PENNSTATE

architectural engineering thesis

[ashrae standard 62.1 & 90.1 compliance]

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CONTENTS

Executive Summary

Buildings must abide by numerous codes on a local, state, and national level. Among many reasons, these codes ensure accepted levels of comfort and health for its occupants. As the first technical report of three, compliance with respect to ventilation, indoor air quality, & equipment efficiencies will be analyzed.

The architectural engineering thesis building to be analyzed for this and all three technical reports is the **Phipps Center for Sustainable Landscapes (CSL).** 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 objective of this first mechanical report is to analyze the building with respect to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1 and 90.1. ASHRAE publishes standards for the purpose of establishing consensus for performance criteria for use as designers/facilitators concerned with refrigeration processes and the maintenance of indoor environments. This building is checked in compliance with 2007 published standards.

ASHRAE Standard 62.1-2007, *Ventilation for Acceptable Indoor Air Quality*, is the first standard to be evaluated.

- The **purpose** of this standard is to specify minimum ventilation rates and other means to provide acceptable indoor air quality for the building's occupants. Two of the standard's section were selected, Section 5 and Section 6. These two were selected because they are directly related to the design and specifications of the building.
- **Section 5** incorporates requirements in the building mechanical components that control indoor air quality such as outdoor intake requirements, particulate filtration, and combustion air. All requirements under Section 5 were checked against the Phipps Center for Sustainable Landscapes and were determined to be compliant.
- **Section 6** diagrams a procedure in order to calculate the minimum ventilation air that is required for acceptable indoor air quality. The rooftop air handler in the Phipps Center for Sustainable Landscapes was selected for a compliance check analysis.

ASHRAE Standard 90.1-2007, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, is the second standard to be evaluated.

- The **purpose** of this standard is to provide minimum equipment efficiencies and insulation values in order to create an energy efficient design. The Center for Sustainable Landscapes was checked against Sections 5 through 10 in this standard.

The Phipps Center for Sustainable Landscapes has submitted its application for LEED certification and is striving for LEED Platinum. This report will provide a more detailed breakdown of each section in each standard and illustrate which system parts succeed & which parts fail.

Building Overview

Name	**Phipps Conservatory, Center for Sustainable Landscapes (CSL)**   Figure 1 Location Map
Location	One Schenley Park Drive Pittsburgh, PA
Occupant	Phipps Employees / University Researchers 367 persons; 1st: 140, 2nd: 112, 3rd: 115
Function	Classroom / Office / Conference Education / Administration / Research
Size	24,350 SF: 1st: 11,209 SF, 2nd: 11,151 SF, 3rd: 1,990 SF
Floors	3 stories
Construction	Dec. 2010 - Apr. 2012
Cost	$20 million
Team	Integrated Project Delivery (IPD) required by the owner. The progressive green design would not be possible without the integrated team. During the design process, everyone was present: owner, CFO, architect, landscape architect, structural engineer, mechanical engineer, water management, process consultant, and energy consultant, all working towards a holistic solution. This was possible through a meeting called a "charrette": a collaborative working session that includes all stakeholders & generates design solutions.
Sustainability Goals	1. LEED Platinum 2. Living Building Challenge 3. SITES Certification for landscapes "The new Center for Sustainable Landscapes will be one of the world's first certified living buildings, a model of sustainability for architects, scientists, planners and anyone interested in living greener." –Richard Piacentini [Owner]

Mechanical System Overview

Heating & Cooling	A ground-source geothermal system satisfies 70% of the CSL's heating and cooling loads. Ten to fourteen geothermal wells bored 500 ft deep into the ground sink, which remains at a consistent temperature of 57 °F, create a ground source heat exchanger. In the summer, heat rejected from the CSL is dumped into water circulating through the underground loops of PEX (cross linked polyethylene) tubing which is then transferred to the cool ground. In the winter, heat stored during the summer in the geothermal wells is recovered to help heat the CSL. The geothermal system allows the heat pump to run more efficiently by creating sympathetic heat sinks. A rooftop energy recovery unit supports the geothermal system in heating, cooling, ventilation 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. Alternatively, in the winter, the desiccant wheel humidifies and pre-heats incoming cold air. By reducing incoming moisture levels comfortable indoor environments can be achieved at a higher set point of 78°F. This enables the unit's economizer feature to provide for free cooling and enhanced natural ventilation. When the economizer and desiccant wheel can no longer maintain comfort conditions, the geothermal heat pump system is automatically energized. The energy recovery unit also provides superior indoor air quality with a high performance MERV 13 air filter and UV light that reduces the microbial growth. The CSL also manages heating and cooling loads passively. A green roof is in place to provide both insulation and thermal storage to the roof of the CSL while also reducing the heat island effect. The building envelope was made of high performance wall and roof insulation as well as low-e (low emissivity) windows which increase thermal efficiency and maximize natural day lighting. A large, three story atrium at the Center for Sustainable Landscapes is 100% passively cooled. In the winter, the atrium is conditioned through passive solar strategies such as high thermal mass building materials and solar gain. 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.
Ventilating	An sensor system inside the building automatically notifies building occupants when conditions are appropriate for natural ventilation. Operable windows allow occupants to naturally ventilate administrative, educational and support spaces thus providing the building fresh ambient air. A computational fluid dynamics (CFD) analysis was conducted to determine optimal window location for natural convection. Through natural ventilation and humidity reduction a comfort setpoint of 78°F reduces the mechanical cooling load and HVAC system fan energy usage. 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. By providing only the ventilation that is needed, the DCV allows the heating and cooling systems to run more efficiently.

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. The DDC will use this information to notify occupants when natural ventilation is favorable, while also locking out mechanical systems, and at night will trigger "night purges" to draw cool, dry outside air through building spaces daytime occupancy, saving energy. Sensors and meters will also provide building managers and occupants building operating profiles and trend data to monitor energy efficiency.

ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality

62.1 Section 5: Systems & Equipment

5.1 Natural Ventilation

Despite the north western Pittsburgh location, the engineers of CSL attempted to take advantage of every natural ventilation opportunity. Operable windows were designed in administrative, educational, and support spaces to provide this natural ventilation. An expanded upper comfort temperature setpoint of 78°F instead of a typical 75°F thermostat setpoint maximizes the number of hours of natural ventilation

- **Location & Size of Openings**: A Computational Fluid Dynamics study determined optimal window location for natural airflow.
- **Control & Accessibility**: Notification system alerts building occupants when conditions are appropriate to open the windows.
- **Result**: Reduced HVAC system fan energy usage.

5.2 Ventilation Air Distribution

Specifications state that the air handling and distribution systems shall be adjusted to obtain minimum ventilation requirements for all specified spaces within the building. The ventilation air distribution system can be adjusted to achieve these minimum ventilation airflows under any load condition as required by Section 6 of ASHRAE Standard 62.1. A full analysis of Section 6 is contained later in this report.

5.3 Exhaust Duct Location

All exhaust ducts that convey potentially harmful contaminants have been specified as being negatively pressurized, and are sealed in accordance with SMACNA Seal Class A. This sealing methodology is described in *HVAC Duct Construction Standards, Metal and Flexible, 2nd Edition (1995)*. In addition, according to specification 26 22 13 – 4 :2.6A, all ventilation openings shall be protected against falling dirt.

5.4 Ventilation System Controls

The mechanical ventilation of the building is supplied via a rooftop outside air handling unit.

- Supply Fan VFD - Variable Supply Air & soft start. The VFD to be used in order to maintain the constant air volume as the percentage of OA is increased or decreased, which is affected by internal/external static pressure.
- Exhaust Fan VFD - Varies based on OA & RA bypass airflow amounts required. While allowing the system to provide Maximum Outside Air loads without exceeding the design guidelines. Exhaust fan CFM stated does not include energy wheel purge cfm. A min and max purge cfm will be stated on the submittals as to how much more cfm is added during operation.
- All components mentioned above will be powered by the Berner Energy control panel, but are to be controlled by the BMS, unless noted "By BERI" which means Berner Energy will control it via the main control panel. Otherwise, the control wires will be wired to a terminal strip at the single point power control panel location.

Demand Controlled Ventilation (DCV)

- Uses CO_2 sensors located in the classroom, conference rooms, and office areas to match the amount of ventilation air required to the occupancy level
- Values are utilized by the AHU controller to provide sufficient outdoor air
- At less than full building occupancy, the DCV system reduces ventilation air volume, and thus reduces energy required to heat or cool and dehumidify the ventilation air

Building Management System Hardware & Software Configuration

- Mechanical & electrical engineers were involved in the design of this advanced building management system requiring TCP/IP protocol & access through a web browser.
- From specification 23 09 00 – 20: Q3b3: Figure 2 below details an example of necessary data points in the BAS database. These data points will serve as data values to be used as setpoints in the building control systems for values such as minimum outside air levels, overall ventilation rates, humidity levels, and others as indicated in the specification or on the drawings.

	Hardware Points				Software Points					
Point Name	AI	AO	BI	BO	AV	BV	Sched	Trend	Alarm	Show On Graphic
Space Temperature	×							×	X	×
SpaceSetpoint Adjust	×						×	×		×
Override Button Status			×							×
Space CO2	×							×	X	×
Diffuser damper		×						×		×
Totals	3	1	1	0	0	0	1	4	2	5

Total Hardware (5 per zone) Total Software (7 per zone)

Figure 2 Building Management System Hardware & Software Points Example

5.5 Airstream Surfaces

Specifications state that duct fabrication shall be "in accordance with SMACNA HVAC Duct Construction Standards", which specifies an acceptable resistance to both mold growth and erosion. In addition, it is noted that the insulation inside of energy recovery ventilators, ground source heat pumps, water source heat pumps, and make-up air units meets the air erosion and mold growth limits of UL-181.

5.6 Outdoor Air Intakes

All of the outdoor air intakes on the CSL (including operable windows) are located such that the shortest distance from the intake to any specific potential outdoor contaminant source is greater than the separation distance listed in Table 5-1 of ASHRAE Standard 62.1, shown below as Figure 3. Specification 26 22 13 – 4: 2.9 notes that ventilated outdoor units must provide suitable weather shields over ventilation openings.

Object	Minimum Distance, ft (m)
Significantly contaminated exhaust (Note 1)	15 (5)
Noxious or dangerous exhaust (Notes 2 and 3)	30 (10)
Vents, chimneys, and flues from combustion appliances and equipment (Note 4)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 5)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 5)	25 (7.5)
Driveway, street, or parking place (Note 5)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 6 and 7)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Note 1: Significantly contaminated exhaust is exhaust air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor.
Note 2: Laboratory fume hood exhaust air outlets shall be in compliance with NFPA 45-1991[3] and ANSI/AIHA Z9.5-1992.[4]
Note 3: Noxious or dangerous exhaust is exhaust air with highly objectionable fumes or gases and/or exhaust air with potentially dangerous particles, bioaerosols, or gases at concentrations high enough to be considered harmful. Information on separation criteria for industrial environments can be found in the ACGIH Industrial Ventilation Manual [5] and in the *ASHRAE Handbook—HVAC Applications*.[6]
Note 4: Shorter separation distances are permitted when determined in accordance with (a) Chapter 7 of ANSI Z223.1/NFPA 54-2002[7] for fuel gas burning appliances and equipment; (b) Chapter 6 of NFPA 31-2001[8] for oil burning appliances and equipment, or (c) Chapter 7 of NFPA 211-2003[9] for other combustion appliances and equipment.
Note 5: Distance measured to closest place that vehicle exhaust is likely to be located.
Note 6: No minimum separation distance applies to surfaces that are sloped more than 45 degrees from horizontal or that are less than 1 in. (3 cm) wide.
Note 7: Where snow accumulation is expected, distance listed shall be increased by the expected average snow depth.

Figure 3 Air Intake Minimum Separation Distance

5.7 Local Capture of Contaminants

CSL does not have any non-combustion equipment that produces contaminants, thus section 5.7 is inapplicable.

5.8 Combustion Air

In compliance with section 5.8, all combustion producing processes are designed to expend the proper amount of combustion air, and are vented directly outdoors.

5.9 Particulate Matter Removal

Filters are required to be rated MERV 6 or above to be placed upstream of all cooling coils and wetted surfaces. In compliance with section 5.9, filters for CSL are detailed below.

- Filter Racks: Bolt-on rack constructed of not less than 0.080 inch thick aluminum; with hinged side access door and snap fasteners.
- Pre-Filter: Farr 30-30 MERV 8 pleated filters, two inches thick on Outside Air Inlet , RA-typical & RA toilet exhaust.
- Filter Removal Hooks: Means to remove filters that are not immediately accessible from exterior of ERU.
- Final Filter Module:
    - Housing: Provide Farr 3P Glide Pack housing in supply air plenum.
    - Final Filter: Farr DURAFIL ES mini pleated V-Bank 12" 85% MERV 13
    - Filters: Provide one set of replacement filters for pre-filter for OA, RA-typical & RA toilet exhaust.

5.10 Dehumidification Systems

The building management system is specified to enable the dehumidification mode to maintain the supply air relative humidity setpoint at 50%.

Desiccant Dehumidification

- Desiccant wheel utilizes energy that would otherwise be exhausted to pre-treat temperature and moisture in incoming outside air with minimal energy use and without mechanical refrigeration
- Reduces moisture levels and humidity control of the air & allows for a higher comfortable indoor temperature setpoint of 78°F
- Enables economizer feature to provide for free cooling and enhanced natural ventilation
- Geothermal heat pump system in conjunction with the Rooftop Energy Recovery Unit to provide heating, cooling, ventilation, and dehumidification is energized when economizer and desiccant wheel cannot maintain comfort conditions due to extremes in outside weather conditions

5.11 Drain Pans

In accordance with section 5.11, CSL's drain pans are sealed, sloped, and have outlets at the lowest location. Specifications notes:

- Drain Pan: Minimum 3 inches deep and no less than 29 inches long per coil, and sloped for drainage.
- Drain: Provide 3 inch minimum diameter drain.

- Drain Line: Provide 1-1/2 inch diameter minimum drain line without P-trap and stubbed to exterior of ERU for field-provided P-trap and continuation of drain line.

5.12 Finned-Tube Coils & Heat Exchangers

A drain pan has been provided and correctly placed beneath all dehumidifying cooling coil assemblies and all condensate-producing heat exchangers. The distance between coils is 18 inches to allow access to coil inlet face for cleaning which is compliant with section 5.12.

5.13 Humidifiers & Water-Spray Systems

Section 5.13 is not applicable because CSL does not utilize any humidifiers or water-spray systems.

5.14 Access for Inspection, Cleaning, & Maintenance

Equipment access doors have been sized and located appropriately and all of the proper equipment clearances have been met. These access doors and clearances provide unobstructed access for inspection, cleaning, and routine maintenance for all applicable equipment in conformance with section 5.14.

5.15 Building Envelope & Interior Surfaces

The construction of the building envelope includes proper vapor barrier to avoid liquid water penetration into the building. All interior surfaces are insulated properly to prevent condensation from forming on the exterior surfaces and within the insulating material.

Robust Building Envelope

- Provides optimal energy efficiency
- Building envelope reduces thermal heating losses and solar cooling loads, and maximizes natural daylighting
- High performance wall and roof insulation reduce winter heat losses and summer heat gains
- High performance, low-e (low-emissivity) windows provide state-of-the-art solar and thermal control and energy efficiency, while admitting maximum daylight

The atrium is covered by TPO Thermal Plastic Olefin. The green roof takes up the majority of the roof (with the exception of the energy recovery unit). This roofing membrane is similar to TPO and is applied to the concrete, followed by soil, plants.

5.16 Buildings with Attached Parking Garages

CSL does not have attached parking garages, thus section 5.16 is not applicable.

5.17 Air Classification for Recirculation

Being an office/education building, CSL is categorized as Class 1 air classification for recirculation. Thus, air can be recirculated or transferred to any space because it has a low contaminant concentration, low sensory-irritation intensity, and inoffensive odor.

5.18 ETS Areas & ETS-Free Areas

CSL is a non-smoking facility, and therefore does not have any environmental tobacco smoke areas, thus, section 5.18 is not applicable.

62.1 Section 6: Ventilation Rate Procedures

Section 6 of ASHRAE Standard 62.1 outlines what is known as the Ventilation Rate Procedure, which is used to design each ventilation system in a building. The Ventilation Rate Procedure is "a prescriptive procedure in which outdoor air intake rates are determined based on space type/application, occupancy level, and floor area", and is subject to a number of considerations and restrictions.

The entire mechanical ventilation system of CSL was looked at for this study. These ventilation systems include an energy recovery unit and demand controlled ventilation. Natural ventilation considerations are compliant with Section 5.1, and will not be considered in this Section 6 analysis. Outdoor air quality at the site has been classified as acceptable in accordance to section 4.

The following calculations come directly from Section 6 of ASHRAE Standard 62.1, and are used to calculate compliance with Section 6:

Breathing Zone Outdoor Airflow (V_{bz}):
$V_{bz} = R_p \cdot P_z + R_a \cdot A_z$

where
A_z = zone floor area: the net occupiable floor area of the zone (ft_2)
P_z = zone population: the largest number of people expected to occupy the zone during typical usage
R_p = outdoor airflow rate required per person as determined from ASHRAE Standard 62.1 Table 6.1 (cfm/person)
R_a = outdoor airflow rate required per unit area as determined from ASHRAE Standard 62.1 Table 6.1 (cfm/ft_2)

Zone Air Distribution Effectiveness (E_z) as determined by ASHRAE Standard 62.1 Table 6.2:
$E_z = 1$

Zone Outdoor Airflow (V_{oz}):
$V_{oz} = V_{bz} / E_z$

Outdoor Air Intake Flow (V_{ot}) for makeup air units:
$V_{ot} = V_{oz}$

Outdoor Air Intake Flow (V_{ot}) for outside air units:
$V_{ot} = \Sigma_{all\ zones} V_{oz}$

Primary Outdoor Air Fraction (Z_p):
$Z_p = V_{oz} / V_{pz}$

where V_{pz} = zone primary airflow (mixed air). For VAV systems, V_{pz} is the minimum expected primary airflow for design purposes.

System Ventilation Efficiency (E_v) as determined using ASHRAE Standard 62.1 Table 6.3:
$E_v = 1$

ASHRAE Standard 62.1 Users Manual includes a Microsoft Excel based spreadsheet that computes ASHRAE Standard 62.1 Section 6 compliance based on inputs including room square footage, room occupancy type, and room supply air. This spreadsheet was used to analyze CSL's ventilation system with the result that the school was Standard 62.1 Section 6 compliant. This calculation can be found in Appendix A.

62.1 Summary

The mechanical design of the Center for Sustainability surpasses the requirements of Section 5 where the Section is applicable. The Center for Sustainability is applying for LEED certification, which dramatically effects the design considerations from day one. The collaborative efforts used to achieve this progressive green design have been proven to to be successful at this stage of the analysis, as nearly every part of section 5 is compliant. The most impressive of these include the innovative natural ventilation system and advanced controls system.

The minimum ventilation requirements of Section 6 are met, sometimes exceeded, and sometimes not met in the design of Center for Sustainability. The 1st floor classroom, storage, work area, mechanical room, education storage, reception, and work room unfortunately do not me the standard for minimum outdoor air (the worst of which by -56% is the storage). Further details are outlined in Appendix A1. Overall, the ventilated environment within the the CSL building meets standards set forth in 62.1

ASHRAE Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings

90.1 Section 5: Building Envelope

5.1.4 Climate Zone

The Phipps Center for Sustainable Landscapes is located in Pittsburgh, PA. As seen in Figure 4 below, the complex is located in climate zone 5A. The climate in this zone is described as cool – humid.

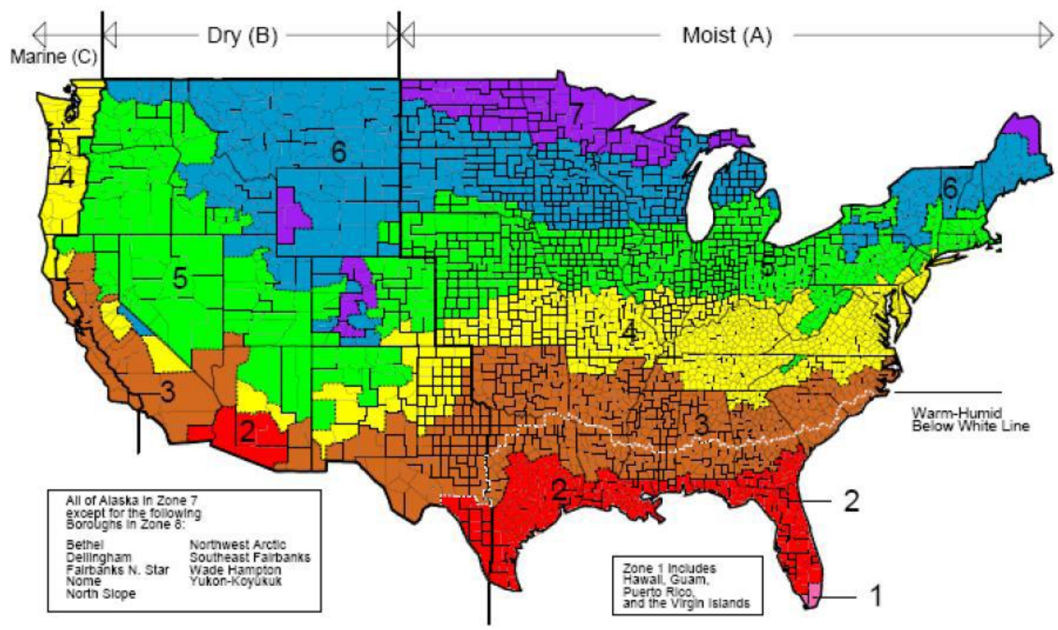

Figure 4 ASHRAE 90.1 Climate Zone Map

5.2 Compliance Paths

Vertical fenestration area: 34%
Skylight fenestrations area: less than 1%,
Because these areas are less than 40% and 5%, respectively, the building is able to follow the Prescriptive Building Envelope Compliance Path specified in section 5.5 of Standard 90.1.

5.4 Mandatory Provisions

The main building entrance of CSL has a vestibule that meets the minimum requirements of 7 feet between exterior and interior doors.   The building envelope is specified to be sealed where all precast panels and windows meet. Providing a building envelope that minimizes air leakage will help to significantly reduce the building energy cost.

5.5 Prescriptive Building Envelope

To analyze the building envelope requirements, the Prescriptive Building Envelope Option was utilized. The requirements for construction in climate zone 5A are located from Standard 90.1 – 2007 is located in ASHRAE 90.1 section 5.5. As seen in Figure 5 below, CSL complies with the maximum vertical fenestration allowable, 40%, in zone 5A. Figure 6 outlines the minimum building material insulation and minimum glazing information for the CSL.

Glazing Area [ft2]	Wall Area [ft2]	Percentage Glazing = glazing/wall	Compliance < 40% (Y/N)
4,317	12,698	34%	Y

Figure 5 Building Glazing/Window Area

Area	Maximum U-Value	Actual U-Value	Compliance (Y/N)
Roof	U-0.048	U-0.042	Y
Walls Above Grade	U-0.104	U-0.101	Y
Windows	U-0.55	U-0.41	Y
Floors	U-0.087	U-0.082	Y

Figure 6 Building & Glazing Materials Properties

90.1 Section 6: Heating, Ventilating, and Air Conditioning

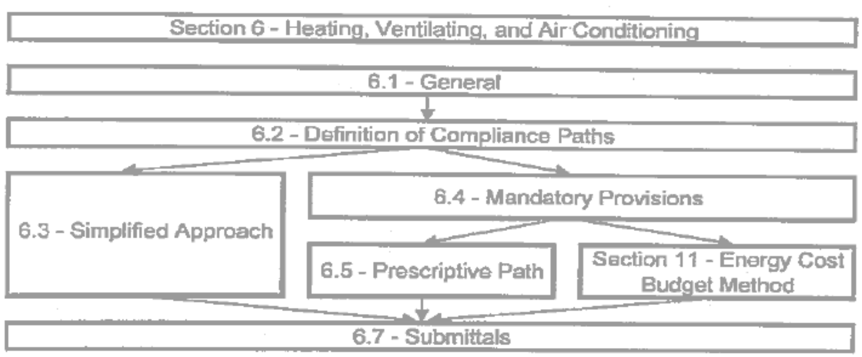

Figure 7 ASHRAE 90.1 Section 6 Outline

6.2 Compliance Path

As noted in Figure 7 above, there are two options to evaluate the efficiency of a buildings HVAC system, the simplified approach (6.3) and the prescriptive path (6.5). The prescriptive path was used for this evaluation because CSL will be over the maximum two story requirement as stated in order to use the simplified approach.

6.4 Mandatory Provisions

All HVAC load calculations are completed based on the requirements from section 6.4.2. Table 6.8.1 B in Standard 90.1-2007 provide minimum performance requirements that must be met for the mechanical equipment in CSL. HVAC controls have been located in most zones to provide occupant comfort and space adjustability. The ventilation rate in some occupancy zones is able to be setback during unoccupied hours, but this is not applicable to all HVAC zones.

Equip. No.	Purpose	HP	Speed [RPM]		MIN Efficiency	Compliance (Y/N)
EF-1	Elevator Mer	1/20	1550			Y
P-1	Geothermal End Suction	2	1750	90°F EWT 79.9° LWT 65.6° WB	3.1 COP	Y
P-1	Geothermal End Suction	2	1750	90°F EWT 79.9° LWT 65.6° WB	3.1 COP	Y

Figure 8 ASHRAE Minimum Equipment Efficiency vs. Actual Efficiency

TABLE 6.8.1B Electrically Operated Unitary and Applied Heat Pumps— Minimum Efficiency Requirements *(continued)*

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum Efficiency[a]	Test Procedure[b]
Air cooled (heating mode)	≥65,000 Btu/h and <135,000 Btu/h (cooling capacity)	—	47°F db/43°F wb outdoor air	3.2 COP (before 1/1/2010) 3.3 COP (as of 1/1/2010)	ARI 340/ 360
			17°F db/15°F wb outdoor air	2.2 COP	
	≥135,000 Btu/h (cooling capacity)	—	47°F db/43°F wb outdoor air	3.1 COP (before 1/1/2010) 3.2 COP (as of 1/1/2010)	
			17°F db/15°F wb outdoor air	2.0 COP	
Water source (heating mode)	<135,000 Btu/h (cooling capacity)	—	68°F entering water	4.2 COP	ISO-13256-1
Groundwater source (heating mode)	<135,000 Btu/h (cooling capacity)	—	50°F entering water	3.6 COP	ISO-13256-1
Ground source (heating mode)	<135,000 Btu/h (cooling capacity)	—	32°F entering water	3.1 COP	ISO-13256-1

[a] IPLVs and part-load rating conditions are only applicable to equipment with capacity modulation.
[b] Section 12 contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.
[c] Single-phase, air-cooled heat pumps <65,000 Btu/h are regulated by NAECA. SEER and HSPF values are those set by NAECA

Figure 9 ASHRAE 90.1 Table 6.8.1 B

6.5.2 Zone Controls

In compliance with Section 6.5.2, zone thermostatic controls are capable of "operating in sequence the supply of heating and cooling energy to the zone". This allows certain heat pumps to utilize reheat after air is dehumidified by the condensing units. In most cases, this section is irrelevant due to the fact that the air is dehumidified via desiccant wheels.

6.5.4 Hydronic System Design and Control

Standard 6.5.4 specifies that "HVAC hydronic systems having a total *pump system power* exceeding 10hp shall meet provisions of Sections 6.5.4.1 through 6.5.4.4". Figure 2 , below, shows that the CSL ground source heat pump motors are both under 50 hp, and thus are not subject to the requirements set forth in Section 6.5.4.1.

Mark	Service	Efficiency	GPM	Head (ft)	HP
P-1	Heat Pump Loop	93.0%	1750	50	2
P-1	Heat Pump Loop	93.0%	1750	50	2

Figure 10 Ground Source Heat Pumps

6.5.5.2 Fan Speed Control

Section 6.5.5.2 specifies that "each fan powered by a motor of 7.5 hp or larger shall have the capability to operate that fan at two-thirds of full speed or less and shall have controls that automatically change the fan speed to control the leaving fluid temperature or condensing temperature/pressure of the heat rejection device". The heat pumps (which ultimately exchange heat with the ground) specified for CSL are rated at 2hp / motor, it is exempt from this section for unique and small scale geothermal design.

6.5.6 Energy Recovery

CSL utilizes a rooftop energy recovery unit in the northeast corner of the building. The unit has a capacity greater than 5000 cfm, so they must use exhaust energy recover as stated in section 6.5.6.1. The exhaust air energy recovery system must be at least 50% effective in the transfer of enthalpy between air streams. The energy recovery system is 93% efficient which qualifies as being complaint.

6.5.6.2 Heat Recovery for Service Water Heating

Section 6.5.6.2 states that "condenser heat recovery systems shall be installed for heating or preheating of service hot water" if the implied building has a specific set of characteristics. Among these defined characteristics is that the building must be a 24-hour facility. Because CSL is not open 24 hours a day, it is exempt from this section of the standard.

6.5.8.2 Radiant Heating Enclosed Spaces

Radiant heating panels used in the CSL atrium as supplemental enclosed space heating, which are typically disabled, are in conformance with the governing provisions of this standard.

6.7 Submittals

Construction documents, operation and maintenance manuals, and submittals were turned over to the owner at the completion of construction. Commissioning was and will be continued to be performed on the complex. The initial commissioning was done due to LEED perquisite requirements.

90.1 Section 7: Service Water Heating

Section 7 of ASHRAE Standard 90.1-2007 evaluates service water heating requirements for additions to existing buildings and new buildings. The heating hot water system and equipment for new building construction must comply with section 7.2. Domestic hot water in CSL is supplied by an electric water heater detailed in Figure 11.

Type	Number of Elements	Fuel	Input (kW)	Storage Capacity (Gal)	Recovery (100F dx T GPH)	Compliance
Water Heater	1	Electricity	1.5	10	6	Achieved

Figure 11 Electric Water Heater

Section 7 of ASHRAE Standard 90.1-2007 specifies minimum efficiencies for water heating equipment as being 80%. Because the direct efficiency of electrical heaters is assumed to be 100%, they will be ignored from this analysis.

TABLE 7.8 Performance Requirements for Water Heating Equipment

Equipment Type	Size Category (Input)	Subcategory or Rating Condition	Performance Required [a]	Test Procedure[b]
Electric water heaters	≤12 kW	Resistance ≥20 gal	0.93–0.00132V EF	DOE 10 CFR Part 430
	>12 kW	Resistance ≥20 gal	$20 + 35\sqrt{V}$ SL, Btu/h	ANSI Z21.10.3
	≤24 Amps and ≤250 Volts	Heat Pump	0.93–0.00132V EF	DOE 10 CFR Part 430

Figure 12 ASHRAE 90.1 Table 7.8 Performance Requirements

90.1 Section 8: Power

Section 8 outlines requirements for the building's power distribution system. Feeder conductors shall be sized for a maximum voltage drop of 2% design load and branch circuit conductors shall be sized for a maximum voltage drop of 3% design load. The electrical engineer designed the CSL to adhere to this standard, so the complex is assumed to be compliant with this section.

90.1 Section 9: Lighting

ASHRAE 90.1 Section9 applies to all interior and exterior lighting systems of CSL and follows the outline in Figure 13.

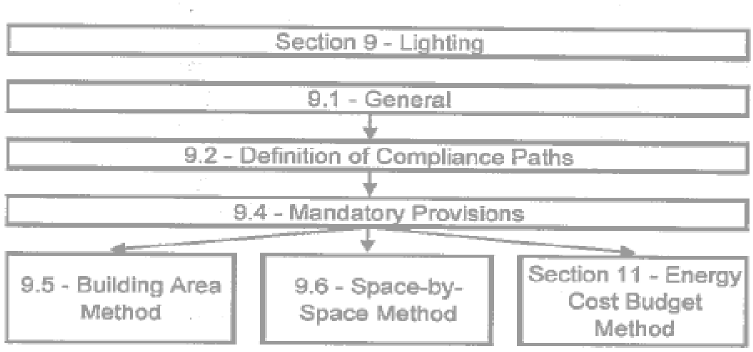

Figure 13 ASHRAE Section 9 Outline

9.4.1.1, Automatic Lighting Shutoff

States that "interior lighting in buildings larger than 5000 ft$_2$ shall be controlled with an automatic control device to shut off building lighting in all spaces". Specification section 26 27 26 -1.3-B states that "Occupancy sensors with automatic control shall be certified for operation with specific ballasts utilized in controlled lighting fixtures." This specification satisfies the requirements set forth in Section 9.4.1.1.

9.5 Building Area Method Compliance Path

Table 9.5.1 within Standard 90.1-2007 (referenced in Appendix A5) lists lighting power densities for various building area types. Since CSL is an office building, the maximum lighting power density for an office building is 1.0 W/ft$_2$. The building interior lighting is mainly 4' T8 or T540 Direct/Indirect Pendant Mounted Fixture with High Efficiency Ecosystem Dimming Ballast or various forms of LEDs.

90.1 Section 10: Other Equipment

From Table 10.8 of ASHRAE 90.1 – 2007, all motors met the criteria set forth in, "Minimum Nominal Efficiency for General Purpose Design A and Design B Motors."

90.1 Section 11: Energy Cost Budget Method

Section 11 describes how to use building modeling to determine if the structure meets the energy cost budget. Technical assignment three will illustrate this in further detail.

90.1 Summary

The CSL building was compatible with Standard 90.1 – 2007 for the majority of sections The use of more progressive designs such as an Energy Recovery Ventilator, Geothermal heat source, and radiant heating requires that CSL abides by additional standards, resulting in extra up front money, but benefiting the costs of energy throughout its life dramatically. Each additional system is compliant with ASHRAE 90.1 standards. The non-compliant fields only make up a fraction of the total building system. Explanations for non-conformity could be due to human error in calculations and/or errors with equipment specifications. Inaccuracies will be determined in technical report 2, which will include energy modeling for the entire building. It will be interesting to see if this building can perform as well as it is intended to.

Appendix

[A1] Minimum Ventilation Calculations

Setup

	IP		SI		Default Occupant Density
Function	Rp (cfm/per)	Ra (cfm/ft2)	Rp (L/s-per)	Ra (L/s-m2)	#/1000 ft2 (#/1000 m2)
Classrooms (age 9 plus)	10	0.12	5	0.6	35
Conference/meeting	5	0.06	2.5	0.3	50
Corridors	0	0.06	0	0.3	0
Electrical Room	0	0.06	0	0.3	0
Main entrance Lobby	5	0.06	2.5	0.3	10
Office Space	5	0.06	2.5	0.3	5
Reception Areas	5	0.06	2.5	0.3	30
Storage Rooms	0	0.12	0	0.6	0

Phipps Conservatory

ASHRAE 62.1 2004 Minimum Ventilation Calculations

Zone Identification				ASHRAE Standard 62.1 2004																
Room Name	Room Number	Location	Occupancy Category	Area (SF)	Time Averaging Required?	Volume (CF)	People O.A. Rate (cfm/person)	Area O.A. Rate (cfm/SF)	# of Occupants per furniture plan	Breathing Zone O.A. Flow Required per furniture plan (cfm)	Averaging Time Period (min)	FTE # of Occupants	Effective # of Occupants	Breathing Zone O.A. Flow Required Vbz (cfm)	Table 6-2 Zone Air Dist. Eff. Ez	Table 6.3 System Vent. Eff. Ev	Zone Primary Air Flow Vpz (cfm)	Actual O.A. Flow 19.4% O.A.	% Above Min OA	Meets Standard?
Classroom	102	1st Floor	Classroom (age 9 plus)	1273	No	-	10	0.12	30	453	-	-	30	453	1.0	1.00	2090	404.5	-11%	**No**
Storage	102A	1st Floor	Storage	110	No	-	0	0.12	0	13	-	-	0	13	1.0	1.00	30	5.8	-56%	**No**
Volunteer Area	104	1st Floor	Office Space	400	Yes	4264	5	0.06	8	64	200	4	4	44	1.0	1.00	480	92.9	111%	**Yes**
Phone Booth	105	1st Floor	Office Space	64	No	-	5	0.06	0	4	-	-	0	4	1.0	1.00	30	5.8	51%	**Yes**
Research Open Office Area	107	1st Floor	Office Space	2042	No	-	5	0.06	24	243	-	-	24	243	1.0	1.00	2525	488.7	102%	**Yes**
Conference Room	108	1st Floor	Conference/meeting	219	Yes	2336	5	0.06	4	33	211	2	2	23	1.0	1.00	180	34.8	51%	**Yes**
Work Area	109	1st Floor	Office Space	117	Yes	1112	5	0.06	2	17	196	1	1	12	1.0	1.00	50	9.7	-19%	**No**
Break Room	110	1st Floor	Conference/meeting	400	Yes	4264	5	0.06	16	104	123	5	5	49	1.0	1.00	950	183.9	275%	**Yes**
Mechanical Room	112	1st Floor	Storage	330	No	-	0	0.12	0	40	-	-	0	40	1.0	1.00	100	19.4	-51%	**No**
Education Storage	113	1st Floor	Storage	328	No	-	0	0.12	0	39	-	-	0	39	1.0	1.00	175	33.9	-14%	**No**
Jan.	116	1st Floor	Storage	12	No	-	0	0.12	0	1	-	-	0	1	1.0	1.00	75	14.5	908%	**Yes**
Conference Room 2	201	2nd Floor	Conference/meeting	247	Yes	2511	5	0.06	8	55	137	3	3	30	1.0	1.00	260	50.3	69%	**Yes**
Conference Room 1	202	2nd Floor	Conference/meeting	596	Yes	6060	5	0.06	18	126	145	6	6	66	1.0	1.00	1260	243.9	271%	**Yes**
Reception	203	2nd Floor	Reception	306	No	-	5	0.06	1	23	-	-	1	23	1.0	1.00	100	19.4	-17%	**No**
Open Office	204	2nd Floor	Office Space	4875	No	-	5	0.06	65	618	-	-	65	618	1.0	1.00	4860	940.6	52%	**Yes**
Break Out Area	205	2nd Floor	Conference/meeting	372	Yes	3966	5	0.06	8	62	191	4	4	42	1.0	1.00	1000	193.5	357%	**Yes**
Conference Room 3	206	2nd Floor	Conference/meeting	194	Yes	1972	5	0.06	5	37	161	2	2	22	1.0	1.00	300	58.1	168%	**Yes**
Work Room	207	2nd Floor	Office Space	248	Yes	2976	5	0.06	2	25	359	2	2	25	1.0	1.00	100	19.4	-22%	**No**
Secure Files	209	2nd Floor	Storage	162	No	-	0	0.12	0	19	-	-	0	19	1.0	1.00	50	9.7	-50%	**No**
Jan.	211	2nd Floor	Storage	13	No	-	0	0.12	0	2	-	-	0	2	1.0	1.00	75	14.5	831%	**Yes**
Total										**1977**							**14690**	2843.2		**Yes**

[A2] Minimum Ventilation Compliance Check 1

Design Occupancy per IBC 2009					62.1 Section 6	
Floor	Function	Area (SF)	Floor Area per Occupant	Design Occupancy	cfm/SF	cfm/person
1	Accesory Storage Areas, Mechanical Equipment Room	905	300	3	-	0.12
1	Assembly without Fixed Seats - Unconcentrated	539	15	36	7.5	0.06
1	Business Area	3725	100	37	5	0.06
1	Educational - Classroom Area	1282	20	64	7.5	0.06
1	TOTAL	6451		140		
2	Business Area	11174	100	112	5	0.06
2	TOTAL	11174		112		
3	Assembly without fixed seats - concentrated	807	7	115	7.5	0.06
3	TOTAL	807		115		
all	GRAND TOTAL Occupied Space	18432		367		

Note: Design occupancy per IBC 2009.

[A3] Fan Power Limitation Reference

TABLE 6.5.3.1.1A Fan Power Limitation[a]

	Limit	Constant Volume	Variable Volume
Option 1: Fan System Motor Nameplate hp	Allowable Nameplate Motor hp	$hp \le CFM_S \cdot 0.0011$	$hp \le CFM_S \cdot 0.0015$
Option 2: Fan System bhp	Allowable Fan System bhp	$bhp \le CFM_S \cdot 0.00094 + A$	$bhp \le CFM_S \cdot 0.0013 + A$

[a] where
CFM_S = the maximum design supply airflow rate to conditioned spaces served by the system in cubic feet per minute
hp = the maximum combined motor nameplate horsepower
bhp = the maximum combined fan brake horsepower
A = sum of $(PD \times CFM_D/4131)$
where
PD = each applicable pressure drop adjustment from Table 6.5.3.1.1B in in. w.c.
CFM_D = the design airflow through each applicable device from Table 6.5.3.1.1B in cubic feet per minute

TABLE 6.5.3.1.1B Fan Power Limitation Pressure Drop Adjustment

Device	Adjustment
Credits	
Fully ducted return and/or exhaust air systems	0.5 in. w.c.
Return and/or exhaust airflow control devices	0.5 in. w.c.
Exhaust filters, scrubbers, or other exhaust treatment	The pressure drop of device calculated at fan system design condition
Particulate Filtration Credit: MERV 9 through 12	0.5 in. w.c.
Particulate Filtration Credit: MERV 13 through 15	0.9 in. w.c.
Particulate Filtration Credit: MERV 16 and greater and electronically enhanced filters	Pressure drop calculated at 2× clean filter pressure drop at fan system design condition
Carbon and other gas-phase air cleaners	Clean filter pressure drop at fan system design condition
Heat recovery device	Pressure drop of device at fan system design condition
Evaporative humidifier/cooler in series with another cooling coil	Pressure drop of device at fan system design condition
Sound Attenuation Section	0.15 in. w.c.
Deductions	
Fume Hood Exhaust Exception (required if 6.5.3.1.1 Exception [c] is taken)	–1.0 in. w.c.

[A4] Building Envelope Requirements for Climate Zone 5A

TABLE 5.5-5 Building Envelope Requirements For Climate Zone 5 (A, B, C)*

Opaque Elements	Nonresidential Assembly Maximum	Nonresidential Insulation Min. R-Value	Residential Assembly Maximum	Residential Insulation Min. R-Value	Semiheated Assembly Maximum	Semiheated Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.119	R-7.6 c.i.
Metal Building	U-0.065	R-19.0	U-0.065	R-19.0	U-0.097	R-10.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.053	R-19.0
Walls, Above-Grade						
Mass	U-0.090	R-11.4 c.i.	U-0.080	R-13.3 c.i.	U-0.151[a]	R-5.7 c.i.[a]
Metal Building	U-0.113	R-13.0	U-0.057	R-13.0 + R-13.0	U-0.123	R-11.0
Steel-Framed	U-0.064	R-13.0 + R-7.5 c.i.	U-0.064	R-13.0 + R-7.5 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.064	R-13.0 + R-3.8 c.i.	U-0.051	R-13.0 + R-7.5 c.i.	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-0.119	R-7.5 c.i.	C-0.119	R-7.5 c.i.	C-1.140	NR
Floors						
Mass	U-0.074	R-10.4 c.i.	U-0.064	R-12.5 c.i.	U-0.137	R-4.2 c.i.
Steel-Joist	U-0.038	R-30.0	U-0.038	R-30.0	U-0.052	R-19.0
Wood-Framed and Other	U-0.033	R-30.0	U-0.033	R-30.0	U-0.051	R-19.0
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.540	R-10 for 24 in.	F-0.730	NR
Heated	F-0.860	R-15 for 24 in.	F-0.860	R-15 for 24 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.500		U-0.700	
Nonswinging	U-0.500		U-0.500		U-1.450	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Glazing, % of Wall						
Nonmetal framing (all)[b]	U-0.35	SHGC-0.40 all	U-0.35	SHGC-0.40 all	U-1.20	SHGC-NR all
Metal framing (curtainwall/storefront)[c]	U-0.45		U-0.45		U-1.20	
Metal framing (entrance door)[c]	U-0.80		U-0.80		U-1.20	
Metal framing (all other)[c]	U-0.55		U-0.55		U-1.20	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}-1.17	$SHGC_{all}$-0.49	U_{all}-1.17	$SHGC_{all}$-0.49	U_{all}-1.98	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.17	$SHGC_{all}$-0.39	U_{all}-1.17	$SHGC_{all}$-0.39	U_{all}-1.98	$SHGC_{all}$-NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}-1.10	$SHGC_{all}$-0.77	U_{all}-1.10	$SHGC_{all}$-0.77	U_{all}-1.90	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.10	$SHGC_{all}$-0.62	U_{all}-1.10	$SHGC_{all}$-0.62	U_{all}-1.90	$SHGC_{all}$-NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-1.36	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.69	$SHGC_{all}$-0.39	U_{all}-0.69	$SHGC_{all}$-0.39	U_{all}-1.36	$SHGC_{all}$-NR

*The following definitions apply: c.i. = continuous insulation (see Section 3.2), NR = no (insulation) requirement.
[a]Exception to Section A3.1.3.1 applies.
[b]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[c]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance doors.

[A5] Lighting Power Densities

TABLE 9.5.1 Lighting Power Densities Using the Building Area Method

Building Area Type[a]	*LPD* (W/ft^2)
Automotive facility	0.9
Convention center	1.2
Courthouse	1.2
Dining: bar lounge/leisure	1.3
Dining: cafeteria/fast food	1.4
Dining: family	1.6
Dormitory	1.0
Exercise center	1.0
Gymnasium	1.1
Health-care clinic	1.0
Hospital	1.2
Hotel	1.0
Library	1.3
Manufacturing facility	1.3
Motel	1.0
Motion picture theater	1.2
Multifamily	0.7
Museum	1.1
Office	1.0
Parking garage	0.3
Penitentiary	1.0
Performing arts theater	1.6
Police/fire station	1.0
Post office	1.1
Religious building	1.3
Retail	1.5
School/university	1.2
Sports arena	1.1
Town hall	1.1
Transportation	1.0
Warehouse	0.8
Workshop	1.4

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