energy savings through the thermal barrier that it creates is not proven over time. As a way to decrease costs, water sprayed on the roof which acts as an ecologically sound cooling agent could offer similar benefits at lower costs.
- **Radiant Heating Panels**: Radiant heating panels were a part of the original mechanical design of the building, as a supplemental heating system to the atrium. Due to end of project budget

issues, this supplemental system is intended to be cut. Since the atrium is planned to be minimally conditioned, yet it has a roof with 100% glazing, a redesign could investigate if these radiant heating panels were in fact needed to ensure comfort in the space.

- **Traditional Systems**: Since every mechanical system designed within the Center for Sustainable Landscapes is relatively new, a potential for a redesign would be to replace a few of these new systems with more traditional systems. While traditional system offer higher up-front costs and higher energy costs throughout a building's life, they are more common on the Phipps campus, thus, facility managers would have an easier time maintaining them. Since this could offer interesting results from an opposite perspective, it is highly unlikely that the building owner would want to increase energy costs in the future in order to make systems more familiar to facilities staff.
- **Architectural Program Change**: The Center for Sustainable Landscapes is relatively simple from a functional point of view: with only offices, conferences, and classrooms inside. The building would perform much differently if a different type of occupant was required by the architectural program. If additional energy heavy spaces including a laboratory, kitchen, data center, or climate specific greenhouse was added, it is unlikely that CSL would perform as highly as it is now expected. Since its goal and one of the main objectives of the project of achieving LEED Platinum would be more difficult with such spaces, this redesign would not fit the project.
- **Controls**: In response to the complex mechanical systems, the maintainability of CSL could be analyzed through an investigation of the sequence of operations and building automation system chosen. This alternative would streamline the controls coordination & decrease time in operations education.
- **Energy Modeling**: The current energy model discussed in Technical Report Two and Three was not able to capture all design benefits due to limitations in the simulation software. In response to these limitations and data transfers between a building information model (BIM) to a building energy model (BEM), an online web interface will be developed as a way to map all of CSL's mechanical systems to Energy Plus. A potential redesign would be to improve the energy model & metering accessibility.

Proposed depth redesigns include a spray cooled roof and hybrid geothermal system.

4.1 Spray Cooled Roof vs. Green Roof

Green roofs are an expensive initial cost and its energy savings through the thermal barrier that it creates is not proven over time. As a way to decrease costs, water sprayed on the roof, which acts as an ecologically sound cooling agent, could offer similar benefits at lower costs. In pursuit of figuring out which rooftop design would be the most energy conscious throughout its life, the green statement criterion of the owner will be relaxed.

4.2 Hybrid Geothermal System vs. Full Ground Coupled

Since every mechanical system designed within the Center for Sustainable Landscapes is relatively new, a potential for a redesign would be to replace a few of these new systems with more traditional systems. Ground source heat pumps have higher first costs than conventional systems making short-term economics unattractive. An alternative, lower cost approach for such applications can be use of a hybrid GHP design. In hybrid geothermal systems, the ground heat exchanger size is reduced and an auxiliary heat rejecter (e.g., a cooling tower or some other option) is used to handle the excess heat rejection loads during building cooling operation. This depth will analyze the function of life cycle costs vs. ground loop size.

5.0 Breadths

The two interdisciplinary breadth topics to support the spray cooled roof and hybrid geothermal system depths include electrical and construction management.

5.1 Electrical

Using DC distribution within the building could be beneficialsince the controls energy management systems are so critical to the success of it mechanical systems. Additionally, the existing photovoltaic systems have inefficiencies built as it converts DC to AC supplying power back to the grid. In a typical office building, much is already DC-Based:

- Electronic ballasts and drivers for LED Solid State lighting
- Energy management & control systems
- Adjustable speed drives for HVAC & pumping
- Computer and Information Technology Equipment
- Portable and personal electronics

To accommodate the controls system and eliminate PV inefficiency, it is proposed to study the alternative of a DC distribution system within the building. This was not to be considered as an alternative after completion but to be considered as an initial design consideration.

5.2 Construction Management, Bore Hole Optimization

The installation of a hybrid geothermal system will dramatically affect the construction schedule, installation cost, and equipment. In particular bore hole depth and corresponding bore drilling costs will presumably be reduced due to the ground heat exchanger reduction. Bore hole optimization will be analyzed and weighted to see if the proposed hybrid geothermal system is worthwhile to the owner.

6.0 Tools

Table 5 outlines tools to be used throughout the Center for Sustainability redesign.

Table 1 Redesign Tools

TOOL	DESCRIPTION
Energy Plus	EnergyPlus is a software package which "models heating, cooling, lighting, ventilating, and other energy flows as well as water in buildings. EnergyPlus is a stand-alone simulation program without a 'user friendly' graphical interface. EnergyPlus reads input and writes output as text files. Energy Plus will be the back end of the new energy modeling interface.
Design Builder	DesignBuilder is a software tool for checking building energy, carbon, lighting and comfort performance. This software will be used as an alternative to Trane TRACE and as a way to gauge the new energy modeling interface.
Trane TRACE	TRACE 700 software is the complete load, system, energy and economic analysis program that compares the energy and economic impact of such building alternatives as architectural features, HVAC systems, building utilization or scheduling and economic options. Trace was used during the initial energy model and will be referenced throughout the redesign.

7.0 Timeline

As a timeline to the outlined thesis proposal, Figure 3 shows the preliminary schedule work plan.

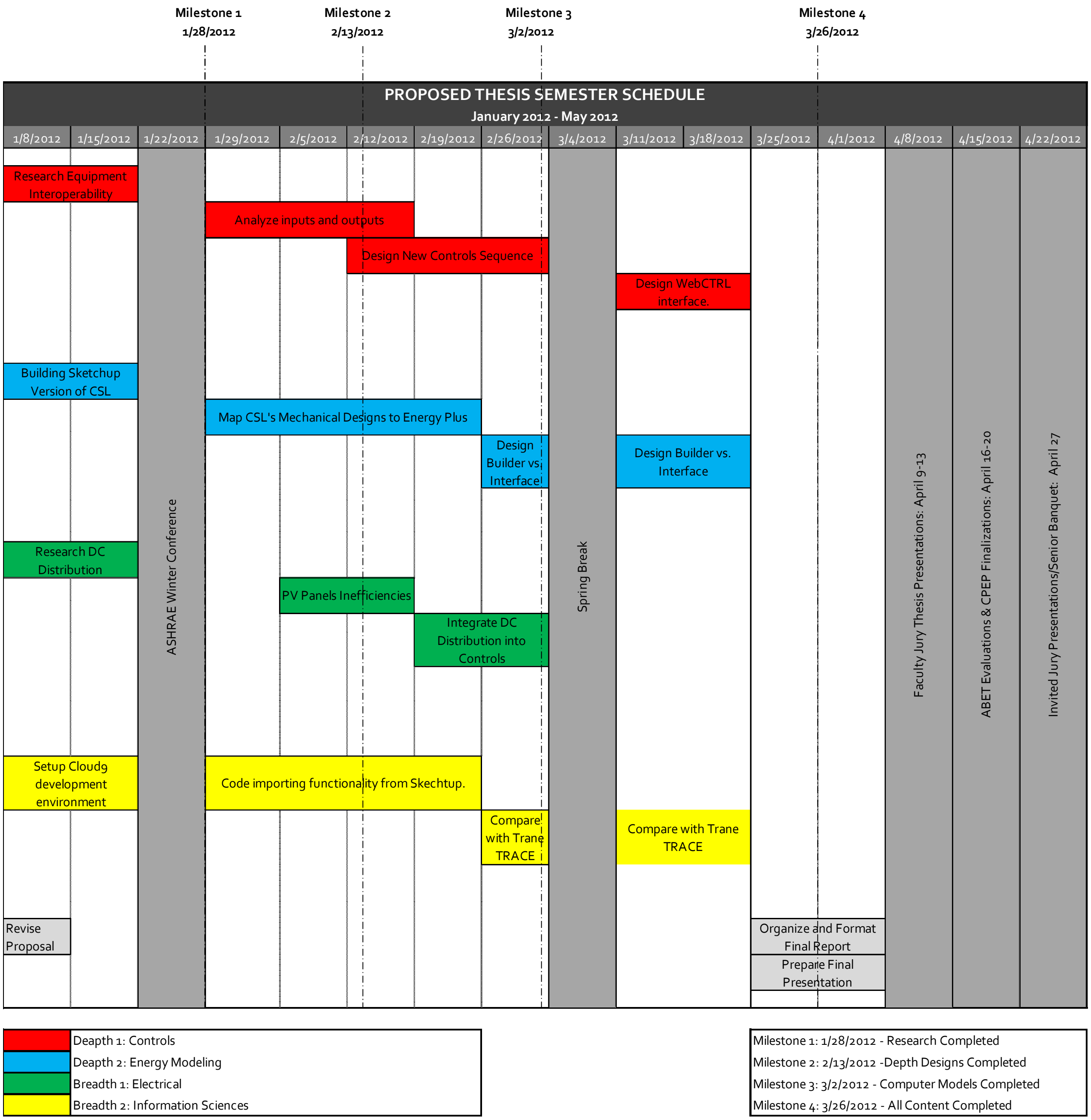

Figure 3 Proposed Schedule Timeline

8.0 Preliminary Research

Berges, Mario, “Non-intrusive Load Monitoring”, *Carnegie Mellon Technical Report.*

Chip Barnaby, “From BIM to BEM in 12 months”, *Greater Philadelphia Innovation Cluster*.

"Life-Cycle Cost Analysis (LCCA)."The Whole Building Design Guide.N.p., n.d. Web. 12 Dec. 2011. <http://www.wbdg.org/resources/lcca.

Liu, Xuesong, “Applying A Self-Managing Approach to Improve the Energy Performance in Operating and Maintaining HVAC Systems”, *Carnegie Mellon Technical Report.*

Romm, Joseph, “Lean and Clean Management”, *Sustainable Building Technical Manual*.

Rowe, Anthony, Mario Berges, Gaurav Bhatia, Ethan Goldman, Raj Rajkumar, LucioSoibelman, James Garrett, José M. F. Moura, “Sensor Andrew: Large-Scale Campus-Wide Sensing and Actuation”, *Carnegie Mellon Technical Report*, ECE-TR-08-11 2008.