NASA Langley Research Center – Administration Office Building One

Hampton, VA

FINAL THESIS REPORT

All renderings from AECOM bridging drawings – www.aecom.com

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NASA Langley Research Center
Administration Office Building One
Hampton, VA

Project Statistics:
- 79,000 SF
- 3 stories + Penthouses
- Construction Milestones:
  - July 17, 2009: broke grounds
  - March-May 2007: occupancy
  - June 17, 2011: ribbon cutting
- Overall project cost: $26 million
- Design-build project delivery method
- LEED Platinum Rating

Project team:
- Owner: NASA & U.S. General Services Administration
- Contractor: The Whiting-Turner Contracting Company
- Architect, Landscape Architect: Cooper Carry
- Structural Engineer: Structura Inc.
- MEP Engineer: H.F. Lenz Company
- Construction Management: Hill International
- Civil Engineer: PBS&J

South Elevation

Images from AECOM bridging drawings – www.aecom.com

Site Plan

Architecture and Sustainability Features:
- Form evokes flight, with rectilinear form and overhanging upper floors, clad in metal and glass façade
- Horizontal overhangs on south and west facades
- Vertical sun shades on east façade
- Interior layout maximizes daylighting, with open offices no wider than three cubicles and glazed interior partitions on private offices
- Green roof
- 30% water reduction plumbing fixtures
- Voluntary segregation of recyclable materials

Structural:
- Steel framed
- Typical floor: 3" 22 GA deck with 2-1/2" NWC
- Slab on Grade: 5" cast-in-place concrete with 6x6-W2.5xW2.5 WWF
- Gravity framing: wide flange and tube steel columns, composite steel beams and girders
- Lateral Resisting System: series of braced frames; two braced frames oriented in both directions

Mechanical:
- Geothermal well field for full heating and cooling load of the building
- One DOAS unit with heat recovery wheel from building exhaust, four AHU's supplied from DOAS unit with VAV and return air at unit
- Under floor air distribution for office areas
- Separate AHU with OA intake to supply first floor meeting rooms
- BCU's for lobby conditioning

Lighting/Electrical:
- Daylight sensors at perimeter
- Occupancy sensor light switches in private offices
- Occupancy sensors in meetings rooms
- LED and fluorescent lights
- Feeder: 1500 kVA, 6600 volt
- Main service switchboard: 480Y/277
- 250 kW diesel generator
- Two photovoltaic systems connected to the photovoltaic skylight glass.

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Executive Summary

The focus for research of this thesis analysis is the NASA Langley Research Center Administration Office Building 1, located in Hampton, VA. This building is a 3 story office building, approximately 75,000 ft^2. The glazing system is made up on insulating laminated low-E glass produced by Viracon. The design of this building focused largely on energy efficiency and "green" building design. This report investigates the use of alternative glazing systems, such as triple insulating glass, multiple layers of low-E coatings, and photovoltaic glass. Interpretation of this analysis focused on the following two key points:

1. Lowering of energy use, thus greenhouse gas emissions, from the original design
2. Maintaining a low construction cost that allowed for a payback period less than the life span of the glass

The mechanical depth analyzed the impact of the glazing systems on the building loads and air handling equipment. The building loads could not see an increase over the design capacity of the geothermal transfer field, as the site does not allow room for expansion of the field. Load and energy comparisons were made for all alternatives, and a 20 year life-cycle cost analysis for each option was performed. This cost analysis consisted of prices of the glass, air handling equipment, and yearly utility costs.

Two supporting breadth analyses were done to accompany this depth. The first was a lighting analysis, which investigated an alternative lighting plan for the open offices and a daylighting comparison for the PV glass. The new lighting plan not only reduced the number of luminaires in the open offices, but was also found to decrease the yearly energy consumption. The daylighting comparison for the PV glass was performed because the PV glass had a significantly lower visible light transmittance (VLT) than the other alternatives. Because the building utilizes dimming schedules based on daylighting performance, it had to be determined if the PV glass would negatively affect the ability to naturally light the space during the work hours. This analysis showed that the PV glass would not be a problem in this regard.

The second breadth, an environmental analysis, studied the emissions of the life-cycle of the PV glass. This life-cycle included the emissions during manufacturing and emissions saved through energy generation on-site. This research showed that the CO_2 paid back the emissions of manufacturing after 13 years of being installed in the proposed location of the mechanical depth, which is only 65% of the minimum anticipated life span of the glass.

With the results of each breadth considered and the results of the mechanical depth, summarized in Figure 1 on the next page, the final recommendation for the building was to implement the new lighting plan and make no changes to the existing glazing system.

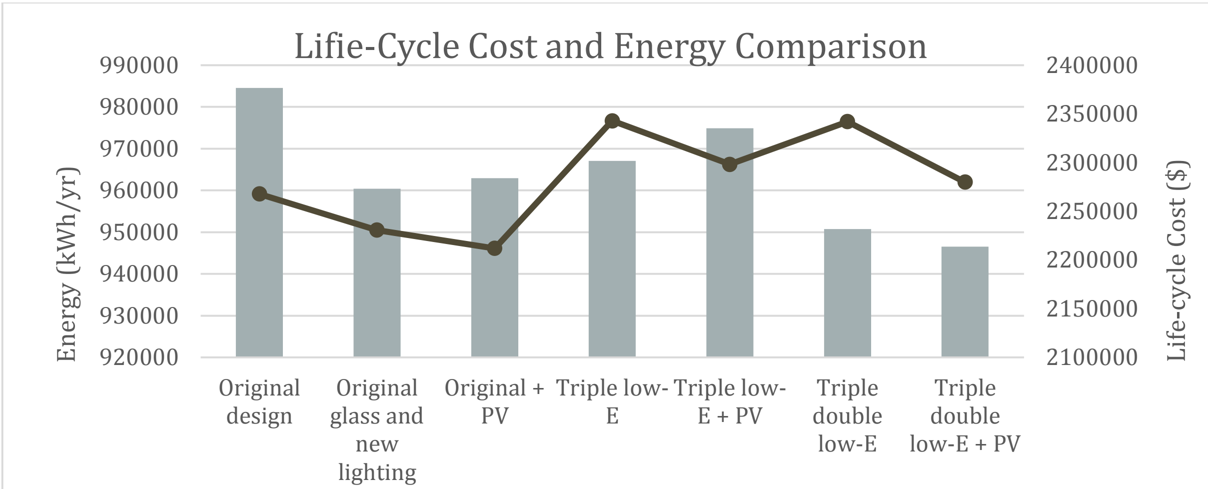

Figure 1 - Summary of depth analysis for energy consumption and life-cycle cost

Building Overview

NASA LANGLEY

The NASA Langley Research Center was founded in 1917 as the first civil aeronautical research laboratory, and currently has approximately 110 buildings that were constructed over 50 years ago. NASA decided to implement a five-phase revitalization program, which would replace existing buildings with newer, more efficient ones. Their goals for these new buildings were sustainability/efficiency, functionality of the interior environment, pedestrian friendly, and curb appeal. The revitalization program is known as the New Town program, and the first phase consisted of the construction of AOB1.

NEW TOWN PHASE 1

AOB1 is the new headquarters building for NASA's Langley Research Center. The project broke ground in July of 2009 and occupancy began in May 2011. The three story building is approximately 79,000 square feet, with a mechanical penthouse. The building was designed to give viewers a perception of flight. The image below, a rendering from the bridging drawings created by AECOM, demonstrates this original concept, with the glass curtainwall and metal paneling façade and parallelogram footprint with the overhanging upper floors.

Figure 2 – South façade rendering from AECOM Bridging Drawings

The exterior form matches the interior function, with the vertical form towards the center of the building indicating the location of the elevators and lobby. This vertical section also helps to separate the first floor into two sections: employee offices, with a glass façade providing adequate daylighting matching the rest of the building, and large conference rooms for hosting events with its stone façade and windows that are more practical for visual presentations [7][10].

ENVIRONMENTAL FEATURES

Having achieved a USGBC LEED Platinum rating in v2.2, sustainability and energy efficiency were important in the building design. Horizontal overhangs were utilized on the south and west facades, above the main strip of windows but below a smaller strip, designed for daylighting purposes. The east façade contains vertical sun shades located approximately ten feet apart. The interior design and building shape helps maximize daylighting use, with open office spaces no deeper than three cubicles, and glazed partitions on interior private offices. The building also contains a green roof, a photovoltaic glass skylight, and 30% water reduction plumbing fixtures.

Part 1: Existing Building Evaluation

Mechanical System Overview

The air distribution system in AOB1 consists of five air handling units and one dedicated outdoor air unit with a heat recovery wheel. The primary air distribution system in the building is an under floor air distribution system (UFAD). The system serves all office spaces and teaming areas on all three floors. Each floor has an air handling unit (AHU-1, 2, 3) located on that floor which ducts into an open floor plenum that distributes to diffusers for the interior spaces and fan powered boxes (FPB) at the perimeter. There is ceiling return, where air is either recirculated to the air handling unit or relieved to the roof, where it goes through the enthalpy wheel at the dedicated outdoor air handling unit (DOAS) that provides pre-conditioned outdoor air for the building. This unit contains heating, cooling and reheat coils, and is set-up for dehumidification. A diagram of the UFAD air handling units is shown in Figure 2.

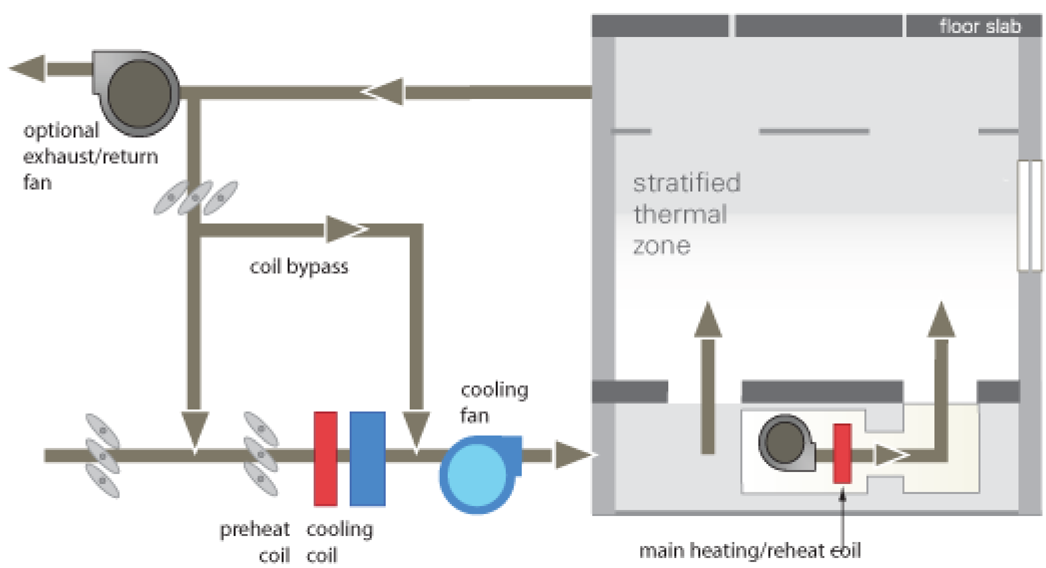

Figure 3 - AHU-1, 2, 3 Diagram

There are four VAV's located in the penthouse that control the amount of OA distributed to each respective AHU. Figure 4 shows the mechanical system breakdown of the second floor.

- AHU-5 serves the large conference rooms (such as those in pink in Figure 4) of the upper floors separate of the UFAD system and is located in the penthouse.
- AHU-4 is located on the first floor and serves the large conference rooms on the first floor. It has its own OA louver and is not supplied by the DOAS unit.
- Blower coil units (BCU) serve the atrium and lobby spaces
- Fan coil units (FCU) are used for the IT room on each floor

All areas in white are not directly supplied, which include spaces such as stairwells, elevators, restrooms, kitchenettes, mechanical rooms and electrical rooms.

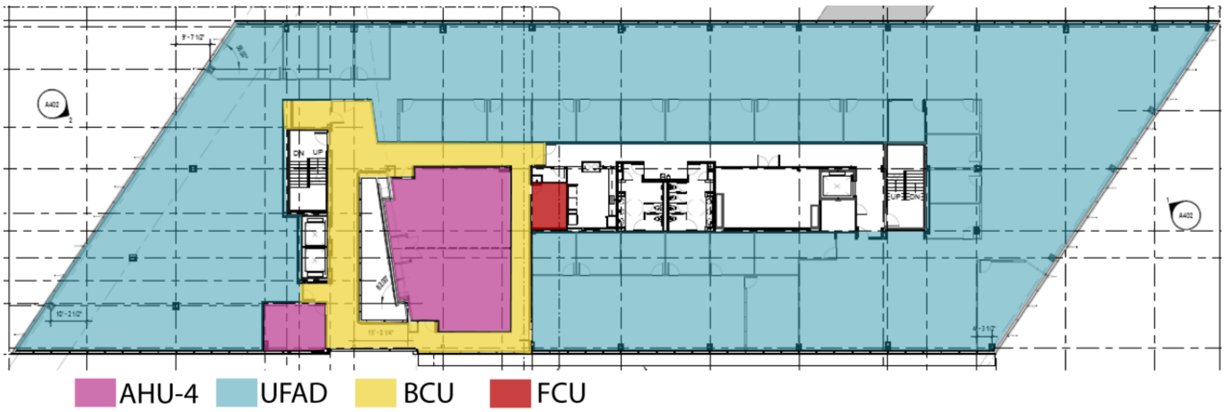

Figure 4 - Second Floor Mechanical System Overview

A geothermal transfer field handles the entire heating and cooling load of the building, with 90 boreholes that are six inches in diameter and 500 feet deep. The well field is connected to six water to water heat pumps (WWHP) with scroll compressors and two sets of three-way control valves that allow the heat pumps to switch between cooling and heating operating, located in the penthouse. The WWHP's have an EER of fourteen and a heating COP of 3.25. Two geothermal water loop circulation pumps with variable frequency drives control the geothermal water loop.

DESIGN OBJECTIVES, REQUIREMENTS AND INFLUENCES

The mechanical system was designed to maximize energy efficiency, provide optimal occupant comfort, and provide an operational system that is flexible. The building was to achieve a minimum LEED rating of Gold, and surpassed this requirement with a Platinum rating. Striving for this goal influenced many of the mechanical system design decisions, as well as other systems in the building. The mechanical systems narrative from the bridge documents states required system components of geothermal transfer field as a heat source and sink, high efficiency heat water to water heat pumps connected to the well field, airside economizers on the air handling units, and an energy recovery unit. The size of the geothermal transfer field was restricted to the small available area provided on site, between the building and the existing tree line that was to be unharmed through construction. The energy supply for all HVAC components is electricity, which provides the power for the heating and chilled water distribution of the building.

The Direct Digital Control (DDC) Building Automation System (BAS) is provided to lower operating costs, increase efficiency, and increase ease of operation by the maintenance staff. The Building Automation System (BAS) was required to be coordinated with the NASA Langley campus system.

In additional to energy performance objectives, the building was designed to provide desired noise criteria through sound attenuating features of the HVAC system. The noise criteria level was designed to not exceed 35 NC in offices and 30 NC in conference rooms.

ASHRAE Standard 62.1-2013 Section 5 Compliance

This section of the report evaluates the compliance of AOB1 with ASHRAE Standard 62.1-2013 Section 5. The building was originally designed to comply with the 2004 Standard. Information used to evaluate this compliance comes from the mechanical narrative, specifications, equipment submittals and construction drawings.

5.1 VENTILATION AIR DISTRIBUTION

AOB1 was designed to comply with ASHRAE 62.1-2014. The narrative provided by the mechanical engineer indicates that the ventilation requirements of section 6 of ASHRAE 62.1-2004 was met. A calculation was done to check compliance to the 2013 standard, the details of which can be found in APPENDIX P1.A1. The design calls for separate plenums for supply and return and is anticipated to supply the correct amount of ventilation air to each floor-mounted terminal unit. The design documents specify 18% OA for AHU's serving the UFAD system and 30% OA for units serving the conference rooms. AHU-1, 2, 3, and 5, which are part of the DOAS unit, met compliance. However, AHU-4 did not meet compliance. See the Section 6 compliance section of this report for more information.

5.2 EXHAUST DUCT LOCATION

Exhaust air ducts for potentially harmful contaminants equipped with an exhaust fan and motorized damper that activates any time the air handling unit for that floor is on.

5.3 VENTILATION SYSTEM CONTROLS

The DOAS unit is equipped with a controller that modulates the damper on the penthouse VAV terminal units that supply OA to each AHU to maintain each units OA setpoint. However, the OA setpoint for AHU-4 does not comply with Section 6.

5.4 AIRSTREAM SURFACES

All ducts are made of sheet metal and comply with section 5.4.1 and 5.4.2 for mold and erosion control, and all equipment was specified to comply with these requirements. Compliance of the open air plenum is unknown.

5.5 OUTDOOR AIR INTAKES

The OA intake for the penthouse DOAS unit is located at least 60 feet away from any contaminant sources, well beyond the minimum distance required in Table 5.5.1, shown below. All other OA intakes also comply with these requirements. OA louvers are designed in such a way to ensure drainage from the center to the sides of the duct through the build-up of insulation to prevent rain entrainment. The mechanical narrative specifies that OA intakes are located a minimum of eight inches above the snow line and that snow drifts have been taken into account. No bird screening devices were specified.

TABLE 5.5.1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Class 2 air exhaust/relief outlet (Note 1)	10 (3)
Class 3 air exhaust/relief outlet (Note 1)	15 (5)
Class 4 air exhaust/relief outlet (Note 2)	30 (10)
Plumbing vents terminating less than 3 ft (1 m) above the level of the outdoor air intake	10 (3)
Plumbing vents terminating at least 3 ft (1 m) above the level of the outdoor air intake	3 (1)
Vents, chimneys, and flues from combustion appliances and equipment (Note 3)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 4)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 4)	25 (7.5)
Driveway, street, or parking place (Note 4)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 5 and 6)	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: This requirement applies to the distance from the outdoor air intakes for one ventilation system to the exhaust/relief outlets for any other ventilation system.

Note 2: Minimum distance listed does not apply to laboratory fume hood exhaust air outlets. Separation criteria for fume hood exhaust shall be in compliance with NFPA 45[5] and ANSI/AIHA Z9.5.[6] Information on separation criteria for industrial environments can be found in the *ACGIH Industrial Ventilation Manual*[7] and in *ASHRAE Handbook—HVAC Applications*.[8]

Note 3: Shorter separation distances shall be permitted when determined in accordance with (a) ANSI Z223.1/NFPA 54[9] for fuel gas burning appliances and equipment, (b) NFPA 31[10] for oil burning appliances and equipment, or (c) NFPA 211[11] for other combustion appliances and equipment.

Note 4: Distance measured to closest place that vehicle exhaust is likely to be located

Note 5: Shorter separation distance shall be permitted where outdoor surfaces are sloped more than 45 degrees from horizontal or that are less than 1 in. (30 mm) wide.

Note 6: Where snow accumulation is expected, the surface of the snow at the expected average snow depth constitutes the "other surface directly below intake."

Figure 5 - From ASHRAE 62.1-2013

5.6 LOCAL CAPTURE OF CONTAMINANTS

Any contaminants produced by noncombustion equipment is properly vented outdoors.

5.7 COMBUSTION AIR

There are no fuel-burning appliances in AOB1, therefore ASHRAE 62.1 Section 5.7 does not apply.

5.8 PARTICULTE MATTER REMOVAL

AOB1 does not comply ASHRAE 62.1-2013 Section 5.8. The DOAS unit is scheduled for a MERV 8 filter, but all other air handling units are scheduled with MERV 7 filters. However, ASHRAE 62.1-2004, which is what AOB1 was designed for, only called for MERV 6 filters and would have therefore complied.

5.9 DEHUMIDIFICATION SYSTEMS

The space was designed for a relative humidity of 58% in the summer and the air handling units control sequence is to start dehumidification measures if the relative humidity exceeds 65%. Additionally, the DOAS unit and associated exhaust fan are designed for the same CFM, therefore AOB1 complies with section 5.9.

5.10 DRAIN PANS

Per specifications section 237433, drain plans are sloped 2%, or 0.25 in/ft, a slope greater than the minimum 0.125 in/ft required by section 5.10. This specification also states that the length was designed to comply with ASHRAE 62.1. All other drain pans listed in the specifications are also stated to comply with ASHRAE 62.1.

5.11 FINNED TUBE COILS AND HEAT EXCHANGERS

Drain pans are provided for all dehumidifying cooling coil assemblies in compliance with section 5.10. All air handling units comply with either the minimum 18 inch access door or have a pressure drop of less than 0.75 in wg across the coil.

5.12 HUMIDIFIERS AND WATER-SPRAY SYSTEMS

There are no humidifiers or water-spray systems in AOB1, therefore ASHRAE 62.1-2013 Section 5.12 does not apply.

5.13 VENTILATION EQUIPMENT ACCESS

Product brochures for the submitted air handling units and fan coil units discusses appropriate accessibility and serviceability of equipment components. The raised floor system covering the supply air plenum was designed for easy removal of floor panels to access equipment and air distribution system beneath, so compliance with section 5.13.3 is met.

5.14 BUILDING ENVELOPE AND INTERIOR SURFACES

AOB1's building envelope was designed for a continuous vapor barrier, horizontally and vertically, as called-out in Figure 6. Figure 7 further demonstrates this vapor barrier design and shows an area that required sealant and slope for water mitigation away from the wall. Additionally, duct insulation is detailed in specification section 230713, equipment in 230716, and piping insulation in 230719.

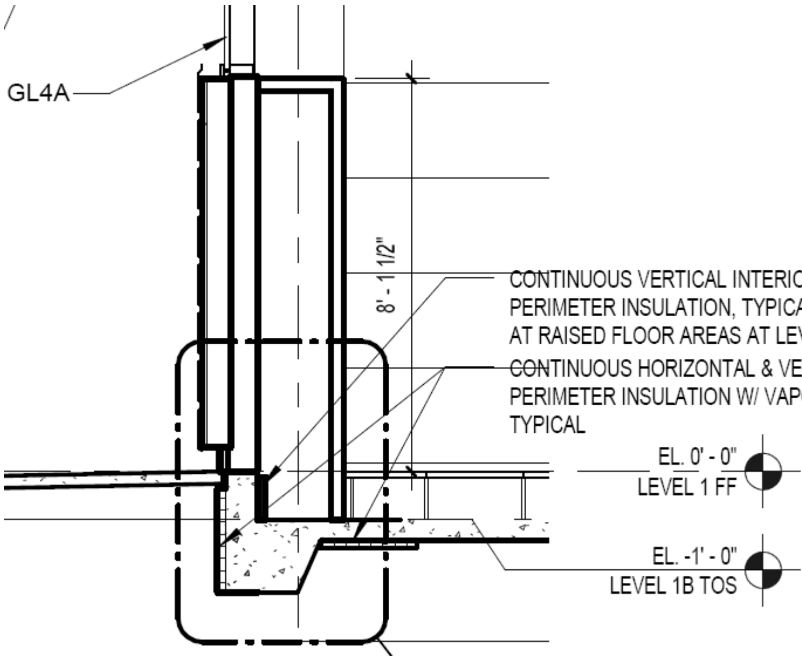

Figure 6 - West Facade Wall Section – Detail 2 on Drawing A502 of CD provided by H.F. Lenz Co.

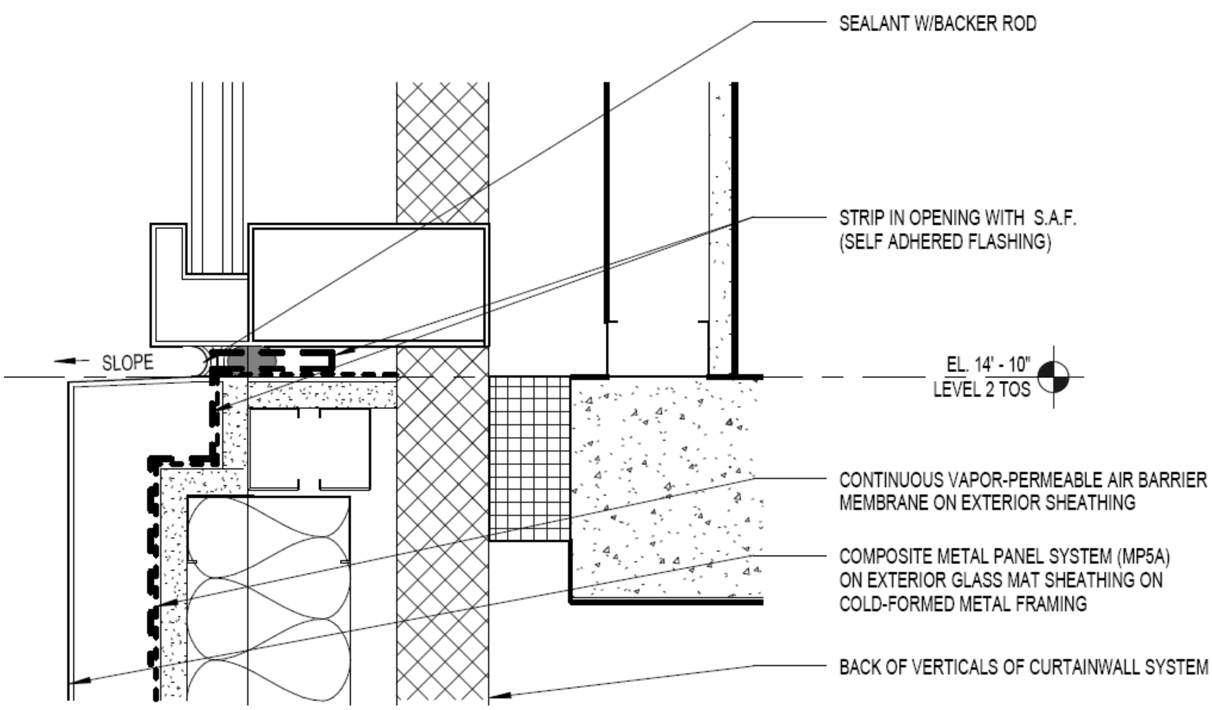

Figure 7 - Detail Section of Sill @ Second Floor - Detail 3 on Drawing A550 of CD provided by H.F. Lenz Co.

5.15 BUILDINGS WITH ATTACHED PARKING GARAGES

AOB1 does not contain an attached parking garage, therefore ASHRAE 62.1 Section 5.15 does not comply.

5.16 AIR CLASSIFICATION AND RECIRCULATION

According to Table 6.2.2.1, which is provided below, the majority of spaces in AOB1, such as offices and conference rooms, are air class 1 and can therefore be recirculated together and used to transfer to all areas of the building, such as unsupplied corridors and toilet exhaust make-up. Areas that do not fall into air class 1, such as toilet rooms and janitors closets, are directly exhausted.

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/ person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/ person	L/s·person	
Coffee stations	5	2.5	0.06	0.3		20	8	4	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	—	—	0.06	0.3		—			1
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	B	2	65	32.5	2
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Banks or bank lobbies	7.5	3.8	0.06	0.3		15	12	6.0	1
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

Figure 8 - From ASHRAE 62.1-2013

5.17 REQUIREMENTS FOR BUILDINGS CONTAINING ETS AREAS AND ETS-FREE AREAS

AOB1 is a smoke-free building, therefore ASHRAE 62.1-2013 Section 5.17 does not apply. Additionally, the outdoor air intake for the DOAS unit is located on the roof, sufficiently away from any smoking areas located outside the building.

ASHRAE Standard 62.1-2013 Section 6 Compliance

ASHRAE Standard 62.1-2013 Section 6 evaluates the building outdoor air requirements. A calculation was performed for all spaces served by the air handling units, including the DOAS system which contains AHU-1, 2, 3 and 5, and AHU-4, which has its own individual OA intake.

6.2 VENTILATION RATE PROCEDURE

The first step in calculating the amount of outdoor air that must be distributed by the air handling units is to determine the outdoor airflow required in the breathing zone. This is determined by the following equation:

$$V_{bz} = R_p * P_z + R_a * A_z$$

Where P_z is the design zone population and A_z is the area of the zone. R_p and R_a are the airflow rate per person and per unit area, respectively, required for the space type. Table 6.2.2.1 of the Standard lists these rates, and can be found in APPENDIX P1.A2. All areas of the building are classified as a Multiple-Zone Recirculating System and therefore require further calculation to determine the outdoor air intake requirements. The outdoor airflow required for the zone, V_{oz}, is affected by the air distribution effectiveness, E_z. This value represents the effectiveness of the air supply system configuration to distribute air to the breathing zone and is determined from Table 6.2.2.2 of the Standard, shown below.

$$V_{oz} = \frac{V_{bz}}{E_z}$$

The primary outdoor air fraction is the ratio of outdoor air required in the zone to the total airflow being supplied, V_{pz},, including return air. It is represented by Z_{pz}. The zone with the lowest primary outdoor air fraction determines the system ventilation efficiency, E_z, for the calculation. This value can be found using the Table 6.2.5.2 or Appendix A of the Standard. The Appendix A calculation was used for this analysis for all zones and should be referenced for further information on this process.

TABLE 6.2.2.2 Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level	1.0
Note: For lower velocity supply air, $E_z = 0.8$.	
Floor supply of cool air and ceiling return, provided that the vertical throw is greater than 50 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) or more above the floor	1.0
Floor supply of cool air and ceiling return, provided low-velocity displacement ventilation achieves unidirectional flow and thermal stratification, or underfloor air distribution systems where the vertical throw is less than or equal to 50 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) above the floor	1.2
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.8
Makeup supply drawn in near to the exhaust and/or return location	0.5

1. "Cool air" is air cooler than space temperature.
2. "Warm air" is air warmer than space temperature.
3. "Ceiling supply" includes any point above the breathing zone.
4. "Floor supply" includes any point below the breathing zone.
5. As an alternative to using the above values, E_z may be regarded as equal to air-change effectiveness determined in accordance with ASHRAE Standard 129[17] for all air distribution configurations except unidirectional flow.

Figure 9 - From ASHRAE 62.1-2013

The uncorrected outdoor air intake, V_{ou}, is the amount of outdoor air required for all the zones, with total system population taken into account.

$$V_{ou} = D\sum(R_p * P_z) + \sum(R_a + A_z)$$

For this calculation, a diversity of 100% was used to account for spaces that may be occupied by more people than the original design anticipated, in response to data obtained from the MEP firm that suggests this may occur, particularly for zones served by AHU-4. The final design for the conference rooms served by AHU-4 called for an occupancy of 64 people, which was used for the calculation; however it is reported that an over seat count of up to 28 people could be anticipated, but is not designed for such.

Finally, the outdoor air intake flow, V_{ot}, is the ratio of the uncorrected outdoor air intake to the ventilation system effectiveness:

$$V_{ot} = V_{ou}/E_v$$

This is the outdoor air flow required at each air handling unit. A full calculation is displayed in APPENDIX P1.A1. The OA values from the design schedules and the results from this analysis are found in Table 1.

Table 1 - OA Calculation Results

	EQUIPMENT	DESIGN CFM	OA CALC RESULTS	COMPLIANCE
DOAS	AHU-1	3060	1605	YES
DOAS	AHU-2	3060	2019	YES
DOAS	AHU-3	3060	1804	YES
DOAS	AHU-5	1950	1395	YES
	DOAS:	11000	6823	YES
	AHU-4	780	837	NO

All AHU's connected to the DOAS system met compliance. However, AHU-4 did not meet compliance. Through comparison of the calculation for AHU-4 from the original design, which can also be found in APPENDIX P1.A3, it was found that the population for the two conference rooms was set at 58 people. The final design of the space called for 64 seats, and this was the value used in the new calculation that created a higher OA requirement than the AHU was designed for, causing AHU-4 to not meet compliance.

6.5 EXHAUST VENTILATION

An exhaust ventilation calculation was also performed for the pantries and restrooms. The exhaust rates required for these spaces are found in ASHRAE 62.1-2013 Table 6.5 and can be found in APPENDIX P1.A4. Through this calculation it was discovered that the second and third floor public restrooms do not meet ventilation requirements by a deficit of 50 CFM per room. Specific information for this calculation can be found in Table 2. All other spaces were found to comply.

Table 2 - Exhaust Ventilation

ZONE	OCCUPANCY CATEGORY	EXHAUST RATE (CFM/UNIT)	# UNITS	AREA (SF)	REQUIRED EXHAUST RATE	DESIGN EXHAUST RATE
109	toilets - public	50 CFM/UNIT	6	360	300	300
110	toilets - public	50 CFM/UNIT	6	360	300	300
111	kitchenettes	0.3 CFM/SF	-	250	75	250
209	toilets - public	50 CFM/UNIT	4	225	200	150
210	toilets - public	50 CFM/UNIT	4	225	200	150

211	kitchenettes	0.3 CFM/SF	-	250	75	250
309	toilets - public	50 CFM/UNIT	4	225	200	150
310	toilets - public	50 CFM/UNIT	4	225	200	150
311	kitchenettes	0.3 CFM/SF	-	250	75	250
324	kitchenettes	0.3 CFM/SF	-	120	36	75
325	toilets-private	25 CFM/UNIT	1	93	25	75

ASHRAE 62.1 CONCLUSION

The main air distribution system used in AOB1 consists of four air handling units, AHU-1, 2, 3, 5, which are fed by a dedicated outdoor air unit for ventilation air. All four units associated with this DOAS unit comply with the outdoor airflow requirements obtained by the ASHRAE 62.1-2013 Section 6 procedure. Another air handling unit, AHU-4, supplies the conference rooms on the first floor and has its own outdoor air intake. Due to a change in zone population between the original design calculation and the final furniture layout, this unit does not comply with the outdoor air requirements. This causes AOB1 to be non-compliant with ASHRAE 62.1-2013 Section 5.1 and 5.3. Additionally, the building was designed to meet the 2004 standard, which required MERV 6 filters on the units, and this was exceeded by the scheduling of MERV 7 filters. However, the 2013 standard requires MERV 8 filters and therefore AOB1 does not comply with ASHRAE 62.1-2013 Section 5.8.

As for exhaust ventilation, the ASHRAE 62.1-2013 Standard specifies a rate of 50 CFM/unit for public toilets per Table 6.5 of the Standard. This would have required 200 CFM of exhaust from each public toilet room on the second and third floor. Only 150 CFM exhaust was designed for these rooms, therefore the building does not comply with ASHRAE 62.1-2013 Section 6.5.

ASHRAE Standard 90.1-2013 Compliance

This section of the report evaluates the compliance of AOB1 with ASHRAE Standard 90.1-2013. The building was originally designed to comply with the 2004 Standard.

BUILDING ENVELOPE – SECTION 5

AOB1 falls into climate zone 4A, and the building is classified as nonresidential.

SECTION 5.2

Section 5.2 requires compliance with sections 5.1, 5.4, 5.7 and 5.8 and either 5.5 or 5.6.

SECTION 5.4

The building envelope contains a continuous air barrier, in accordance with ASTM E 2178. There are two main building entries, connecting into the lobby, and they are both separated from the exterior by vestibules. These vestibules have a distance of ten feet between doors, which exceeds the minimum seven foot requirement.

SECTION 5.5

According to Table 5.5-4 in the Standard, which can be found in APPENDIX P1.B1, vertical fenestration is to be limited to 40% of the building, and the skylight is limited to 3% of the roof area. The skylight does comply with this limit. As shown in Table 3, the area of vertical fenestration exceeds the 40% limit. Normative Appendix C of the Standard provides instructions for determining if the Trade-Off option of 5.6 applies. For the purpose of this report, it is assumed that, being a LEED Platinum building, the fenestration meets compliance.

Table 3 - Fenestration and Doors Percentage

	NORTH	SOUTH	EAST	WEST	ROOF
Surface area (SF)	12585	12450	5020	4950	22500
Fenestration area (SF)	5839	6613	2590	2025	585
% Fenestration	46	53	51.5	41	2.6

Additionally, this section requires that all assembly U values for the building envelope comply with those values provided in Table 5.5-4 of the standard, which is summarized below in Table 4:

Table 4 - Assembly U-Values

	2013 U-VALUE	U-VALUED INSTALLED	COMPLIANT?	2004 U-VALUE
Roof:	0.037	0.063	NO	0.063
Walls, above grade:	0.060	0.113	NO	0.113
Vertical fenestration:	0.420	0.37	YES	For 40-50%: 0.46
Skylight:	0.500	0.46	YES	1.17

The roof and walls are not complaint with the 2013 Standard, but they were complaint with the 2004 Standard that the building was designed for. For Table 5.5-4 of the Standard for both years, see APPENDIX P1.B1 In addition to those U-values, a max SHGC of 0.400 is required for both vertical fenestration and skylights. Both requirements are met, at 0.252 and 0.340, respectively.

HEATING, VENTILATING AND AIR CONDITIONING: SECTION 6

Section 6 of ASHRAE 62.1-2013 covers compliance of the HVAC system design. The simplified approach option is not applicable to AOB1. Therefore, Section 6.3 does not apply and Section 6.4 compliance must be evaluated.

SECTION 6.4

Compliance with this section requires that equipment listed in Table 6.8.1-1 through 6.8.1-13 of the Standard meet the minimum efficiency listed. This equipment requires the water to water, water loop (cooling mode) systems have a minimum of 10.6 EER and a heating mode minimum of 3.7 COP_h, which are both compliant.

HVAC controls requirements of Section 5.4.3 are also met. Because open plenums are used throughout the building with short duct run distances through conditioned spaces, the insulation R-value requirements listed in Table 6.8.2-1 and Table 6.8.2-2 of the Standard do not apply or require no specific R-value.

The hot water system in the building is designed for 100-140^{0}F and the chilled water system is designed for 55-65^{0}F. The thermal conductivity of the specified insulation is 0.24, which complies with the values found in Table 6.8.3-1 and 6.8.3-2 of the Standard.

SECTION 6.5

According to Table 6.5.1-1 of the Standard, an economizer should be required; however, there does not appear to be a control sequence for an economizer on the air handling units or dedicated outdoor air unit and therefore does not comply with ASHRAE 90.1-2013 Section 6.5.1.

Table 5 - Fan Power Limitation Requirements

	HP	CFM	CFM*0.0015	COMPLAINT?
AHU-1, 2, 3	20	17000	25.5	YES
AHU-4	3	2600	3.9	YES
AHU-5	7.5	6500	9.75	YES
DOAS	15	11000	16.5	YES

Table 5 summarizes the fan power limitation compliance of Section 6.5.3.1.1, from Table 6.5.3.1-1 for variable volume flow rates. All air handling units are compliant.

Section 6.5.6 covers energy recovery. Because the ventilation system is 100% OA during all operating hours, there is no requirement for the design supply fan airflow rate.

SERVICE WATER HEATING: SECTION 7

Section 7 of ASHRAE 62.1-2013 covers compliance of the service water heating. The service water for heating comes from the ground field loop through the water to water heat exchangers. All piping insulation meets minimum requirements. The building contains no boilers or water heaters for the HVAC hot water system.

POWER: SECTION 8

Compliance for Section 8: Power requires compliance to sections 8.1, 8.4 and 8.7. A 6600 volt, 1200 amp high voltage feeder supplies the building from a nearby existing substation. It connects to a 1500 kVA 6600 volt primary 480Y/277 volt secondary substation unit. A 100 amp, 480 volt automatic transfer switch serves the emergency systems. Additionally, a 250 kW, 480Y/277 volt diesel generator and two photovoltaic systems that provide solar power to the electrical system are used in the building. An energy management control system remotely monitors the energy use of the building.

The building has a three-phase 75 kVA, low-voltage transformer. Table 8.4.4 from the Standard, shown below, requires that a 75 kVA transformer be 98% efficient. According to the electrical submittals for division 262200, the transformer complies.

TABLE 8.4.4 Minimum Nominal Efficiency Levels for 10 CFR 431 Low-Voltage Dry-Type Distribution Transformers[a]

Single-Phase Transformers		Three-Phase Transformers	
kVA[b]	Efficiency,%[c]	kVA[b]	Efficiency,%[c]
15	97.7	15	97.0
25	98.0	30	97.5
37.5	98.2	45	97.7
50	98.3	75	98.0
75	98.5	112.5	98.2
100	98.6	150	98.3
167	98.7	225	98.5
250	98.8	300	98.6
333	98.9	500	98.7
		750	98.8
		1000	98.9

a. A low-voltage distribution transformer is a transformer that is air-cooled, does not use oil as a coolant, has an input voltage ≤600 V, and is rated for operation at a frequency of 60 Hz.
b. Kilovolt-ampere rating.
c. Nominal efficiencies shall be established in accordance with the 10 CFR 431 test procedure for low-voltage dry-type transformers.

Figure 10- From ASHRAE 90.1-2013

LIGHTING: SECTION 9

The Building Area Method of Section 9.5 was used for the lighting calculations of this analysis.

SECTION 9.4

The lighting control system for the building consists of daylight sensors in the open office areas, occupancy sensor switches in the private offices and small conference rooms, and separate occupancy sensors in the larger meeting rooms.

SECTION 9.5

AOB1 is classified as having an office building area type, with a LPD of 0.82 W/ft^2. The building grow lighted floor area is about 70,000 square feet.

$$Lighting\ power\ allowance = LPD * Area$$

The lighting power allowance of the building is approximately 57,400 W. The lighting calculations performed by the electrical engineer estimate that 62,272 W were designed. According to this calculation, the ASHRAE 90.1-2007 LPD were higher than the 2013 Standard, making it compliant with the 2007 Standard but not the 2013 Standard. Figure 11 is the table from the lighting calculation document obtained from H.F. Lenz, dated for April of 2010.

Floor Level	Room Area (Square Feet)	Allowable Lighting Power Density as per ASHRAE 90.1-2007 (W/ft2)	Allowable Power as per ASHRAE 90.1-2007 (Watts)	Design Lighting Power Density as per H.F. Lenz Design (W/ft2)	Design Power as per H.F. Lenz Design (Watts)
Level 1	21,501	1.13	24,268	0.88	18,972.80
Level 2	**23,809**	1.10	26,247	0.93	22,026.80
Level 3	**23,023**	1.11	25,659	0.92	21,272.20

Figure 11 - LPD, from H.F. Lenz Interior Lighting Calculations

OTHER EQUIPMENT: SECTION 10

ASHRAE 90.1-2010 Section 10 outlines compliance requirements for other equipment. Section 10.4.1 Electric Motors is the section to be analyzed for this report.

This section states that motors with a power rating of at least 1 hp and less than 200 hp must comply with the Energy Independence and Security Act of 2007. Table 10.8-1 and 10.8-2 of the Standard shows these requirements and can be found in APPENDIX P1.B2. The Energy Independence and Security Act of 2007 requirements are defined by NEMA MG 1, which is referenced in specification 230513 – common motor requirements for HVAC equipment. Therefore, AOB1 meets the requirements of ASHRAE 90.1-2010 Section 10.4.1.

ASHRAE 90.1 CONCLUSION

AOB1 complies with Sections 6-9 and 10.4.1 of the ASHRAE 90.1-2013 Standard. However, it does not comply with all requirements of Section 5, building envelope. The vertical fenestration exceeded the limit of <40% of the building area. An in depth calculation must be done to determine if the building trade-off option of Normative Appendix C would be suitable to meet compliance, but is not done for this analysis. Additionally, the roof and wall U-values, which complied with the 2004 Standard, do not comply with the 2013 Standard. Therefore, AOB1 does not comply with ASHRAE 90.1-2013 Standard Section 5 for building envelope.

Design Load Estimation

A load analysis was performed on AOB1 using Trane TRACE 700. For this analysis, spaces were broken down by equipment zones and space types. The space type breakdown consisted mainly of offices, conference rooms, restrooms, corridors, and pantries. The open office spaces, private offices, and teaming spaces that are supplied from the same under floor air distribution air handling unit are modeled as one space. All other spaces that are supplied from adjacent air transfer or are supplied from other equipment were modeled individually.

DESIGN CONDITIONS

AOB1 is located in climate zone 4A. Table 6 below shows the weather information used in the Trace 700 analysis. This data was received from H.F. Lenz, the MEP engineers for the project.

Table 6 - TMY Weather Data

COOLING MAX 0.4%			DEHUMIDIFICATION MAX 0.4%			WINTER DESIGN 99.6%
DB	**MCWB**	**DP**	**DB**	**MCWB**	**DP**	**DB**
93.2	77.5	71.7	83.9	79.02	77.3	20.5

INPUT PARAMETERS

The construction parameters used in this model were obtained from H.F. Lenz Company, the MEP Engineers. These values were obtained from the basis of design documents and from H.F. Lenz Company and construction submittals for elements whose final design thermal properties differed from the basis of design. A summary of these construction parameters used for the TRACE 700 model are shown in Table 7.

Table 7 - Construction Design

	U-FACTOR (BTU/H*FT^{2}*^{o}F)	SHADING COEFFICIENT	HEIGHTS (FT.)	
Slab	0.21		**Wall**	14.75
Roof	0.063		**Floor to floor**	14.75
Wall	0.113			
Window	0.37	0.29	**Plenum**	2.8
Skylight	0.46	0.39		

The U-values and Solar Heat Gain Coefficients from the window submittals were adjusted to account for decreased performance due to the curtainwall system. For this adjustment, data from a Kawneer product that had similar attributes to the glass installed was used and can be found in APPENDIX P1.C.

ASHRAE Standard 62.1-2004/2007 was used for the original design ventilation, and a 30% increase over baseline requirements was used for the CFM rates. The fan static pressures designed ranged from 1.5 to 2.0 in. wg for each unit. The lighting power density anticipated for all space types was 1.0 W/SF, and a power density of 0.3 W/SF for lobbies, conference rooms and training rooms, and 1.0 W/SF for office areas. The thermostat schedule and temperature set points are summarized below in Figure 15.

Table 8 – Original Mechanical Narrative Supply Air Quantity

SPACE:	APPROXIMATE CFM/SF	APPROXIMATE CFM/PERSON
Offices	0.078	6.5
Conference Rooms	0.078	6.5
Corridors	0.060	0
Toilet Rooms:	40 per fixture	0

Table 9 - Ventilation Air Supplied

FLOOR	APPROXIMATE CFM/SF
1st floor	0.19
2nd floor	0.15
3rd floor	0.16

Table 10 - AHU Static Pressure

UNIT	SUPPLY SP (IN. WG)	RETURN SP (IN. WG)
AHU-1	1.5	1.5
AHU-2	1.5	1.5
AHU-3	1.5	1.5
AHU-4	2.0	1.5
AHU-5	2.0	1.5

The static pressures to be used for each air handling unit were obtained from the MEP engineers and coincide with the values given in the design schedule. These static pressures range from 1.5 to 2.0 in. wg for each unit. The exact values are given in Table 10. No diversity was taken for the equipment.

The lighting and power densities used for the model, shown in Table 11, were based on the values provided in the basis of design. These represent the maximum anticipated load contribution. Daylight sensors for the perimeter offices allow for lower lighting densities.

Table 11 - Lighting, Power and People Load Densities for Cooling

	LIGHTING AND POWER LOAD DENSITIES	
	Lighting	**Power**
Office areas	1.0 W/SF	1.0 W/SF

Lobbies	1.0 W/SF	0.3 W/SF
Conference	1.0 W/SF	0.3 W/SF
Training rooms	1.0 W/SF	0.3 W/SF

The occupancies used for the model were based on the final design furniture layout. An exact person count was used for each room, as opposed to a per square foot basis that was used for the original design model by the mechanical engineers. For floor plans with occupancies, see APPENDIX P1.D.

Table 12 - Thermostat Settings

Cooling dB:	75^{0}F
Heating DB:	72^{0}F
Relative Humidity:	60%
Cooling Driftpoint:	75^{0}F
Heating Driftpoint:	62^{0}F

The thermostat settings used in the TRACE 700 were taken from the basis of design and assumed to be that used in the current building. The dry bulb settings, relative humidity, and driftpoint temperatures are displayed in Table 12.

A schedule was applied to the model, which has a base work occupancy of weekdays from 8 a.m. to 5 p.m. The system will be set to maintain temperature between 55^{0}F and 90^{0}F for all hours of the day, and between 65^{0}F and 80^{0}F an hour before occupancy and as low as 60^{0}F after occupancy. A summary of this information for heating and cooling is shown in Table 13.

Table 13 - Thermostat Schedule

COOLING STAT			HEATING STAT		
WEEKDAYS					
Start Time	**End Time**	**Setpoint (^{0}F)**	**Start Time**	**End Time**	**Setpoint (^{0}F)**
Midnight	7 a.m.	90	Midnight	7 a.m.	55
7 a.m.	8 a.m.	80	7 a.m.	8 a.m.	65
8 a.m.	5 p.m.	75	8 a.m.	5 p.m.	72
5 p.m.	6 p.m.	80	5 p.m.	6 p.m.	60
6 p.m.	Midnight	90	6 p.m.	Midnight	55
WEEKENDS					
Midnight	Midnight	90	Midnight	Midnight	60

The geothermal system was modeled in TRACE 700, and all AHU's were modeled separately and rooms assigned accordingly.

LOAD ANALYSIS RESULTS

The calculated airflow rates and load requirements from the TRACE 700 model were compared to the values from the design drawings provided. These results, provided in Table 14, show that the design airflow rates exceeded those required. However, some of the cooling and heating requirements did exceed those designed. These included both cooling and heating coils for AHU-4, AHU-5's heating coil, and AHU-2 and AHU-3 cooling coils. It is important to note here that AHU-4 supplies two interior conference rooms, which can each be completely divided in half, and will not usually meet maximum occupancy at the same time.

Table 14 - Design and Calculated Airflow Rates

EQUIPMENT	RESULT TYPE	COOLING CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	Design	17000	5100	37	491
	Calculated	8728	2925	30	236
AHU-2	Design	17000	5100	37	491
	Calculated	12707	3023	39	346
AHU-3	Design	17000	5100	37	491
	Calculated	12842	3112	44	354
AHU-4	Design	2600	780	8.3	37.7
	Calculated	2387	780	9	66.3
AHU-5	Design	6500	1950	20.5	85.0
	Calculated	3812	1810	18	101

Because the dedicated outdoor air system (DOAS) preconditions the air before the air handling units condition it further, the conditioning provided by both systems had to be included in the design data above. Since the air is assumed to be conditioned uniformly at the DOAS unit, the cooling and heating loads were proportionally split and the total capacity at both the DOAS unit and AHU combined are the values displayed in Table 14.

A total design cooling capacity for a building maximum block load was found to be 116 tons through this simulation, and a total heating capacity of 1220 MBh. This can be compared to the design capacities of the geothermal well field, which has a design cooling capacity of 130 tons and heating capacity of 2230 kBtu/hr.

Energy Consumption Analysis

ANNUAL ENERGY AND OPERATING CONSUMPTION

An economical simulation was also run using the same TRACE 700 model used for the load analysis above. The fuel rate used for AOB1 was $0.077/kWh. This value was provided by the MEP engineers and represents the rate provided to them by the appropriate local utility. All consumption is electric. Through this analysis the following energy consumption data was found:

- Building energy consumption: 48,571 Btu/ft^2*year
- Source energy consumption: 145,727 Btu/ft^2*year

This gives a site Energy Use Intensity (EUI) value of 48 and source EUI of 146, both below the national site and source averages of 67.3 and 148.1, respectively [6]. A breakdown of the energy consumption can be found in Figure 12. This shows that the auxiliary equipment, such as fans, are the largest consumers, which is logical considering that the geothermal well field takes care of the load for the entire building and no supplemental boilers or chillers were needed.

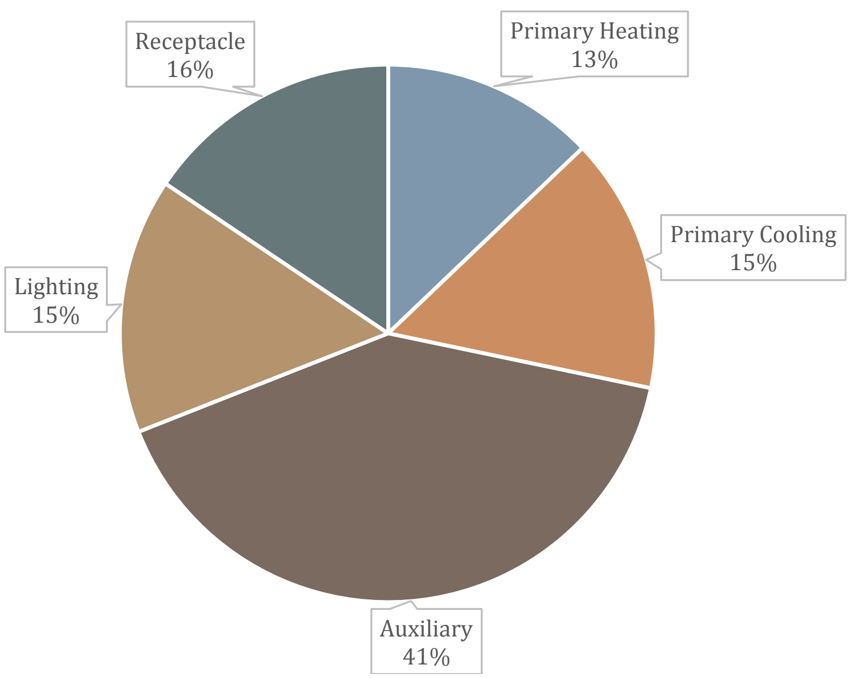

Figure 12 - Energy Consumption Summary

A monthly breakdown of the energy consumption for heating and cooling equipment, fans, lighting and miscellaneous loads is given in Figure 13. This breakdown categorizes all pumps and equipment, other than fans and accessory equipment, into cooling and heating.

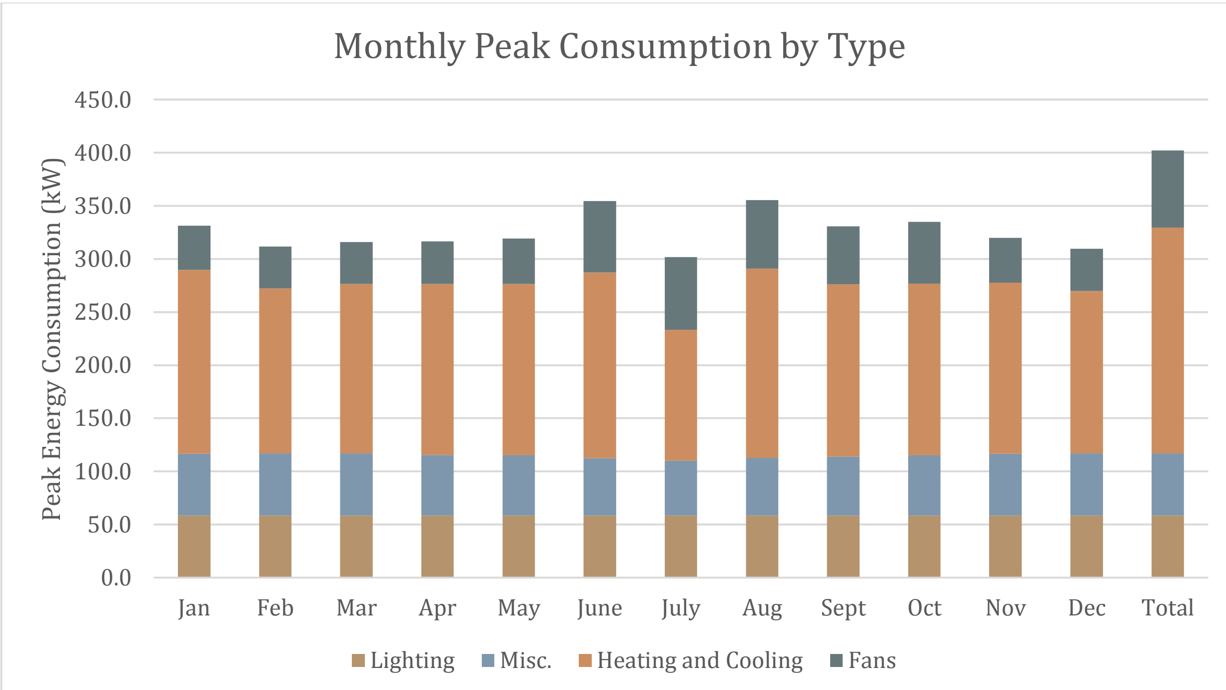

Figure 13 - Load Type Monthly Peak Consumption

Using the fuel rate provided above, the approximate utility cost per area came out to \$1.10/ft^2. The total operating cost is estimated to be \$75,808 a year, based on an annual energy consumption of 3360.2*10^6 Btu/year. A monthly breakdown for the energy consumption and cost can be found in Table 15.

Table 15- Monthly Energy Consumption and Utility Costs

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
kW	245	245	249	244	247	278	295	276	285	258	244	250
Total on-peak demand:				295 kW								
$	6495	5978	6231	5458	5688	6787	7054	7158	6022	6132	5872	75808
Total cost:				\$75,808								
Utility cost per area:				\$1.10/ft^2								

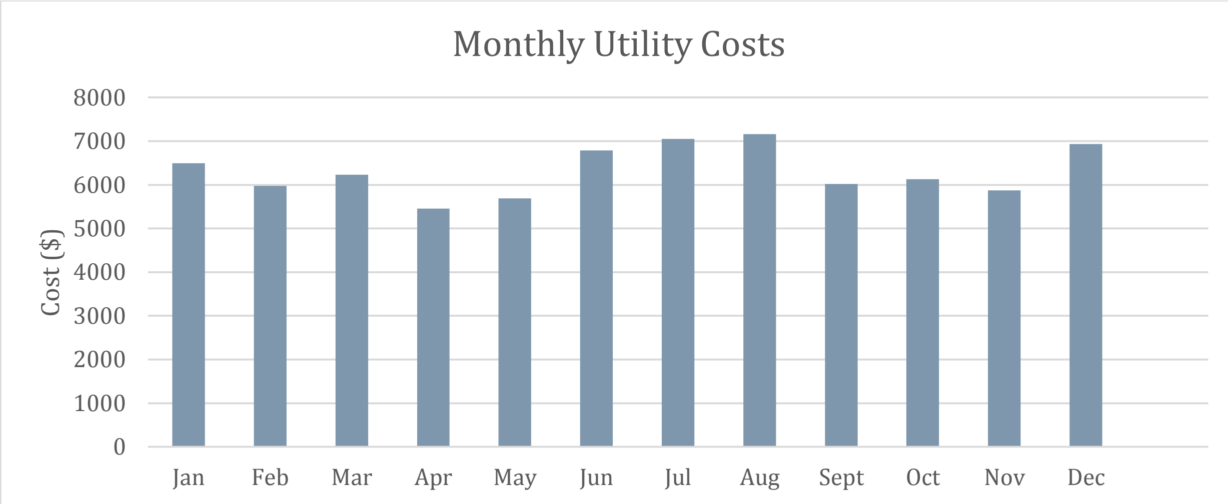

Figure 14 - Monthly Utility Costs

The U.S. Department of Energy Buildings Energy Data Book provides an average annual energy expenditure per square foot of commercial floor space on their website. This data shows an average cost of $2.44/ft^2 for commercial buildings, over 222% more than what is anticipated for AOB1. This Data Book is provided in APPENDIX P1.E.

BUILDING EMISSIONS

All energy consumed on the site was created off site and delivered. The building emissions data is based on the source energy consumption obtained through the TRACE 700 analysis. The building is located in the SERC NERC interconnection, an eastern region. The pounds of pollutant per kWh of electricity for each pollutant type are provided in Figure 15, which comes from the National Renewable Energy Laboratory's Source Energy and Emission Factors for Energy Use in Buildings technical report from 2007.

Table 3 Total Emission Factors for Delivered Electricity
(lb of pollutant per kWh of electricity)

Pollutant (lb)	National	Eastern	Western	ERCOT	Alaska	Hawaii
CO_{2e}	1.67E+00	1.74E+00	1.31E+00	1.84E+00	1.71E+00	1.91E+00
CO_2	1.57E+00	1.64E+00	1.22E+00	1.71E+00	1.55E+00	1.83E+00
CH_4	3.71E-03	3.59E-03	3.51E-03	5.30E-03	6.28E-03	2.96E-03
N_2O	3.73E-05	3.87E-05	2.97E-05	4.02E-05	3.05E-05	2.00E-05
NO_X	2.76E-03	3.00E-03	1.95E-03	2.20E-03	1.95E-03	4.32E-03
SO_X	8.36E-03	8.57E-03	6.82E-03	9.70E-03	1.12E-02	8.36E-03
CO	8.05E-04	8.54E-04	5.46E-04	9.07E-04	2.05E-03	7.43E-03
TNMOC	7.13E-05	7.26E-05	6.45E-05	7.44E-05	8.40E-05	1.15E-04
Lead	1.31E-07	1.39E-07	8.95E-08	1.42E-07	6.30E-08	1.32E-07
Mercury	3.05E-08	3.36E-08	1.86E-08	2.79E-08	3.80E-08	1.72E-07
PM10	9.16E-05	9.26E-05	6.99E-05	1.30E-04	1.09E-04	1.79E-04
Solid Waste	1.90E-01	2.05E-01	1.39E-01	1.66E-01	7.89E-02	7.44E-02

Figure 15 - Emission Factors from NREL Source Energy and Emission Factors for Energy Use in Buildings 2007

The energy results from TRACE 700 are in kBtu/year and were converted to the following kWh/year through the conversion of 1 Btu = 0.0002931 kWh:

- Total Building Energy: 3,360,121 kBtu/year = 984,851 kWh/year
- Total Source Energy: 10,081,539 kBtu/year = 2,954,899 kWh/year

Using these values, it was found that approximately 4.84 million pounds of CO_2 are emitted, 8,865 pounds of NO_x, 25,323 pounds of SO_x, and 274 pounds of PM10 (particulate matter less than 10 microns in size). This information will be compared to emissions anticipated from proposed alterations to the design, an analysis outside the scope of this report. This information is particularly important because larger environmental impacts are important for “green” building design and progress.

Mechanical System Operation

SYSTEM OPERATION AND SCHEMATICS

Water Side

A geothermal transfer field handles the entire heating and cooling load of the building, with 90 boreholes that are six inches in diameter and 500 feet deep. The well field is connected to six water to water heat pumps (WWHP) with scroll compressors located in the penthouse. The WWHP's have an EER of fourteen and a heating COP of 3.25.

As Figure 16 shows, there are four sets of pumps (eight total pumps): one set for the geothermal field, two sets for the chilled water, and one set for the heating hot water set. The chilled water and hot water pumps are equipped with variable frequency drives. All supply pipes contain flow meters; the chilled and hot water flow meters can be found to the right of the figure, just after the respective pumps, and the geothermal flow meter is on the line back to the field. The chilled water system is equipped with a three-way valve that allows for water to bypass the pumps. These valves are controlled to modulate appropriately to divert return water to maintain a 55^{0}F supply water temperature. To prevent short cycling, both the chilled and hot water systems are set to operate for a minimum of five minutes when activated.

Each of the six heat pumps is configured like the one shown, with an individual pump on the return and three-way valves on the supply and return lines that allow for the system to send the water to either the chilled water system or the hot water system. Whenever heating or cooling is called upon by the equipment, the first stage of the two-stage compressor is enacted. If the loop set point temperature is not achieved, the second compressor will be activated. After enacting both compressors, if the set point temperature is still not achieved the controller will stage the heat pumps on and off. The staging of the heat pumps for heating is opposite of that for cooling, allowing both heating and cooling water to be supplied at one time. However, the controls for the heat pumps place heating demand as a priority over cooling.

After the water is sent through the pumps, it continues past what Figure 16 shows. The chilled water in the system is supplied to all AHU, FCU, BCU, and the DOAS unit. The heating hot water continues to all AHU, BCU, CUH, UH, and re-heat coils in FPB, and the DOAS unit.

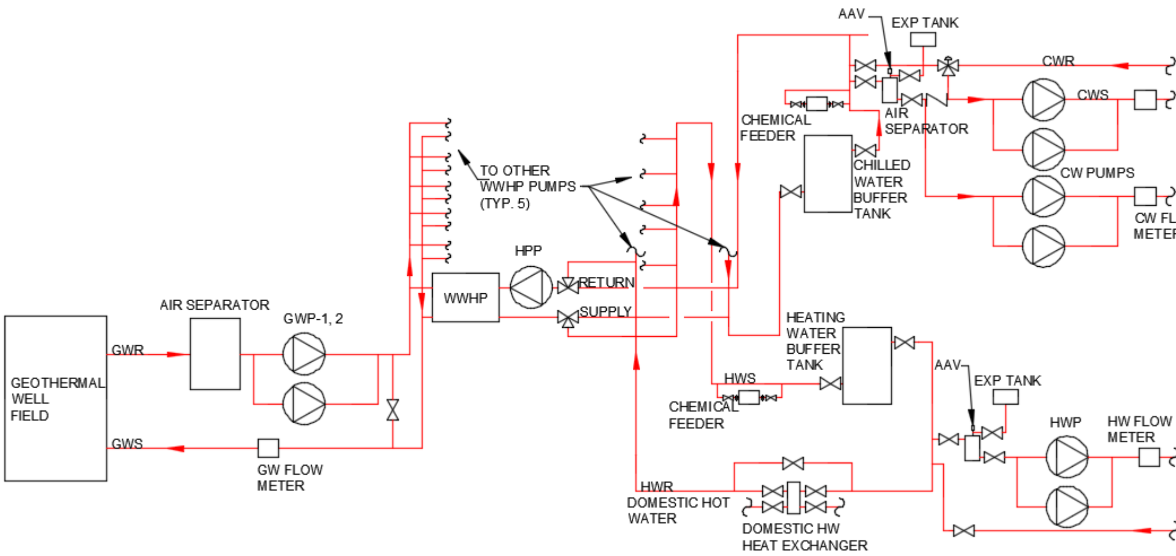

Figure 16 - Flow Diagram

Air Side

The main air distribution system of the building is an under floor air distribution (UFAD) system, with ventilation air supplied from a dedicated outdoor air (DOAS) unit located in the penthouse. This unit contains heating, cooling and reheat coils, and is set-up for dehumidification. The cooling coil is set to run whenever the supply air temperature exceeds five degrees above the setpoint and the outdoor air temperature is above 50 degrees. The heating coil operates the same way, with five degrees below setpoint and outdoor air temperature below 50 degrees. If the freezestat in the DOAS unit OA duct is on, the heating coil will open 100% to prevent freezing of the pipes.

Each floor contains an air handling unit (AHU-1, 2, 3) which supplies air into the under floor plenum, where occupant adjustable floor diffusers serve the air to the offices and teaming rooms. Fan powered boxes (FPB) are located around the perimeter of the building with hot water reheat coils. A ceiling return plenum is used to bring return air back to each AHU. This double plenum can be seen in Figure 17 - Air Riser Diagram, which is also found in APPENDIX P1.F. As shown in this figure, each of these AHU's has a return fan and is either ducted back to the unit or to an exhaust duct. This exhaust air, as well as that from the core building restrooms, is sent through a heat recovery wheel on the DOAS unit and helps with the preconditioning. The heat recovery wheel is constant volume with a bypass damper. The DOAS unit also contains a bypass damper, for when recovery energy is not desired.

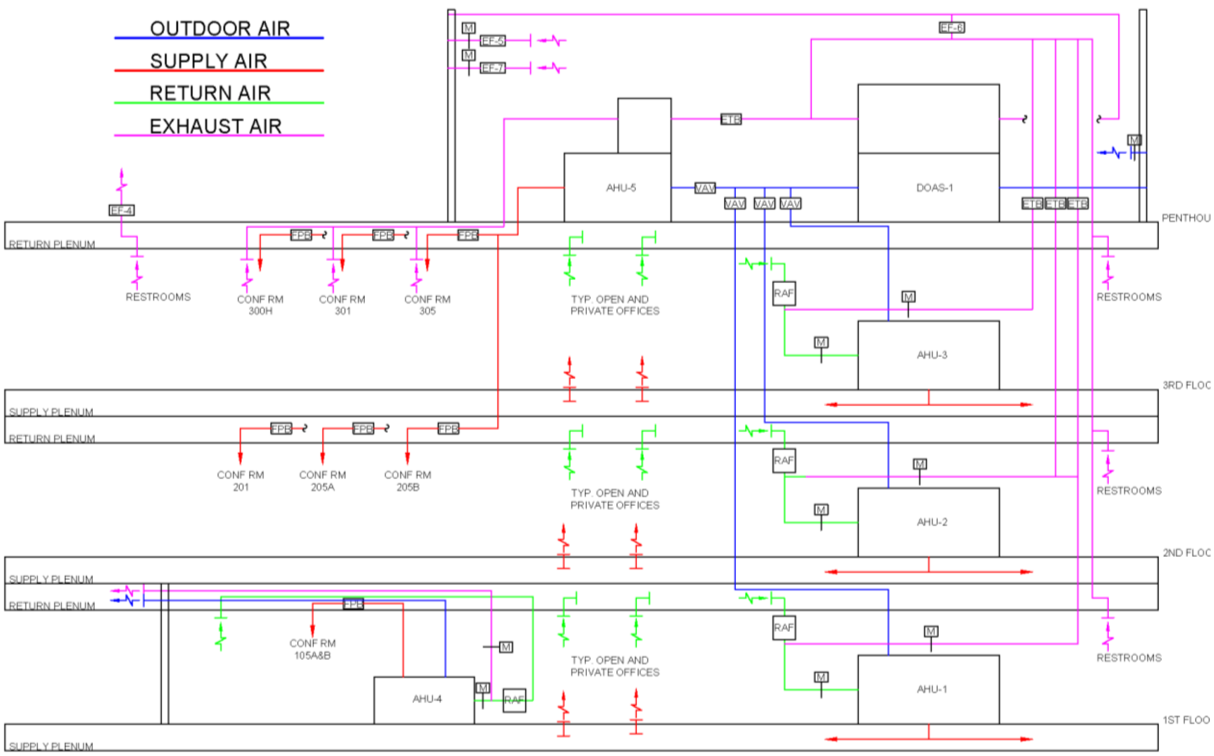

Figure 17 - Air Riser Diagram

AHU-5, which is seen in the penthouse in Figure 17, supplies air to the second and third floor conference room with overhead supply and return, and is also connected to the DOAS unit. Each of these conference rooms has individual carbon dioxide and temperature sensors, unlike the UFAD system, which groups areas into zones for temperature sensor control.

As seen in the figure, there are five variable air volume (VAV) boxes located in the penthouse on each branch of the outdoor air supply from the DOAS unit. This allows for control of the amount of outdoor air being supplied to each AHU.

The AHU on the first floor in the schematic (AHU-4), which is not connected to the DOAS unit, supplies the large conference rooms on the first floor. It has individual exhaust and its own outdoor air intake, which are located on the west wall of the building under the overhang with the exhaust further south and ducted away from the outdoor air intake.

Although the AHU's do not all serve the same purpose, they all have the same basic controls and operation. Figure 18 shows the components that are a part of every AHU, including supply and return fans, temperature sensors, smoke detectors, chilled and hot water coils, and a high static shutdown on the supply. Additionally, AHU-1, 2, and 3 have humidity sensors on the supply air, and are equipped with CO_2 demand control. Each AHU's control sequence of operations is programmed to handle supply air temperature set points for heating and cooling mode, and return air humidity limits. Not shown in the schematic are the variable frequency drive (VFD) devices on each fan, which is typical for all AHU's.

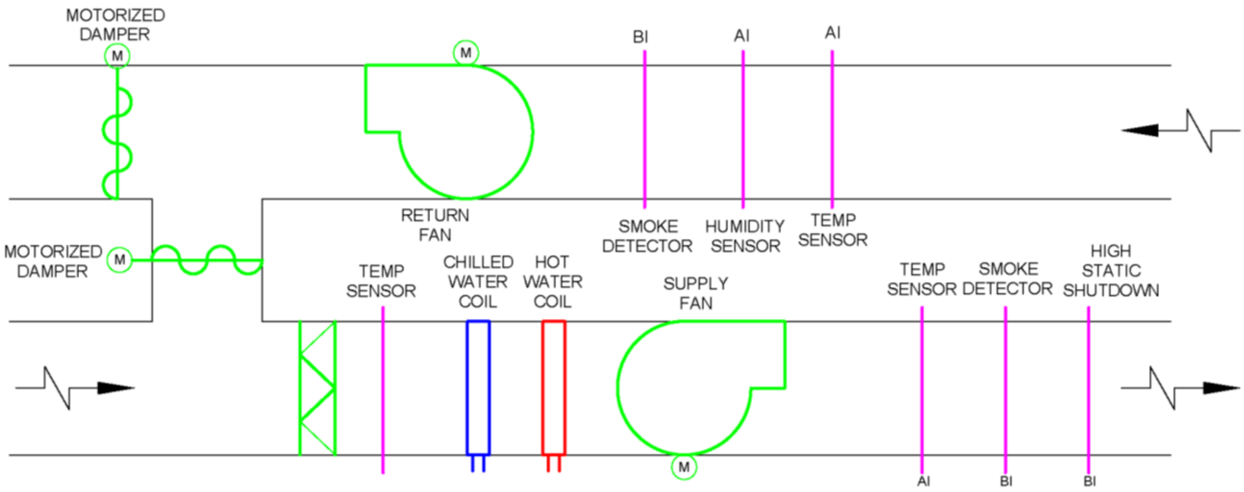

Figure 18 - AHU Schematic

In addition to the AHU's, blower coil units (BCU) serve the atrium and lobby spaces, and fan coil units (FCU) are used for the IT rooms on each floor. There are some areas that are not directly supplied, which include spaces such as stairwells, elevators, restrooms, kitchenettes, mechanical rooms and electrical rooms. A floor plan with this basic breakdown is given below in Figure 19:

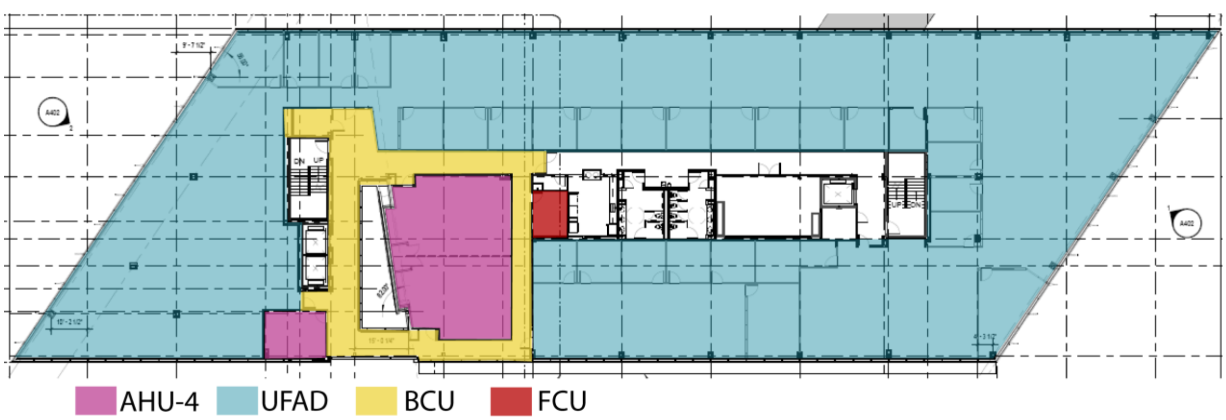

Figure 19 - Second Floor Air Side Supply; floor plan from CD provided by H.F. Lenz Co.

Mechanical System Costs

MECHANICAL SYSTEMS FIRST COSTS

The Whiting-Turner Contracting Company provided the budget for AOB1, broken down loosely by division. The overall building budget was $26,115,000. The costs associated with the HVAC system were split into mechanical and geothermal:

- Mechanical budget: $2,778,933
- Geothermal budget: $413,887

The total cost for the entire mechanical system was approximately $3,193,000, about 12.2% of the total budget. On a building area basis, this is loosely $40.42 per square foot. The pie chart below (Figure 20) shows a breakdown for the budget by division. It is important to note that Division 15: Mechanical includes the sprinkler system, which was not included in the HVAC data above.

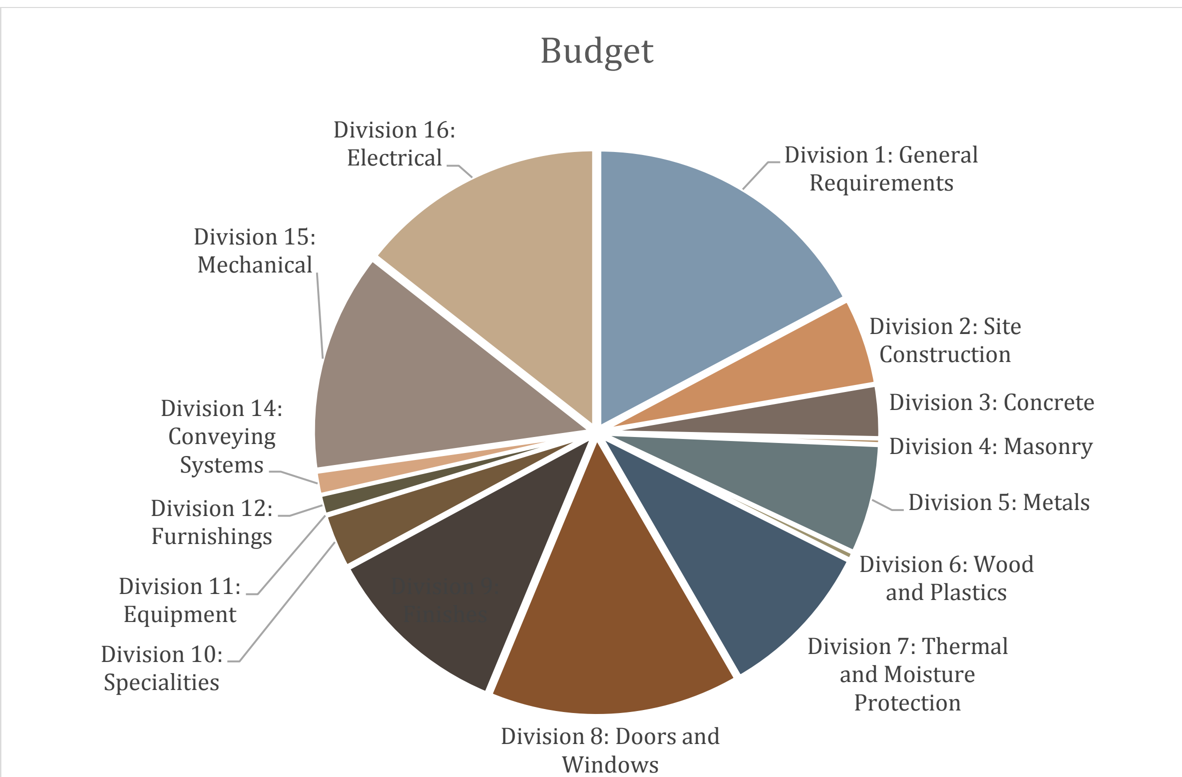

Figure 20 - Budget Breakdown by Division

OPERATING HISTORY

Real electrical data from the whole building meter and submeters were obtained from the owner. Extraneous information that was not included in the TRACE 700 model was removed, and the real-life kWh consumption of the building, which was from years 2013 and 2014, was compared with the results of the energy model. This comparison, displayed in Table 16, shows that the TRACE 700 model range was usually within 15% of the real monthly data and only 5.15% lower than the real yearly data. Overall, this is considered a fairly accurate energy model.

Table 16 - Building Submeter Data and Energy Model Monthly Energy Use

(thousand kWh)	Jan	Feb	Mar	Apr	May	Jun	Jul
Real-life data:	84.25	80.1	72.93	76.82	105.9	99.27	112.8
TRACE 700 results:	84.35	77.6	80.92	70.88	73.84	88.15	91.61
% difference:	(0.12)	3.12	(10.96)	7.73	30.27	11.20	18.79

(thousand kWh)	Aug	Sept	Oct	Nov	Dec	Total
Real-life data:	80.93	70.67	70.78	83.93	99.59	1038
TRACE 700 results:	92.96	78.21	79.64	76.26	90.04	984.5
% difference:	(14.86)	(10.67)	(12.52)	9.14	9.59	**5.15**

Equipment and Space Requirements

COOLING AND HEATING PLANT EQUIPMENT

The cooling and heating requirements of AOB1 are served by a geothermal transfer field. Two buffer tanks, one for heating and one for cooling, accompany this system. No additional boilers or chillers are used. The well field is connected to six equally sized water-to-water heat pumps, with characteristics shown in Table 17. These heat pumps are provided with two sets of three-way control valves, which allow the pumps to switch between cooling and heating operation, and are equipped with variable frequency drives.

Table 17 - WWHP Schedule

	REF	COOLING MBH	EER	HEATING MBH	COP	GPM	SOURCE PD (FT)	LOAD PD (FT)
WWHP-1, 2, 3, 4, 5, 6	R-410a	345	14	296.5	3.25	86	3.5	4.4

The conditioned water is supplied to coils inside the air handling units, fan coil units, unit heaters, energy recovery wheel, blower coil units, and hot water coils in fan powered boxes.

AIRSIDE EQUIPMENT

The main air distribution system in the building is an under floor air distribution system (UFAD). Each floor contains a mechanical room with one air handling unit, AHU-1, 2, and 3, which service this system on each respective floor. These air handling units do mixed air and conditioning at the unit, and receive ventilation air from a dedicated outdoor air system (DOAS) located in the penthouse mechanical room. This unit is equipped with an energy recovery wheel and preconditions the outdoor air before supplying the other air handling units for further conditioning and distribution. The supply to each air handling unit, AHU-1, 2, 3, and 5, is controlled by variable volume boxes for each. AHU-1, 2, and 3 are equally sized units serving the UFAD systems. AHU-5, which is also supplied from the DOAS unit and is located in the penthouse, services the second and third floor conference rooms. None of these air handling units are equipped with a return air fan.

AHU-4 is not supplied by the DOAS unit. Instead, it has its own individual outdoor air supply in the first floor mechanical room, which is located next to the first floor conference rooms which is supplies. This unit does contain a return air fan, with a static pressure of 1.55 inches, 93% efficiency and a variable frequency drive.

Table 18 - AHU and DOAS Schedule

				COOLING COIL		HEATING COIL
	TOTAL CFM	% OA	EXT SP (IN)	TOTAL MBH	SENS MBH	TOTAL MBH
AHU-1, 2, 3	17000	18	1.5	234	231	237.6
AHU-4	2600	30	2	100	59.7	37.7
AHU-5	6500	30	2	150.6	107.7	48.2
DOAS-1	11000	100	0.3 INITIAL 0.7 FINAL	633	402	345

The airflow and cooling and heating capacities of each unit are given in Table 18. All air handling units are equipped with a MERV-7 pre-filter and a MERV-13 final filter, and are three phase, 460 Volts and equipped with variable frequency drives. The DOAS unit has a MERV-8 filter. The energy recovery wheel connected to the DOAS unit has a total summer efficiency of 64% and a total winter efficiency of 65.6%.

In addition to the main air distribution equipment, the building also contains fan coil units for the IT rooms, unit heaters for vestibules and stairwells, and blower coil units for the atrium and lobby, with various heating and cooling characteristics (Table 19). The fan powered boxes, used at the perimeter of the building for the UFAD system, are each equipped with hot water coils. These coils range from 5.8 MBH to 35 MBH and 1 GPM to 4.7 GPM, and have either 1 or 2 rows of coils. All fan powered boxes are single phase, 277 V.

Table 19 - Misc. Airside Equipment Schedule

		COOLING COIL		HEATING COIL	
	CFM	MBH	GPM	MBH	GPM
FCU-1	660	11	11	-	-
FCU-2	235	8.5	1.7	-	-
CUH-1	166	-	-	5.43	0.38
CUH-2	438	-	-	10.5	0.73
CUH-3	139	-	-	4.94	0.4
HUH-1	245	-	-	8	0.8
HUH-2	580	-	-	24.8	2.5
BCU-1	1200	45	9	101	10.1
BCU-2	800	24	4.8	18.7	1.3

Table 20 - Exhaust Fan Schedule

	CFM	STATIC PRESSURE
EF-1, 2, 3, 8	75	0.125
EF-4	150	0.75
EF-5	400	0.75
EF-6	3125	1
EF-7	1300	0.75

The exhaust fans for the building, which serve spaces such as the restrooms, kitchenettes, and mechanical and electrical rooms, have a wide range of characteristics, as shown in Table 20. They are controlled by either thermostats, sensors, or the BAS system.

PUMPS

Although there is only one supply of conditioned water from the heating and cooling plant, there are separate sets of pumps for heating and cooling. There are two heating water pumps, in duty/standby operation, and are two sets of duty/standby pumps for the chilled water, making for a total of four chilled water pumps. All hot water and chilled water pumps are equipped with variable frequency drives. The GPM, efficiency and feet of head provided by each pump can be found in Table 21.

Table 21 - Pump Schedule

	GPM	FT HD	EFF
HWP-1, 2	394	48	76
CWP-1, 2	135	38	68
CWP-3, 4	150	46	63.8
HPP-1, 2, 3, 4, 5, 6	86	46	64
GWP-1, 2	540	92	80

Each water-to-water heat pump is equipped with one inline pump, in the duty operation. The geothermal transfer field also has its own set of duty/standby pumps, which is constant speed.

SPACE REQUIREMENTS

There are 500 square foot mechanical rooms on each floor for the UFAD system, and an additional 275 square foot mechanical room on the first floor for the air handling unit for the conference rooms. The main mechanical equipment is located in a rooftop penthouse, another 4,000 square feet. Altogether, the mechanical rooms take up 5,775 square feet of floor space. The shaft space is included in this area. In addition to the horizontal floor space consumed by the mechanical equipment, the vertical height of the building had to account for the under floor supply air plenum and the ceiling supply air plenum, which added to the building height.

LEED Evaluation

The USGBC's Leadership in Energy and Environmental Design (LEED) rating is a system which measures a buildings performance and sustainability in design. A checklist is submitted for a project and a point system is used. There are four ratings, from lowest to highest: certified, silver, gold, and platinum. AOB1 had a design goal of a gold rating, but received a platinum rating based on LEED for New Construction v2.2. The following is an assessment of the current standard, which is v4.

ENERGY AND ATMOSPHERE

EA Prerequisite 1: Fundamental Commissioning and Verification

This prerequisite requires that new construction work be commissioned. A commissioning plan was created for AOB1, and therefore the prerequisite requirements were met.

EA Prerequisite 2: Minimum Energy Performance

The purpose of this prerequisite is to provide a minimum energy improvement over ASHRAE Standard 90.1 baseline. AOB1 would have complied with Option 1: Whole-Building Energy Simulation. According to the original LEED submittal, this requirement was met and exceeded at 28%.

EA Prerequisite 3: Building-Level Energy Metering

This prerequisite did not exist in v2.2. New construction is required to provide building-level energy meters or submeters. AOB1's electrical system was set up for remote monitoring of the electrical meter through the building's energy management control system. Electrical submetering was also specified in Specification Section 262713.

EA Prerequisite 4: Fundamental Refrigerant Management

This requirement states that no CFC's are to be used in new construction. The HVAC system uses chilled and hot water, and the refrigerant used in the water to water heat pumps is R410a. No CFC's were specified.

EA Credit 1: Enhanced Commissioning (3/6)

The intention of this credit is to encourage commissioning early in the design phase as well as continuously through building occupancy, but enhanced energy, water, indoor environmental quality, and durability.. AOB1 qualifies for at least three points with this credit, for the enhanced commissioning in option 1. It is unknown if the building meets all requirements for the additional point from monitoring-based commissioning.

EA Credit 2: Optimize Energy Performance (12/20)

This credit outlines points awarded for improvement percentages over an energy baseline for new construction. According to the original LEED scorecard, AOB1 fell into the 31.5% improvement category (meaning it ranged between 31.5% and 34.9%), and has been moved down to the 29% category for the new version, since the exact value of improvement was unknown.

EA Credit 3: Advanced Energy Metering (0/1)

Compliance with this credit allows for building-level and system-level energy use tracking to save energy. It is not known if all required characteristics of the energy metering system were met to comply with this credit.

EA Credit 4: Demand Response (0/2)

This credit requires participation in an available demand response program or that infrastructure is provided in the design to incorporate future demand response programs. It is unknown if a demand response program was anticipated or participated in.

EA Credit 5: Renewable Energy Production (1/3)

If renewable energy is produced on site, points may be awarded if a minimum percentage of energy is anticipated to come from the renewable resources. The number of points awarded are based on that percentage. The original LEED v2.2 scorecard listed that at least 2.5% of the buildings energy came from renewable energy. The new point system is based on 1%, 3%, 5% and 10%. Since the exact amount of renewable energy anticipated is unknown and cannot be assumed to be at least 3%, compliance with 1% is conservatively assumed.

EA Credit 6: Enhanced Refrigerant Management (1/1)

The first option for this credit is awarded if no refrigerants are used, or if the refrigerants have a ODP of zero and GWP less than 50. If this requirement is not met, a calculation can be made for the refrigerant impact. R410a is the only refrigerant used in the system. This refrigerant has an ODP of zero, but the GWP is greater than 50 and therefore does not meet the requirements of option 1. The calculation for option 2 has not been changed since v2.2, for which a point was awarded in the original scorecard.

EA Credit 7: Green Power and Carbon Offsets (0/2)

This credit requires that at least 50% of energy be from green power or carbon offsets. In LEED v2.2, this minimum value was 35% and the point was earned. It is unknown if AOB1 met this points requirements.

EA Credit Total: 17 points

INDOOR ENVIRONMENTAL QUALITY

EQ Prerequisite 1: Minimum Indoor Air Quality Performance

Option 1 of this prerequisite requires compliance with ASHRAE Standard 62.1-2010. Through the calculation done in Technical Report 1: ASHRAE Standard 62.1 Ventilation and Standard 90.1 Energy Design Evaluations, it was found that with the final furniture layout design, compliance with this standard was not met. However, using the population densities provided in the Standard over the final furniture layout, compliance would have been met. For the purpose of this report, it is assumed that this prerequisite is met.

EQ Prerequisite 2: Environmental Tobacco Smoke Control

This prerequisite limits the locations around the building in which smoking is acceptable. AOB1's design intention fulfilled this prerequisite.

EQ Prerequisite 3: Minimum Acoustical Performance

This requirement does not apply to AOB1.

EQ Credit 1: Enhanced Indoor Air Quality Strategies (1/1)

This credit specifies strategies to improve indoor air quality. Option 1 addresses requirements for different space types. Below is a summary of these requirements:

- Entry way system for the first ten feet into building from entrance
- A minimum of 0.5 CFM/SF of exhaust to prevent cross-contamination from janitors closets and restrooms
- Minimum of MERV 13 filter on AHU's supplying outdoor air
- Compliance with CIBSE Applications Manual

While the first three requirements are met, it is unknown if the design complied with CIBSE, and therefore compliance with this option is unknown. However, Option 2 is based on ventilation types. One means of fulfilling this requirement was to provide a 30% increase over the minimum ventilation requirements. In the original design, based on the population densities provided in ASHRAE Standard 62.1, this requirement was fulfilled. Out of consistency with EQ Prerequisite 1, these original design calculations are assumed to be correct.

EQ Credit 2: Low-Emitting Materials (0/3)

The purpose of this credit is to reduce harmful chemical contaminants. In LEED v2.2, all requirements for this credit were met. However, the compliance method changed from specific volume amounts to threshold percentages. It is unknown if all materials meet these threshold values.

EQ Credit 3: Construction Indoor Air Quality Management Plan (1/1)

This credit addresses indoor air quality during the construction phases. This credit was acquired for the original evaluation, which had it split between during construction and before occupancy, and has had little change. Therefore, it is assumed that this credit is still applicable.

EQ Credit 4: Indoor Air Quality Assessment (1/2)

This credit deals with indoor air quality after construction. Option 1 of this credit is similar to the second part of LEED v2.2 Indoor Air Quality Management Plan for before occupancy, addressed above. Again, it is assumed that this credit still applies. Option 2 is also similar to the previous version, but has stricter concentration limitations. Therefore, it cannot be assumed that the second point would be achieved.

EQ Credit 5: Thermal Comfort (1/1)

Compliance with this credit requires the design to take into account thermal comfort standards through either ASHRAE Standard 55 or ISO and CEN Standards. Additionally, it requires thermal comfort controllers be provided for at least 50% of occupant spaces. LEED v2.2 had a credit for Thermal Comfort Design, which was achieved. The requirements are approximately the same, with the ASHRAE Standard year having been changed. For the purpose of this report, it is assumed to comply. As for thermal comfort controls, the interior offices are on a single control zone and contain one occupant controlled floor diffuser. Open offices also contain occupant controlled floor diffusers, providing air speed comfort controls for most of the building. Therefore, this credit is met.

EQ Credit 6: Indoor Lighting (1/2)

Indoor Lighting is split into two options, each worth one point: control and quality. For control, at least 90% of individual occupant spaces must provide individual lighting controls, multizone control in multioccupancy spaces, lighting for presentation or projection walls separately controlled, and the controls located within sight of luminaires. This credit is similar to LEED v2.2 EQ Credit 6.1: Controllability of Systems: Lighting, which was obtained. This previous credit did not specify that at least three lighting levels should be used, but according to the bridging document narrative, which was used as the lighting basis of design, this requirement is met.

The lighting quality option provides a list to choose four strategies from. It is unknown if the building complied with at least four of these strategies, therefore this point is not assumed to be awarded.

EQ Credit 7: Daylight (2/3)

The intent of this credit is to reduce electrical lighting through the means of natural daylight. Again, this credit is similar to LEEC v2.2 EQ Credit 8.1: Daylight and Views: Daylight 75% of Spaces, and is assumed to comply with the new version following either Simulation Option 2 or Measurement Option 3 for 75% of occupied floor area.

EQ Credit 8: Quality Views (1/1)

This credit is similar to LEED v2.2 EQ Credit 8.2: Daylight & Views: Views for 90% of Spaces. LEED v4 specifies more requirements for the kinds of views, but it is still assumed that this credit is met.

EQ Credit 9: Acoustical Performance (0/1)

Acoustical performance must meet certain HVAC background noise, sound transmission, reverberation time, and sound reinforcing and masking system requirements. Although the basis of design for sound attenuation specified an HVAC NC level, it is unknown if any calculations or measurements were made for any acoustical performance. Because of this, no points were assumed to be achieved from this credit.

EQ Credit Total: 8 points

LEED SUMMARY

Between the Energy & Atmosphere credits and the Indoor Environmental Quality credits, the same number of points are expected to be awarded through LEED v4 as were awarded in the original v2.2 version. However, more EA points and fewer EQ points were earned.

Table 22 - LEED Versions Point Comparison

	EA	EQ
LEED v2.2	10/17	15/15
LEED v4	17/33	8/16

As seen in Table 22, there were more points available for each category in the newer version than the previous version. The cutoffs for each LEED rating has also been adjusted as more points were added. The original cutoffs were as follows:

- Certified: 26-32
- Silver: 33-38
- Gold: 39-51
- Platinum: 52+

AOB1 received 52 credits, pushing it just over the Platinum rating. The new system has the following breakdown:

- Certified: 40-49
- Silver: 50-59
- Gold: 60-79
- Platinum: 80+

Due to the change in point distribution and that the EA and EQ point total did not increase, it is assumed that the building would no longer comply with the Platinum certification requirements.

System Evaluation

The design goal of AOB1 was to create an energy efficient and comfortable space for the occupants. This goal was relatively well achieved. Per LEED v2.2, the building received a Platinum rating, and would be expected to receive at least minimum certification per LEED v4. The site has an anticipated EUI of 48, below the national average of 67.3, and an operating cost that is 46% of the national average for office buildings. The average mechanical cost per square foot was $40.42, a higher than normal number, which is to be expected with energy efficient design strategies.

The outdoor air requirements were met and exceeded for all office spaces, with the only exception being the first floor conference rooms, which had a final furniture layout that exceeded the original design occupant density. The under floor air distribution system is equipped with adjustable floor diffusers that allow occupants to individually adjust their supply.

Overall, the mechanical design of AOB1 met design objectives. Evaluation of alternative system layouts may present more design options that further satisfy these goals. These alternative strategies, and others which are determined to be considerable options for analysis, are further discussed in parts 2 and 3 in this report below.

Part 2: Building Alteration Proposal

Depth Options

The existing building design meets all the needs of AOB1. However, alternative systems and components could be examined to determine if a more efficient design may have been viable. Options considered for an in-depth analysis include mechanical system design changes and envelope alterations. Options considered include the following:

- **Variable refrigerant flow (VRF):** This alternative, which would be used in the areas served by the UFAD system, would possibly allow a shorter floor-to-floor height by reducing the size of the ductwork required, as only ventilation air would need to be circulated in those spaces. It may also remove the need for the air handling units on each floor that supply the under floor air distribution system.
- **Chilled beams:** This alternative may provide improvements in occupant comfort in the areas supplied by the UFAD system, as well as reduce energy usage in the summer months by allowing the air to naturally mix through the space.
- **Mixed-mode air system:** A mixed-mode air system might consist of mechanically operable windows that would have a control sequence to open the windows for natural ventilation when outdoor air temperature and humidity are ideal. However, this could compromise the acoustical comfort of the space.
- **Window type alterations:** This alternative would explore the impact different glass types would have on the building envelope load. Five types of glass would be explored: the original glass, which is a laminated low-E glazing; low-E triple glazed; double low-E triple glazed; a basic double pane glass; photovoltaic glass panels. The photovoltaic glass panels would be considered for the main window sections on the south façade, the area under the horizontal overhangs, shown on the south elevation in blue in Figure 21. Energy generated from the photovoltaics would then be used for the operation of the mechanical system.

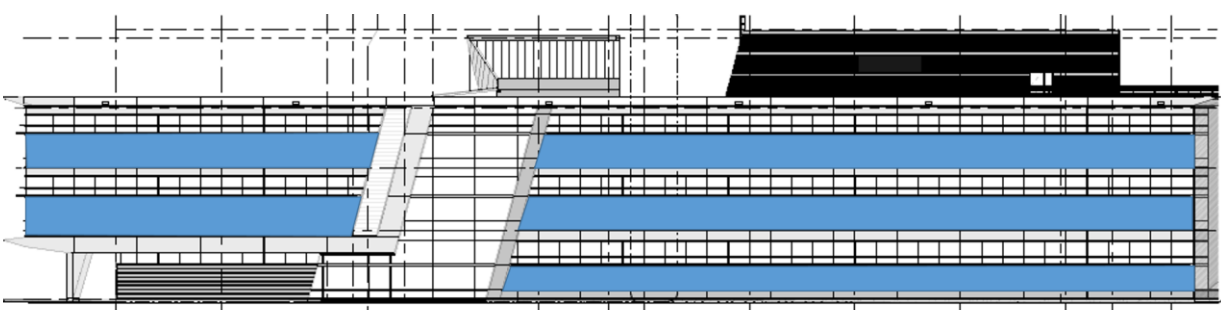

Figure 21 - South Facade: Proposed Photovoltaic Locations; elevation from CD provided by H.F. Lenz Co.

PROPOSED DEPTH

After careful consideration of each option, a decision was made to study the effects of using alternative window types on the building's envelope load, effect on mechanical equipment, and the off-site energy usage to operate the HVAC System, taking into account the energy generated by the on-site photovoltaic system for that window option. This option was chosen for educational purposes, which includes learning about the performance of photovoltaic glass and the impacts different glass types have on the mechanical system.

Six alternative glazing combinations will be studied for this depth against the original design glass. The first will include changing all windows in the curtainwall to a low-E triple glass type. The second alternative will include the triple low-E glass on the north, east, and west facades, and the windows above the horizontal overhangs on the south façade, and photovoltaic glass under the overhang on the south façade. The same two alternatives will be done with double low-E triple pane glass, and a basic two pane glazing system on every window of the building will be tested. The final alternative will be the photovoltaic glass on the south façade under the overhangs only. Again, Figure 21 above shows the planned locations of the photovoltaic glass panels on the south façade.

Breadth Options

LIGHTING BREADTH

The design for AOB1 strove to create an energy efficient building that made use of natural daylight. The alternative window types to be explored have different visible light transmittance than the original windows, which will affect the daylighting. Therefore, a lighting calculation must be performed to determine if the new daylight levels will affect the ability to naturally light the space. Additionally, the electrical lighting system was designed to provide at least 45 foot candles to the task surface. Current suggested design is between 30 and 50 foot candles, leaving room for a possible reduction. A new lighting plan will be explored for all open office areas of the building to determine if the number of luminaires can be decreased, and cost savings will be calculated.

ENVIRONMENTAL BREADTH

The second breadth to be explored deals with life-cycle energy and emissions of the photovoltaic windows, including energy required for and emissions during production. This analysis will include a comparison of the energy required to make the windows and the emissions produced with the energy and emissions avoided with their application in the building. The main metric for comparison of emissions will be CO_2 production. The purpose of this analysis is to determine what the full life-cycle costs of the alteration would be.

Additional Resources

PRELIMINARY RESEARCH

A number of sources were used in the preliminary research for this proposal. These sources were helpful for determining the various depth options, and provide valuable information for various aspects of a building that will not necessarily correlate directly to the proposed depth.

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7. Heating, R. (2006). *ASHRAE GreenGuide: The Design, Construction, and Operation of Sustainable Buildings* (2nd ed.). Atlanta, GA: American Society of Heating, Refrigerating, and Air-conditioning Engineers.
8. Dale, M., & Benson, S. (2013). Energy Balance of the Global Photovoltaic (PV) Industry - Is the PV Industry a Net Electricity Producer? *Environmental Science & Technology,* 130312080757002-130312080757002.

TOOLS AND METHODS

A variety of resources will be used for analysis. Trane TRACE 700 will continue to be used for future load and energy simulations. The same model will be used with alternatives for each glass type, in order to remain consistent for the results comparisons. COMFEN will be used in the early phases of analysis to predict the type of results that should be anticipated from the TRACE 700 calculation, for clarification. Various publications, such as the ASHRAE Handbook and Standards and the resources listed above, will also be referenced. A hand calculation will be done for determining the energy generated by the photovoltaic glass, based on the manufacturer specifications chosen for the analysis. Programs such as AGi32 and Daysim will be utilized for the lighting breadth, and the Greenhouse Gas Equivalencies Calculator provided by the EPA will be used to determine the tons of carbon dioxide emitted.

DRAFT WORK PLAN

A draft work plan has been created for the Spring Semester and can be found in APPENDIX P2.G. The major milestones are as follow:

1. January 23rd
    a. Windows selected for analysis
    b. PV electricity output determined
    c. Trace 700 updates begun
    d. Schedule determined
2. February 13th
    a. Trace 700 façade updates finished
    b. AGI32 lighting simulation complete, DAYSIM analysis begun
    c. New lighting layout complete
    d. PV research underway
3. March 6th
    a. Lighting breadth complete
    b. Environmental breadth complete
    c. Cost analysis underway
    d. Mechanical equipment resized
4. April 3rd
    a. Final energy comparisons from depth and breadths done
    b. Cost analysis complete
    c. Final report finished

Part 3: Proposed Alterations Analysis

Depth Study: Alternative Glazing Systems

An analysis of alternative glazing systems was studied to determine a proposed redesign option. For this analysis, various types of glass were chosen and modeled in Trace 700, using the same model as Part I of this report. This model was used to produce building loads, energy consumption, and yearly operating costs. A cost analysis was performed that looked at equipment and glass costs for each type of glazing system. The goal for this analysis was to determine the effects different glazing systems would have on equipment sizing, energy consumption, construction costs, and operating costs. This information, combined with the results of the environmental and lighting breadth analyses, will determine the recommendation for the proposed redesign.

ALTERNATIVE GLAZING SYSTEMS

The manufacturer of the glass used in the building is Viracon, so alternatives were explored in this company first, in order to keep a consistent cost analysis. The original glass is laminated, so insulating glass options were explored for alternatives. Additionally, a transparent photovoltaic (PV) glass option was also explored to determine if this "green" building technology would positively affect the off-site energy consumption of the building.

As explained in Part II of this document, because the glass is part of a curtainwall system, the thermal properties had to be adjusted to reflect real performance. Data from a Kawneer product catalog was used to adjust these values, and this catalog can be found in APPENDIX P1.C. These adjusted values are displayed in Table 23. The original cut sheets can be found in APPENDIX P3.M.

Table 23 - Properties of glass types used in analysis

GLASS TYPE	MANUFACTURER	U-VALUE (ADJ)	SHGC (ADJ)
Original glass	Viracon – low-E insulating laminated	0.37	0.255
Triple Low-E	Viracon – triple insulating	0.33	0.275
Triple Double Low-E	Viracon – triple insulating w/ second low-E coating	0.29	0.24
Basic glass: double pane	NA – Trace 700 default	0.6*	0.71*
PV glass	Onyx Solar	0.42	0.37

*Note: this glass would not meet ASHRAE 90.1 requirements for this climate zone; these values are just for educational comparison purposes

Alternative A: Original glass, original daylighting

This alternative represents the existing conditions of the building, which uses an insulating laminated glass. This means that there are three layers of glass, with an air gap between the outer and middle pane, and the inner pane is laminated against the middle one.

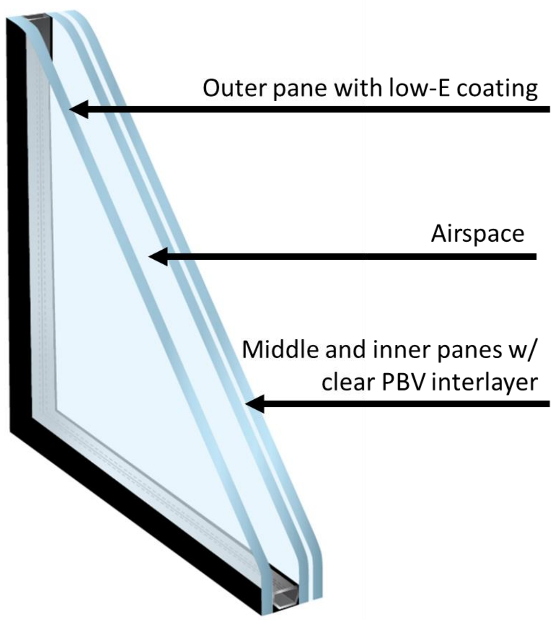


Figure 22 - Laminated insulating glass example, taken from Viracon's product guide

The "operating history" section of Part I displays the results of this particular model. In summary, the Trace 700 model yearly energy consumption results were 5.15% lower than the real-life building consumption reported from the submeters, which was provided by the owner.

- Real building consumption: 1,037,990 kWh
- Trace 700 model estimate: 984,526 kWh

Alternative B: Original glass, new daylighting plan

This alternative does not change the building façade, but instead takes into account the alterations made to the lighting plan, which are explained in the "Breadth Analysis 1: Electric and Natural Lighting" section of this report, following this depth analysis. An alternative lighting plan was created that reduced the lighting load of the building. This reduced wattage to the space was modeled in Trace 700 and resulted in a reduced cooling load and energy consumption, shown in Figure 23 and Figure 24, respectively. For more information about the lighting plan changes see Breadth Analysis 1: Electric and Natural Lighting.

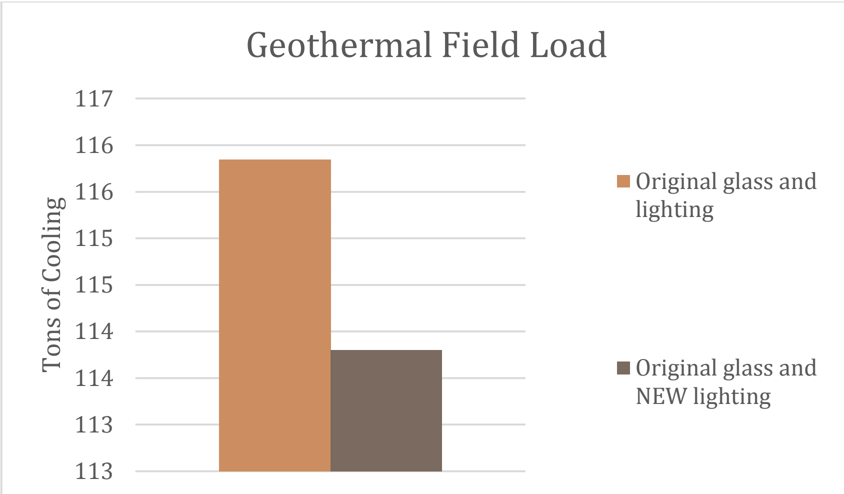


Figure 23 - Geothermal field load for design vs. new lighting plan

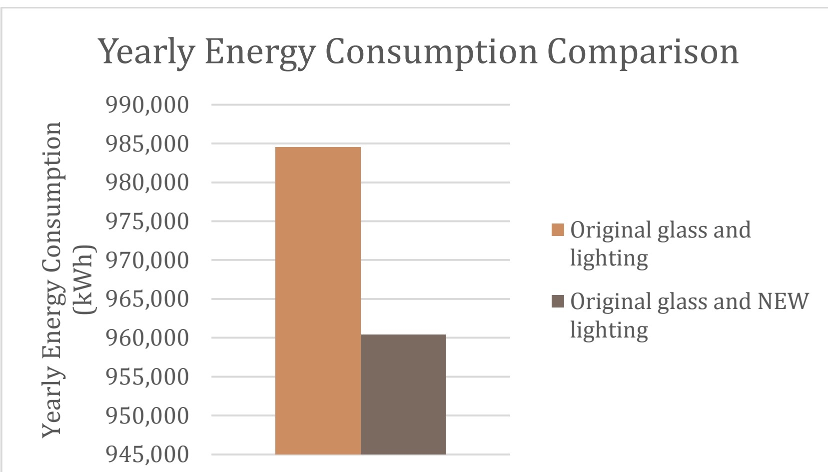


Figure 24 - Yearly energy consumption for design vs. new lighting plan

With an electrical rate structure of $0.077/kWh, which was provided by H.F. Lenz Company, this decrease in energy translates to over $1,800/year in savings.

Alternative C: Original glass + PV

The lighting plan changes were incorporated into all remaining alternatives. Alternative C implements the photovoltaic glass on the main window sections on the south façade, which are the areas highlighted in blue in Figure 25. This window section is located below the overhang, as to not interfere with the upper section of glass that is designed with a higher VLT than the lower section for daylighting. This upper section is highlighted in yellow, and is still modeled as the original glass, as is all glass on the north, east, and west facades. Additionally, the light shelves on the south façade were pulled inside so they would not shade the photovoltaics. The shading from the light shelves is not needed with the lower VLT of the PV.

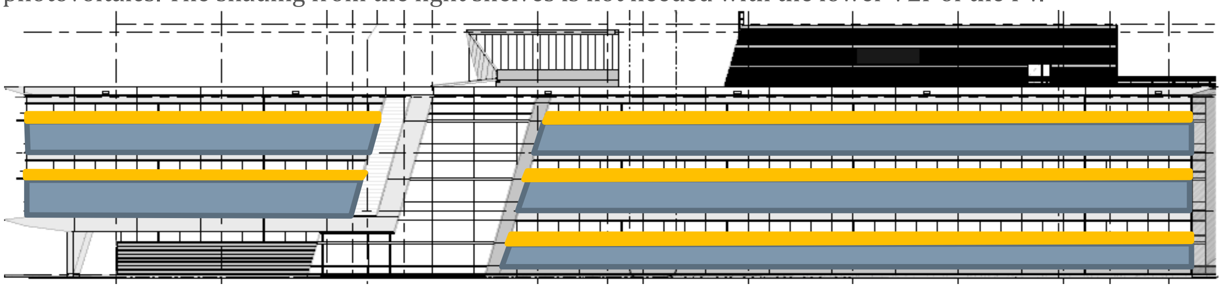


Figure 25 - Alternative C south elevation with PV glass sections highlighted; elevation from of CD provided by H.F. Lenz Co.

Onyx Solar's PV glass is made by applying a thin film amorphous silicon (a-Si) layer on top of a standard single spacer, low-E glass. The PV layer is then etched off to allow the desired amount of transparency, which is 30% in this case.

Alternative D: Triple low-E

Viracon has a triple insulating glass similar to their insulating laminated glass. In this system, there are equally sized air gaps separating all three panes. One low-E coating is applied to the outer layer of glass. See Figure 26 for component placement example.

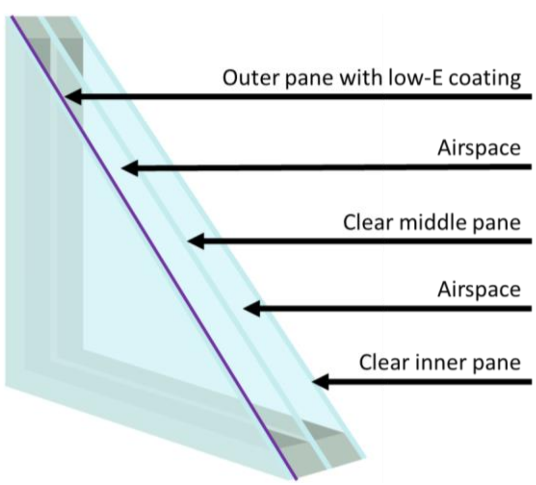


Figure 26 - Triple insulating low-E glass example, from Viracon's product guide

This glass alternative replaces the original glass on the entire building, and does not incorporate the PV glass system on the south façade.

Alternative E: Triple low-E + PV

A combination of Alternative A and D, this system combines triple low-E and PV glass. The PV glass is located on the south façade in the same spots shown in Figure 25, and the remaining glass on the building is the triple low-E type.

Alternative F: Triple double low-E

Viracon also produces a triple insulating glass with two layers of the low-E coating, instead of one as the previous alternatives had, shown in Figure 27. This glass is used on the entire building.

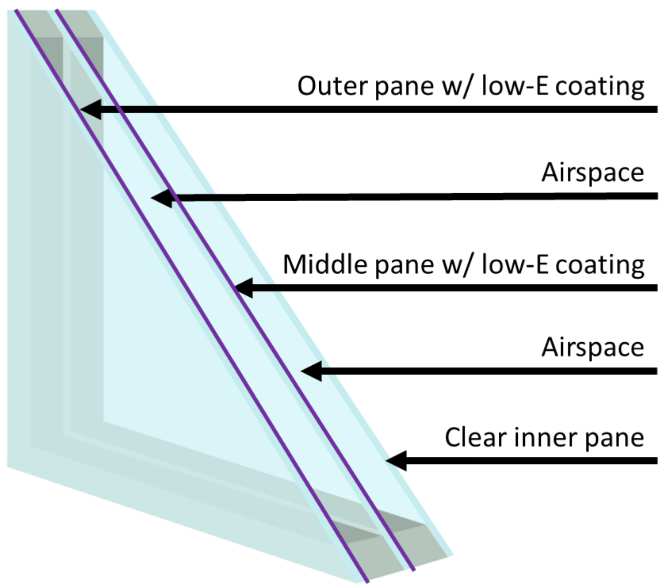


Figure 27 - Triple insulating double low-E glass example, from Viracon's product guide

Alternative G: Triple double low-E + PV

Again, the PV is located in the same areas shown in Figure 25, but this alternative uses the triple insulating glass with double low-E coating.

Alternative H: Basic glass: double panes

A basic double pane glass type, which was a default option in Trace 700, was analyzed as a basis of comparison for the other alternatives. This glass type would not comply with ASHRAE Standard 90.1-2013 for this climate, so it is not an option for a proposed redesign. It is used in place of the original glass on all part of the building.

LOAD/ENERGY MODEL RESULTS

Part I: Design Load Estimation - Load analysis results summarized the results of the Trace 700 model and compared them to the design loads. For continuity, the analysis in this section only compares results between the original Trace 700 model and alternatives.

The first step of analysis was to determine if the geothermal transfer field design had sufficient capacity to handle each alternative. Because the site does not allow room for an expansion of the field, if alternatives required to a higher load than the field was designed for they would not have been considered for further analysis. A graph of the block loads for each alternative is displayed in Figure 28. The field is designed to handle 130 tons of cooling, which was found to be sufficient to handle all alternatives, except the basic glass type, which requires 139 tons of cooling. Because the basic glass type is only used for a basic comparison with the other loads, it was still utilized throughout the rest of this analysis.

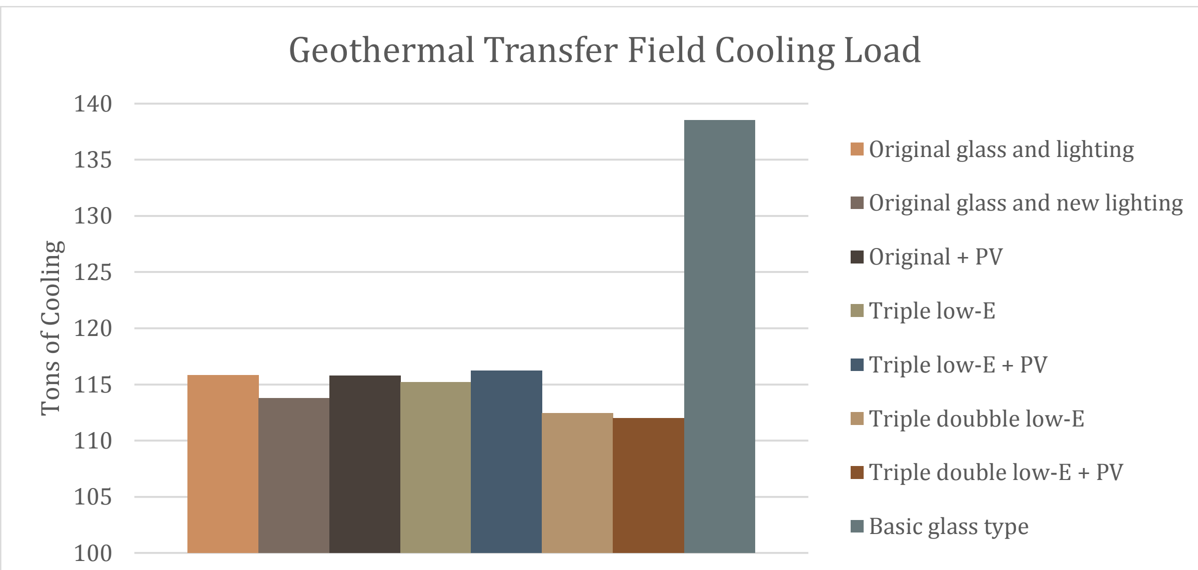


Figure 28 - Geothermal transfer field cooling ton capacity for alternatives

Recall that AHU-1, 2 and 3 service the office areas on floor 1, 2 and 3, respectively. A comparison of the cooling loads for the alternatives can be seen in Figure 29 and are based on peak load requirements, not block loads. As the graph shows, the basic glass type has the largest cooling requirement, as expected. This cooling load is 123-133% of the original design load for each air handling unit. The triple low-E + PV and original glass + PV alternatives have the same or slightly higher cooling loads for each of the air handling units. All other alternatives have at least slightly lower cooling loads, with the lowest cooling loads being that of both triple double low-E alternatives. Due to the lower solar heat gain coefficient (SHGC), the triple double low-E alternative with the PV glass produced a lower peak load than the alternative without it, even though the PV glass has a higher U-value. The same comparative trends are seen in the peak heating loads in Figure 30.

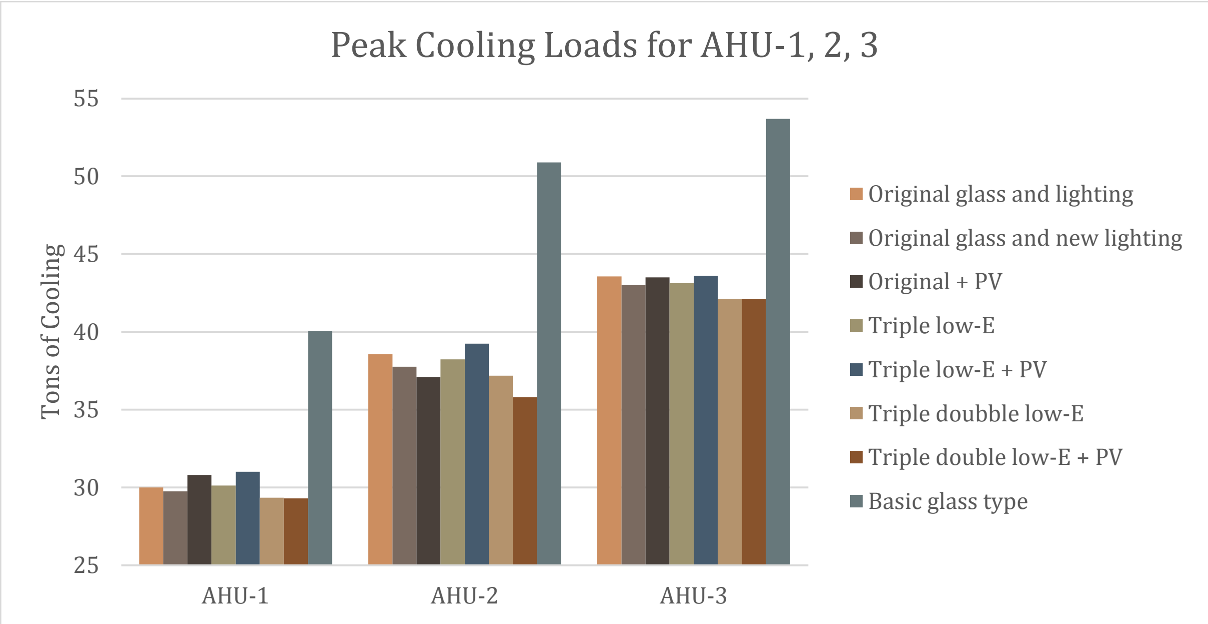


Figure 29 - Peak cooling loads for AHU-1, 2 and 3 for alternative glazing systems

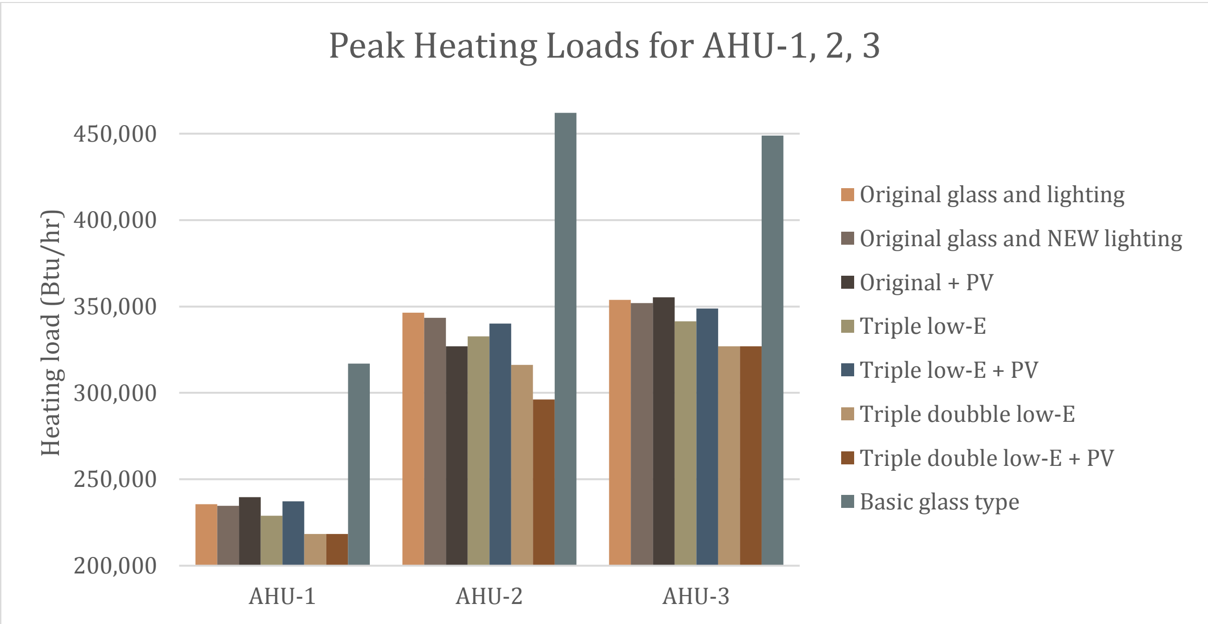
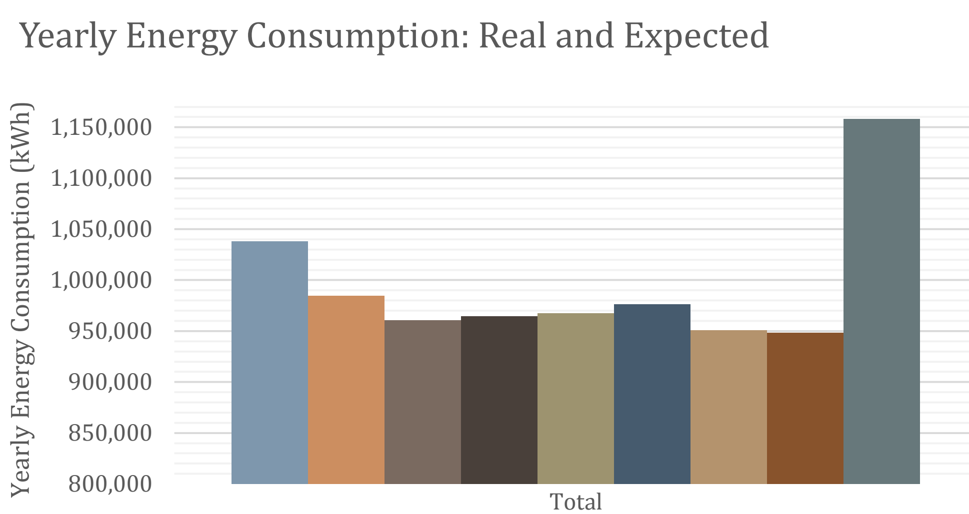


Figure 30 - Peak heating loads for AHU-1, 2 and 3 for alternative glazing systems

Equipment schedules with airflows and cooling and heating loads for the air handling units can be found in APPENDIX P3.H.

The yearly energy consumption was also analyzed and is displayed in Figure 31. Unlike the previous graphs, this graph also displays the real yearly energy consumption recorded by the building sub-meters, which was provided by the owner. The yearly energy consumption relatively follows the geothermal trend, with the exception of the trend in the triple low-E and original + PV alternatives. The total combined block loads for the original + PV alternative were higher than the loads for the triple low-E alternative. This was also observed for AHU-1 and AHU-3. However, for AHU-2, the original + PV alternative required a lower load, and this impacted the yearly energy consumption of the system enough to make the energy use of the original + PV option the lower of the two.



	Total
Real monthly total	1,037,990
Original glass and lighting	984,526
Original glass and NEW lighting	960,399
Original + PV	964,375
Triple low-E	967,089
Triple low-E + PV	976,339
Triple doubble low-E	950,768
Triple double low-E + PV	948,017
Basic glass type	1,157,847

Figure 31 - Yearly energy consumption for each glazing system and real energy reports

A photovoltaic estimation tool provided by Onyx Solar anticipated a production of 1,451 kWh a year, less than 0.2% of the yearly energy consumption of each alternative. For more information about Onyx Solar's product, see Breadth Analysis 2: Emissions Analysis of PV Glass.

Based on these monthly building energy consumptions and the default resource utilization factor in Trace 700 (33%), and the emission factors referenced in Figure 15 - Emission Factors from NREL Source Energy and Emission Factors for Energy Use in Buildings 2007, total pounds of pollutants were determined for each alternative. These values are displayed in Table 24. The triple double low-E alternatives had the lowest energy consumption, with the PV option being the lower of the two. This alternative saved almost 375 MMBtu/year of energy, 180 million lbs of CO_2, 329 lbs of NO_x, 939 lbs of SO_x and 10 lbs of PM10 from the original design.

Table 24 - Various emissions per year for source energy consumption of alternatives

EMISSION FACTORS FOR EASTERN U.S. (LB/KWH)		CO2:	1.6400	SOX:	0.0086	
		NOx:	0.0030	PM10:	0.0001	
	Total source energy (kBtu/yr)	Total source energy (kWh/yr)	CO2 (lb)	NOx (lb)	SOx (lb)	PM10 (lb)
Original glass and lighting	10,081,540	2,954,899	4,846,035	8,865	25,323	274
Original glass and new lighting	9,834,494	2,882,490	4,727,284	8,647	24,703	267
Original + PV	9,875,242	2,894,433	4,746,871	8,683	24,805	268
Triple low-E	9,902,983	2,902,564	4,760,206	8,708	24,875	269
Triple low-E + PV	9,916,958	2,906,660	4,766,923	8,720	24,910	269
Triple double low-E	9,735,911	2,853,596	4,679,897	8,561	24,455	264
Triple double low-E + PV	9,707,685	2,845,323	4,666,329	8,536	24,384	263
Basic glass type	11,856,378	3,475,104	5,699,171	10,425	29,782	322

COST ANALYSIS

The cost analysis for each glazing system consists of a calculation of the glass itself, the air handling equipment for the alternatives, including the energy recovery unit, and a 20 year life cycle. 20 years was chosen for the life cycle because it is the minimum anticipated life of the photovoltaic glass.

Viracon provided a cost breakdown for their glass types, which are as follows:

- Triple IGU VRE1-54 (triple low-E): $27.80/ft^2
- Triple insulating VRE1-54 (triple double low-E): $29.40/ft^2
- Insulating laminated w/ low-E (original glass): $21.50/ft^2

Onyx Solar was not able to provide an estimate for their glass. However, an article written for The Guardian expressed an increase of only 10% cost for "solar glass" over original glazing for a British firms product [13]. Another article from PV Magazine, "Smart Glass", expressed a cost for a Hybridsil Solar Coating technology from NanoSonic of only $1/ft² [14]. According to RSMeans Assemblies Cost Data 2015, an "insulating ½" thick, two lite, 1/8" float, clear" glass panel costs $11.10/ft². Because the two PV coating cost estimate methods are close in price (10% of $11.10 is $1.10), the 10% estimate was used. An additional $1.60/ft² was added to this estimate to account for the low-E layer, based on the value provided by Viracon, making a total cost of $13.80/ft² for the PV glass. The bare RSMeans value was used for the basic glass system.

The glass analyzed makes up a total area of 15,202 ft², with 3,575 ft² of that total dedicated to the PV glass for the respective alternatives, and 11,627 ft² non-PV.

Because the PV glass is about half the cost of the other low-E options, it has a lower first cost than the other systems. Because there are photovoltaics in the building already, the PV system could be incorporated in to the existing system, which would have less of a financial impact for additional equipment. However, an additional cost would be added for the increased capacity of a DC to AC inverter. The 2015 RSMeans Green building Cost Data average cost of a DC to AC inverter to be about $0.85 per Watt of power produced. With 7,440 W of power produced by the system, that would translate to an additional $6,324 for each PV alternative. Another estimate from an article on Energy Informative's website estimated that an inverter would cost about 10% of total costs of PV panels. With the PV section of glass costing about $40,000 ($11.10/ft² base cost and 3,575 ft²), this estimates about $4,000 for an inverter. An average cost of $5,159 was factored in to the PV options, and the following glass costs were calculated:

Table 25 - Initial costs for glass alternatives

ALTERNATIVE	CALCULATION BREAKDOWN	COST OF GLASS
Original glass	=$21.10/ft²*15,202ft²	$320,762
Original + PV	=$21.10/ft²*11,627ft² + $13.80/ft²*3,575ft² +$5,159	$295,927
Triple low-E	=$27.80/ft²*15,202ft²	$422,616
Triple low-E + PV	=$21.10/ft²*11,627ft² + $13.80/ft²*3,575ft²+$5,159	$373,828
Triple double low-E	=$29.40/ft²*15,202ft²	$446,939
Triple double low-E + PV	=$29.40/ft²*11,627ft² + $13.80/ft²*3,575ft²+$5,159	$392,431
Basic glass: double pane	=$11.10/ft²*15,202ft²	$168,742

RSMeans Mechanical Costa Data 2015 was used to estimate the cost of the five air handling units, the DOAS unit, and the energy recovery unit. This data was based on the airflow (CFM) of the units. This information is outlined in Table 26.

Table 26 - Equipment cost estimation based on values from RSMeans Mechanical Cost Data 2015

	AHU-1	AHU-2	AHU-3	AHU-4	AHU-5	DOAS (TON/ MBH)	ENERGY RECOVERY	TOTAL EQUIP COST:
Original glass and lighting								
Total SA CFM:	8728	12707	12842	2387	3812	130/1037	18085	
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000	
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**
Original glass and NEW lighting								
Total SA CFM:	8583	12232	12533	2387	3812	129/1031	17644	
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000	
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**
Original + PV								
Total SA CFM:	9166	11870	12813	2387	3812	130/1023	17882	
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000	
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**
Triple low-E								
Total SA CFM:	8831	12560	12617	2374	3812	130/1004	17958	
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000	
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**
Triple low-E + PV								
Total SA CFM:	9404	12061	12892	2374	3812	132/1027	18123	
RSMeans size used (CFM):	11500	13200	13200	3000	4000	140	20000	
Cost:	**$22,700**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$433,025**
Triple double low-E								
Total SA CFM:	8317	11876	12037	2361	3812	127/962	17113	
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000	
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**

(cont.)

	AHU-1	AHU-2	AHU-3	AHU-4	AHU-5	DOAS (TON/ MBH)	ENERGY RECOVERY	TOTAL EQUIP COST:
Triple double low-E + PV								
Total SA CFM:	8317	11003	12037	2361	3812	125/942	16699	
RSMeans size used (CFM):	9200	11500	13200	3000	4000	140	20000	
Cost:	**$20,600**	**$22,700**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$427,625**
Basic glass type								
Total SA CFM:	15568	21490	18130	2459	3812	163/1329	28017	
RSMeans size used (CFM):	16500	22000	19500	3000	4000	170	20000	
Cost:	**$32,200**	**$42,900**	**$27,900**	**$7,400**	**$9,525**	**$505,000**	**$30,400**	**$655,325**

Based on the yearly energy information from Figure 31 and the $0.077/kWh rate provided by H.F. Lenz Company, the yearly operating cost for each alternative was calculated (Table 27). All alternatives saved between $1,200 and $2,850 per year, except for the basic glass, which required $13,345 more a year to operate.

Table 27 - Yearly operating costs of alternatives

ALTERNATIVE	YEARLY OPERATING COST ($)	YEARLY SAVINGS FROM ORIGINAL
Original glass	$75,808	--
Original glass and new lighting	$73,950	$1,857
Original + PV	$74,256	$1,551
Triple low-E	$74,465	$1,342
Triple low-E + PV	$74,570	$1,237
Triple double low-E	$73,209	$2,599
Triple double low-E + PV	$72,997	$2,811
Basic glass: double pane	$89,154	-$13,345

All cost information is summarized in Table 28 below. Based on the construction data, only two alternatives yielded a positive cost compared to the original design: the original glass and new lighting system, and the original glass + PV. Over the 20 year life-cycle, the new lighting plan saved $37,154 in operating costs, and the original glass + PV alternative saved $55,867 through a combination of lower cost for the glazing system and yearly operating costs. When combined with the anticipated generation from the PV, which should save about $111/year or $2,220 overall, this is increased to a savings of $58,087.

Table 28 - Simplified life-cycle cost of glass alternatives

	TOTAL EQUIP COST:	GLASS SYSTEM COST:	1 YEAR OP COST:	OPERATING COST FOR 20 YEARS:	20 YEAR LIFE-CYCLE COST:
Original glass and lighting	$430,925	$320,762	$75,808.45	$1,516,169	**$2,267,856**
Original glass and NEW lighting	$430,925	$320,762s	$73,950.74	$1,479,015	**$2,230,702**
Original + PV	$430,925	$295,927	$74,256.85	$1,485,137	**$2,211,989**
Triple low-E	$430,925	$422,616	$74,465.85	$1,489,317	**$2,342,858**
Triple low-E + PV	$433,025	$373,828	$74,570.78	$1,491,416	**$2,298,269**
Triple double low-E	$430,925	$446,939	$73,209.13	$1,464,183	**$2,342,046**
Triple double low-E + PV	$427,625	$392,431	$72,997.30	$1,459,946	**$2,280,002**
Basic glass type	$655,325	$168,742	$89,154.20	$1,783,084	**$2,607,151**

Breadth Analysis 1: Electric and Natural Lighting

The vision for AOB1 was to create an energy efficient building. The building design makes use of dimming schedules connected to daylight sensors in the open offices. A new lighting plan for the open office spaces is being proposed to reduce the energy consumption of the artificial lighting system. Additionally, because the PV glass has the lowest visible light transmittance (VLT) of all the proposed glazing systems, an analysis was performed for a sample section of the building to determine if the reduced VLT will affect the daylighting of the space. AGI32 was used for all lighting analysis.

LIGHTING PLAN ALTERATIONS

According to various sources, target illuminance for lighting levels of offices is between 30 and 50 footcandles (fc) at the task height, approximately 2.5 feet [11]. AGI32 calculations for the lighting plan for AOB1 showed a typical range of 50-75 fc, leaving room to explore new lighting plans with fewer luminaires to reduce this range.

Some additional considerations of the new lighting plan were maintaining the ability of the space to change furniture layouts, meaning that all areas of the open office with the ability to have a desk must maintain the required light level, and the visual appearance of the space must not be compromised. In order to maintain this aspect of the original design, luminaires were kept in runs of at least three in most areas and two in less wide areas. The original lighting plan for the second floor can be seen below in Figure 32.

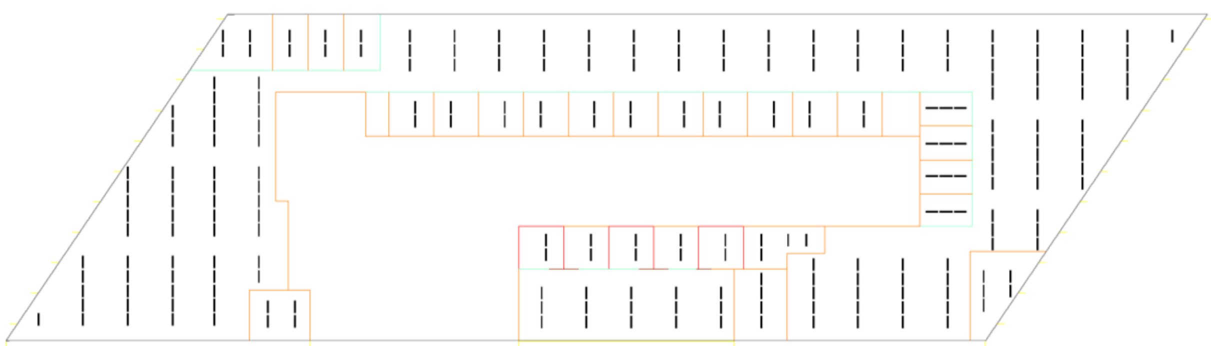


Figure 32 - Original second floor lighting plan

Figure 33 shows a sample office area of this new lighting plan on the second floor, and larger images of the whole second floor original and new plans can be found in APPENDIX P3.K. There are four rows of calculations, with the bottom three covering the area that employee desks occupy, and the top row covering area of circulation between the open office and private offices. As the image shows, the desk areas are all above 30 fc and generally do not exceed 50 fc. The circulation space is lower, with the darkest section being 18.5 fc, an acceptable range for hallways.

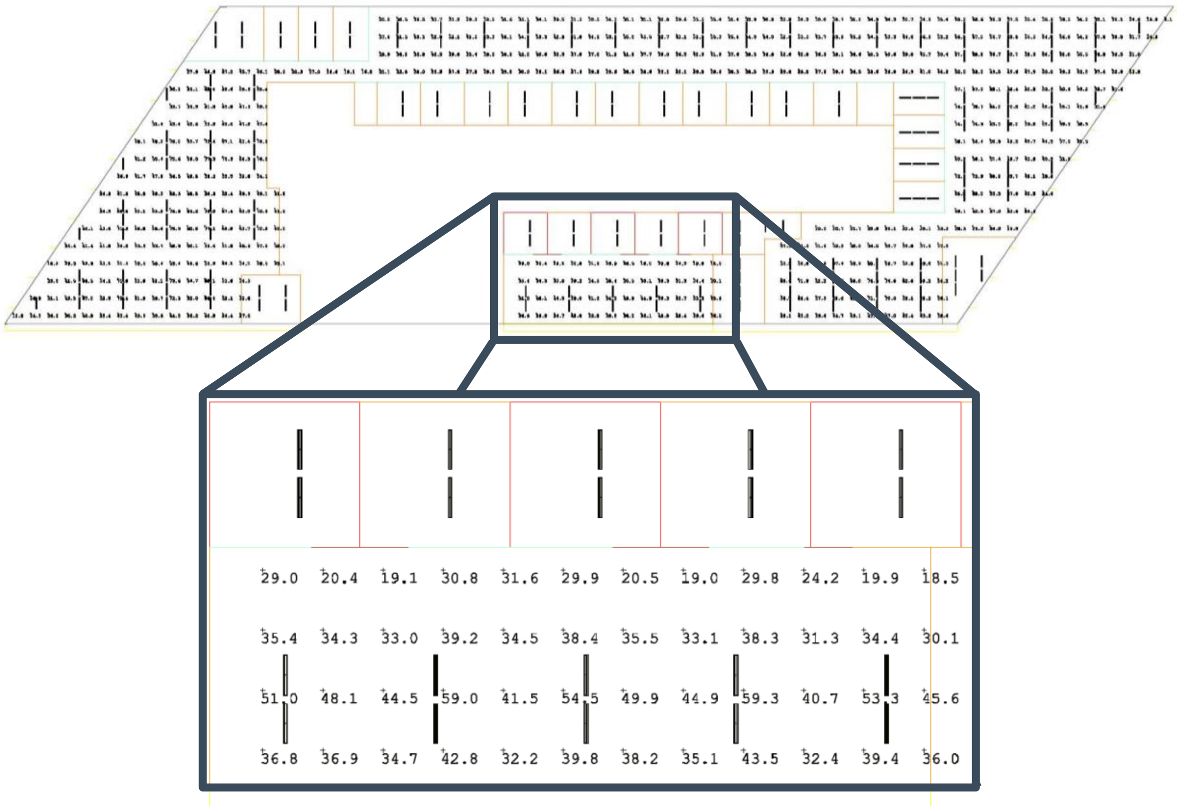


Figure 33 - Sample of new lighting plan on second floor

This new lighting plan reduced the number of fixtures by 15 on the first floor, 50 on the second floor, and 32 on the third floor, for a total reduction of 97 total luminaires throughout the building. FINELITE, the company for the luminaires used in the open offices, provided a guide in their electronic catalog for estimating the cost of installing each pendant fixture. This information was used to determine the cost savings from the 97 luminaire reduction. Table 29 displays the calculation information for this analysis, which yielded a savings of $15,861 in construction.

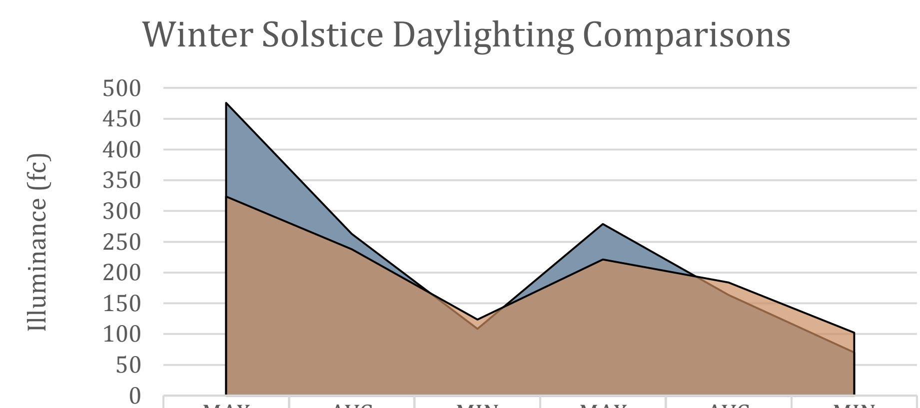
Table 29 - Cost savings from luminaire reduction

Building System Wiring			
Material	**Unit Cost**	**Quantity per lum.**	**Total Cost ($)**
RMC	0.98/ft	0.375	146
conduit clips	1	0.005	2
RMC bodies and covers	10	0.063	24
RMC connectors	s2	0.012	5
J-boxes	3	0.016	6

Metal conduit	0.41/ft	0.003	1
MC connectors	2	0.010	4
ceiling supports	2	0.013	5
SUBTOTAL			192
Labor	**Minutes**	**Quantity per lum.**	**Total Cost ($)**
start-up	45 total	45	49
install RMC	2/ft	0.013	5
install MC	1.5/ft	0.009	4
rough-in ceiling supports	10	0.063	26
SUBTOTAL	--	--	84
	Luminaires		
Material	**Unit Cost**	**Quantity in length (ft)**	**Total Cost ($)s**
luminaires	40/ft	388	15,520
Labor	**Minutes**	**Quantity per lum.**	**Total Cost ($) @ $65/hr**
install luminaires	1.5/ft	0.009	4
make electrical room	15	0.094	39
remove luminaire bags	2	0.013	5
rough-in ceiling supports	15 total	15	16
SUBTOTAL	--	--	65
		Total:	**$15,861**

DAYLIGHTING ANALYSIS

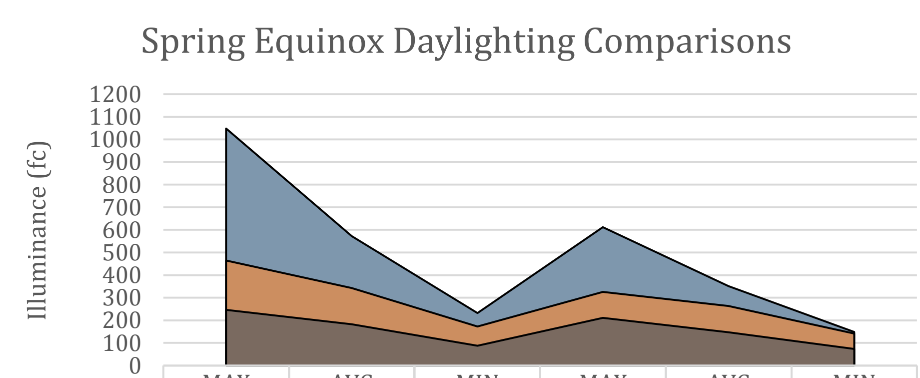
The office section on the second floor highlighted in Figure 33 was used to test the effects that the lower VLT of the PV glass had on the daylight levels of the office. AGI32 was also used for this analysis. This section of office was tested at three times of day: 8 a.m., when employees are expected to arrive; noon; and 5 p.m, the end of the work day. Four times of year were focused on, to keep the calculation short, and they include both equinoxes and solstices. The solstices should represent the extremes for room illuminance, and the equinoxes are medians between the extremes. The results of these calculations can be seen in the graphs below in Figure 34-Figure 37:



	ORIGINAL GLASS			ALTERNATIVE GLASS		
	MAX	AVG	MIN	MAX	AVG	MIN
8:00 AM	475.7678	262.98	108.7084	278.885	163.53	70.0934
12:00 PM	323.7109	237.96	123.6468	221.2734	183.66	102.2942

8:00 AM 12:00 PM

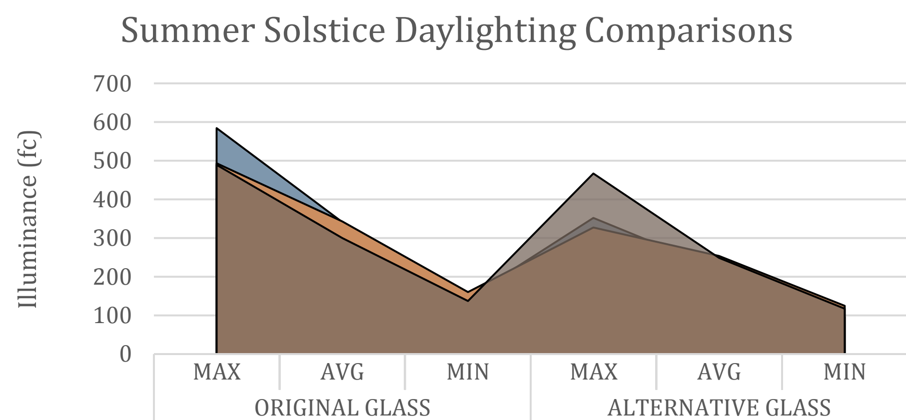
Figure 34 - Winter Solstice daylighting values



	ORIGINAL GLASS			ALTERNATIVE GLASS		
	MAX	AVG	MIN	MAX	AVG	MIN
8:00 AM	1048.484	572.91	232.0529	611.281	351.5	148.419
12:00 PM	464.8176	342.61	172.4139	325.7981	263.18	141.4369
5:00 PM	246.3688	182.8	87.4667	210.9798	146.5	73.1149

8:00 AM 12:00 PM 5:00 PM

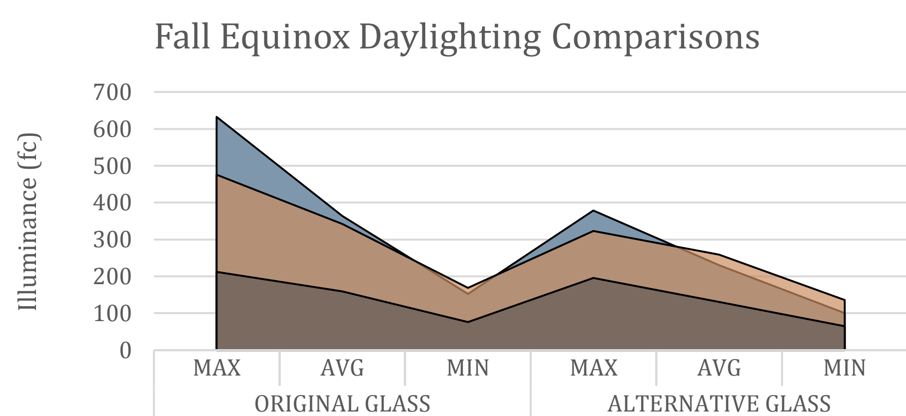
Figure 35 - Spring Equinox daylighting values



	ORIGINAL GLASS			ALTERNATIVE GLASS		
	MAX	AVG	MIN	MAX	AVG	MIN
8:00 AM	584.2779	341.39	144.2519	352.308	218.91	95.9521
12:00 PM	493.4727	343.23	160.0237	327.4791	253.51	124.6796
5:00 PM	489.6951	299.8	136.9317	467.3235	249.01	117.0824

8:00 AM 12:00 PM 5:00 PM

Figure 36 - Summer Solstice daylighting values



	ORIGINAL GLASS			ALTERNATIVE GLASS		
	MAX	AVG	MIN	MAX	AVG	MIN
8:00 AM	632.6481	363.62	152.1109	378.6266	230.5	99.956
12:00 PM	475.7522	342.26	168.6108	323.191	258.97	135.4142
5:00 PM	212.5249	159.49	75.8355	195.501	130.91	64.549

8:00 AM 12:00 PM 5:00 PM

Figure 37 - Fall Equinox daylighting values

As the graphs display, the minimum illuminance value exceeds the 30-50 fc requirement for both glass types. Therefore, the low VLT PV glass does not appear to have a major negative impact on the daylighting abilities of the space.

Breadth Analysis 2: Emissions Analysis of PV Glass

Environmental considerations surrounding photovoltaics often overlook the energy requirements and greenhouse gas emissions during manufacturing. Newer rooftop systems are generally considered to produce enough electricity to offset manufacturing expenditures. However, vertical photovoltaic glass is less efficient than the typical 30^0 layout, and life cycle emissions should be considered to determine if it is a viable option.

GLASS MANUFACTURER

Many photovoltaic window manufacturers provide products with very low visible light transmittance: typically up to 10%. Onyx Solar provides a larger range of options, with a visible light transmittance (VLT) up to 30%. Because daylighting is an important feature in the design of AOB1, Onyx Solar's high VLT made it the most practical option. This glass has an anticipated life span of 20 years and is produced in their plant in Spain [8].

Onyx Solar's high VLT is achieved by etching over the amorphous silicon (a-Si) layer to remove it. The 30% transmittance design is estimated to have a peak power generation of 2.972 W/ft^2. The total area of the south façade window that this glass will cover is 3,575 ft^2, but with 30% etched off only has about 2,500 ft^2 of power generating surface area, making a peak power generation of about 7,440 W. Onyx Solar provides an online photovoltaic estimation tool, which bases data on the project location and tilt of the glass, which is 90^0 in this case. This calculation resulted in an estimation of 1,451 kWh of generated electricity a year and an avoidance of 972 Kg of CO_2. This is equivalent to only $111.65 of annual savings with the electricity rate provided by H.F. Lenz from the building design.

Because the silicon layer is applied over the entire glass surface and then removed, the whole area of the glass must be used to estimate the power required for manufacturing, rather than the reduced area used for the power generation calculation. Onyx Solar did not provide information for energy required for manufacturing, so further research was done to determine typical energy inputs for thin film amorphous silicon. This research provided two means for calculating this value.

ENERGY OF PRODUCTION

Research Method 1

In 1998, E. Alsema wrote "Energy Requirements and CO_2 Mitigation Potential of PV Systems," a section of "Photovoltaics and the Environment." In his report, which has since been summarized in a multitude of other works, he estimated that it takes approximately 120 kWh/m^2 (11.15 kWh/ft^2) to create frameless amorphous silicon PV modules. He also projected that by 2009 there would be a one year payback period for thin-film PV. With a total area of 3,575 ft^2, this research method anticipates that it would require 39,861 kWh to create the total area of PV for this project. It is important to remember here that this estimation was created in 1998, and improvements in manufacturing methods may have reduced this value [9].

Research Method 2

A more recent article published by Environmental Science and Technology in 2013 took another look at estimating manufacturing energy consumption of various types of photovoltaics. This article provides the following figure to determine the energy input into the system based on the estimated energy output.

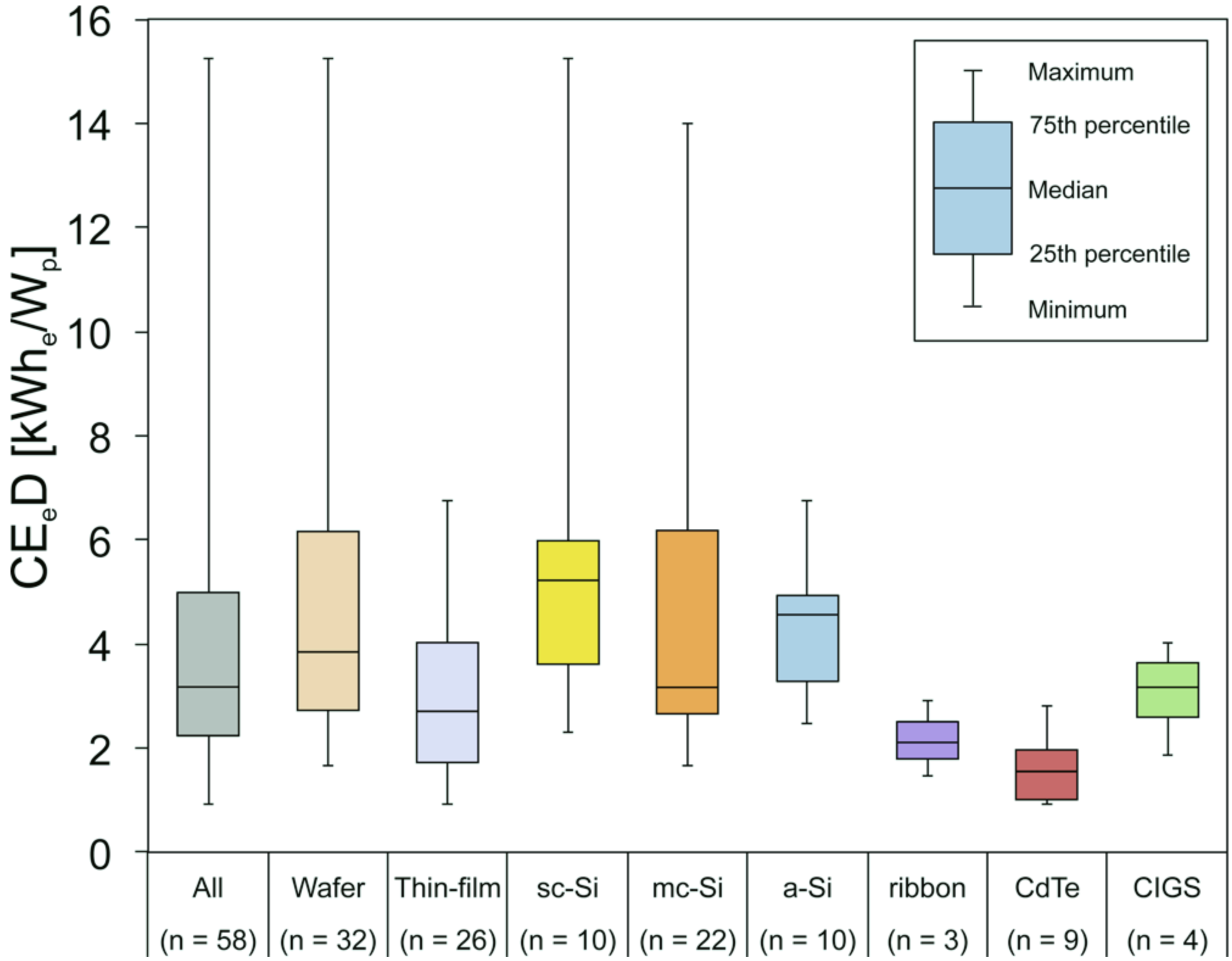


Figure 38 - Distribution of energy input to output of PV technologies, from Environmental Science and Technology article by M. Dale and S. Benson [5].

Figure 38 shows a median value of 4.5 kWh/W for amorphous silicon (a-Si). With the 7,440 W peak power generation value mentioned in the Glass Manufacturer section above, this research method estimates that it will require 33,480 kWh to manufacture the PV [5], 6,381 kWh lower than research method 1's total.

LIFE CYCLE EMISSIONS

Figure 39 displays the emission factors for the United States for various pollutants. The Eastern emission factor for CO_2 is 1.64 lb/kWh of electricity, which is the rate applied to calculate the reduction of CO_2 on-site from the photovoltaic electricity generation. Below, in Figure 40, are emission factors for electricity generated in other parts of the world. Spain, which is where Onyx Solar is based, produces about 0.343 kgCO_2/kWh, equivalent to 0.756 lb/kWh. This is less than half the CO_2 emissions of the United States.

Table 3 Total Emission Factors for Delivered Electricity (lb of pollutant per kWh of electricity)

Pollutant (lb)	National	Eastern	Western	ERCOT	Alaska	Hawaii
CO_{2e}	1.67E+00	1.74E+00	1.31E+00	1.84E+00	1.71E+00	1.91E+00
CO_2	1.57E+00	1.64E+00	1.22E+00	1.71E+00	1.55E+00	1.83E+00
CH_4	3.71E-03	3.59E-03	3.51E-03	5.30E-03	6.28E-03	2.96E-03
N_2O	3.73E-05	3.87E-05	2.97E-05	4.02E-05	3.05E-05	2.00E-05
NO_X	2.76E-03	3.00E-03	1.95E-03	2.20E-03	1.95E-03	4.32E-03
SO_X	8.36E-03	8.57E-03	6.82E-03	9.70E-03	1.12E-02	8.36E-03
CO	8.05E-04	8.54E-04	5.46E-04	9.07E-04	2.05E-03	7.43E-03
TNMOC	7.13E-05	7.26E-05	6.45E-05	7.44E-05	8.40E-05	1.15E-04
Lead	1.31E-07	1.39E-07	8.95E-08	1.42E-07	6.30E-08	1.32E-07
Mercury	3.05E-08	3.36E-08	1.86E-08	2.79E-08	3.80E-08	1.72E-07
PM10	9.16E-05	9.26E-05	6.99E-05	1.30E-04	1.09E-04	1.79E-04
Solid Waste	1.90E-01	2.05E-01	1.39E-01	1.66E-01	7.89E-02	7.44E-02

Figure 39 – U.S. Emission Factors from NREL "Source Energy and Emission Factors for Energy Use in Buildings," 2007

Emissions per kWh of electricity generated

	kgCO_2/kWh	kgCH_4/kWh	kgN_2O/kWh
South Africa	1.069026617	0.00001131304	0.00001694748
South Asia	1.213800412	0.00001520917	0.00001755688
Southeast Asia/ASEAN	0.627076088	0.00001079622	0.00000567292
Spain	0.34287509	0.00000553451	0.00000307467
Sri Lanka	0.417247633	0.00001644053	0.00000328811
Sudan	0.614906086	0.00002436143	0.00000487229

Figure 40 - Spain Emission Factor from Ecometrica "Technical Paper| Electricity-specific emission factors for grid electricity," 2011

Table 30 - PV Emissions Calculation

HAMPTON, VA CO2 EMISSION FACTOR:	1.64 lb/kWh	
SPAIN EMISSION FACTOR:	0.756 lb/kWh	
	Research method 1	**Research method 2**
kWh/year generated:	1,451	
Pounds of CO2 saved/year:	2,380	
kWh to manufacture:	39,861	33,480
Pounds CO2 emitted in manufacturing:	30,131	25,308
CO2 payback (years):	12.7	10.6

With these emission factors, about 2,400 pounds of CO_2 are saved a year from the PV generation. Research method 1 estimates about 30,000 pounds of CO_2 are produced in manufacturing, and method 2 estimates 25,000. Table 30 displays the calculation values and flow used for this life-cycle emissions evaluation. It is important to note that additional emissions from transporting the glass from Spain would be present. However, emissions from shipping are significantly lower than those in manufacturing, and multiple pieces of cargo would also be shipped with the glass. Because of these reasons, shipping emissions have been neglected in this calculation.

As seen in Table 30, with either research method used, the payback period for CO_2 emissions is less than half the 25 year life span of the glass.

Final Evaluation of Proposed Alternatives

From the results of the analyses performed in this report, a proposal could be made for certain building alterations. Firstly, a the new lighting plan for the open office areas reduced the yearly operating cost by over $1,800, saved $15,800 in lighting construction and material costs, and created an environment with a more desirable lighting level range. The photovoltaic glass was found to not negatively affect the daylighting capabilities of the space, and to have a CO_2 payback almost half the minimum life span of the glass. Although it did not significantly reduce the electrical utility costs per year, the PV glass did reduce initial equipment and glass costs for the respective alternatives. All alternatives, with the exception of the basic double pane glass analyzed, had a lower energy consumption than the original design, translating to lowered greenhouse gas emissions.

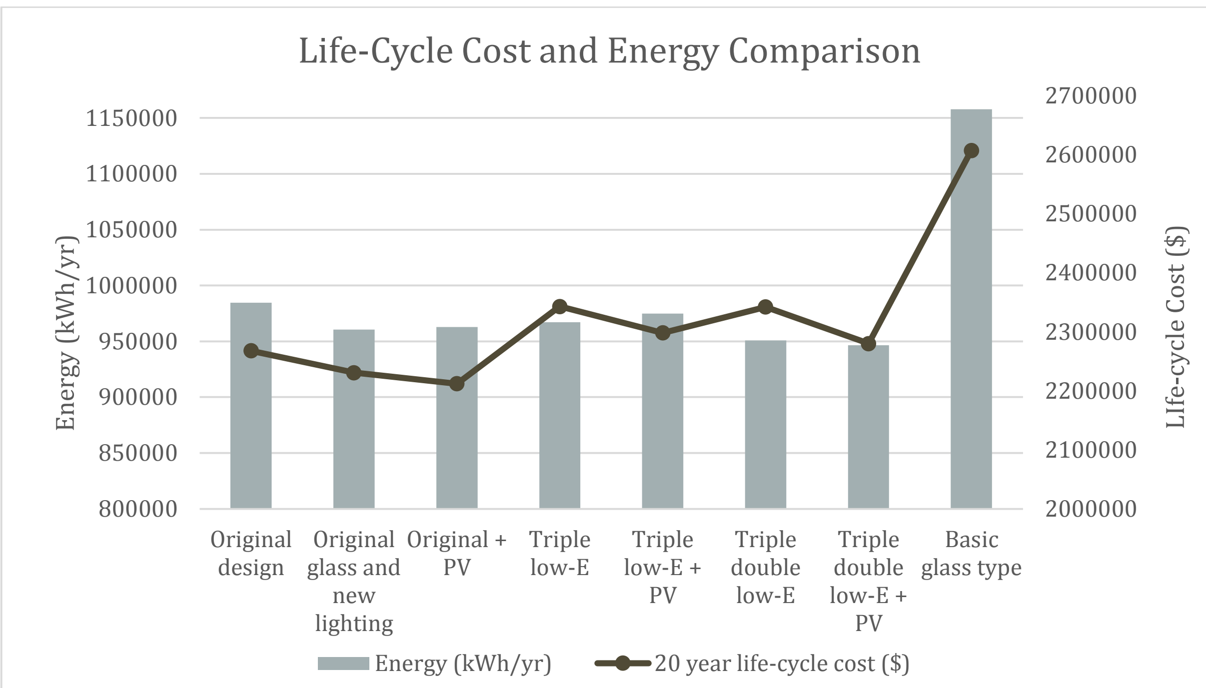


Figure 41 - Life-cycle cost and energy comparison for alternatives, with PV generation accounted for

Figure 41 summarizes the data in the depth portion of this analysis, with the generation of the PV glass removed from the yearly energy consumption. From this graph you can see that the alternatives that utilized the original glazing system had the lowest 20 year life-cycle costs. The cost for the triple insulating glass with single and double low-E coatings increased the initial costs (about $50,000-125,000) more than they decreased the operating costs over a 20 year period. The payback periods for these glass systems ranged from 24 to 76 years. Therefore, these options would not be recommended for implementation to the building design.

Making a decision between the remaining two alternatives, the original glazing system with the new lighting plan and the original glass with the PV addition, comes down to importance of cost savings verses lowering emissions. Because both alternatives paid back in the 20 year minimum life span of the PV glass, and the cost difference for equipment was small (only 3-4% difference), the option with the lowest yearly emissions would be desirable. Therefore, the recommendation of this report is to implement the proposed lighting plan changes and maintain the glazing system of the original design.

This investigation utilized various assumptions and approximations. Although the best efforts were put forth to ensure the accuracy of the analysis, the results herein should not be utilized for any purpose other than that of the report. This analysis in no way implies that there were flaws with the building design, only that there was an opportunity to utilize the building as an educational tool.

Acknowledgements

There were several people integral to the completion of my senior thesis, and I would like to extend my thanks to them. Without the help of these people, I would not have been able to complete this thesis and continue on to graduation.

H.F. Lenz Company, for helping me to obtain the building information and serving as a continued resource for my questions throughout the year. In particular, I would like to thank Bill McGhee.

NASA Langley Research Center employees, for allowing me to use this building, especially Joan Hughes, who was vital in helping me to obtain information on the building operating history.

Jennifer Highfield of Viracon, for providing me with a quote for their glass systems.

Dr. James Freihaut, my thesis advisor, for providing me with support and guidance throughout this project.

Dr. Richard Mistrick, who provided me with guidance and assistance for my lighting breadth.

Jackie Eury, my classmate and friend, for helping me with AGI32 so that I could complete my lighting analysis.

Finally, thank you to the Penn State Architectural Engineering Department faculty and stuff, my friends, family, and the AE class of 2015 for your continued help and support throughout my last five years of education.

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All renderings from AECOM bridging documents: www.aecom.com

Construction documents provided by H.F. Lenz Company

APPENDIX P1.A1

ASHRAE 62.1-2013 OA Calculation for AOB1

DOAS:	6823

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
	AHU-1	**1605**																		
AHU-1	1st floor UFAD	15780	119	office space	5	0.06	595	946.8	1542	0.7	2203	17000	0.130	0.961	17000	1604	1	1542	0.091	0.961
		Total Pz:	119			Total:	595	946.8	1542		2203			Total:	17000				Ev system:	0.961
	Ps=	119																		

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
	AHU-2	**2019**																		
AHU-2	2nd floor UFAD	19685	148	office space	5	0.06	740	1181.1	1921	0.7	2744	17000	0.161	0.952	17000	2019	1	1921	0.113	0.952
		Total Pz:	148			Total:	740	1181.1	1921		2744			Total:	17000				Ev system:	0.952
	Ps=	148																		

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
	AHU-3	**1804**																		
AHU-3	3nd floor UFAD	18750	120	office space	5	0.06	600	1125	1725	0.7	2464	17000	0.145	0.957	17000	1803	1	1725	0.101	0.957
		Total Pz:	120			Total:	600	1125	1725		2464			Total:	17000				Ev system:	0.957
	Ps=	120																		

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
	AHU-5	**1395**																		
FPB-219, 220	conference room	1460	62	conference/meeting	5	0.06	310	87.6	398	0.7	568	740	0.768	0.742	2030	1394	1	1035	0.510	0.742
FPB-221	215 conference r	230	10	conference/meeting	5	0.06	50	13.8	64	0.7	91	125	0.729	1.967	610	526	1	1035	1.696	1.967
FPB-323	318 conference r	635	18	conference/meeting	5	0.06	90	38.1	128	0.7	183	305	0.600	1.489	950	695	1	1035	1.089	1.489
FPB-321	314 conference	1500	54	conference/meeting	5	0.06	270	90	360	0.7	514	700	0.735	0.796	1950	1300	1	1035	0.531	0.796
FPB-322	315 conference r	250	14	conference/meeting	5	0.06	70	15	85	0.7	121	150	0.810	1.648	710	628	1	1035	1.457	1.648
		Total Pz:	158			Total:	790	244.5	1035		1478			Total:	6250				Ev system:	0.742
	Ps=	158																		

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
	AHU-4	**837**																		
AHU-4	117A & 117B	1460	64	conference/meeting	5	0.06	320	87.6	408	0.8	510	765	0.666	0.493	2590	836	1	413	0.159	0.493
		Total Pz:	64			Total:	320	87.6											Ev system:	0.493
	Ps=	65																		

APPENDIX P1.A2

ASHRAE 62.1-2013 Table 6.2.2.1 Minimum Ventilation in Breathing Zone

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone

(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1
Media center	10	5	0.12	0.6	A	25	15	7.4	1
Music/theater/dance	10	5	0.06	0.3		35	12	5.9	1
Multiuse assembly	7.5	3.8	0.06	0.3		100	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2
Kitchen (cooking)	7.5	3.8	0.12	0.6		20	14	7.0	2
General									
Break rooms	5	2.5	0.06	0.3		25	7	3.5	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.

2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.

3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.

4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.

5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.

6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.

B Rate may not be sufficient when stored materials include those having potentially harmful emissions.

C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. “Deck area” refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, “spectator area”).

D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.

E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.

F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.

G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Coffee stations	5	2.5	0.06	0.3		20	8	4	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	—	—	0.06	0.3		—			1
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	B	2	65	32.5	2
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Banks or bank lobbies	7.5	3.8	0.06	0.3		15	12	6.0	1
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.
B Rate may not be sufficient when stored materials include those having potentially harmful emissions.
C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.
F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Freezer and refrigerated spaces (<50°F)	10	5	0	0	E	0	0	0	2
General manufacturing (excludes heavy industrial and processes using chemicals)	10	5.0	0.18	0.9		7	36	18	3
Pharmacy (prep. area)	5	2.5	0.18	0.9		10	23	11.5	2
Photo studios	5	2.5	0.12	0.6		10	17	8.5	1
Shipping/receiving	10	5	0.12	0.6	B	2	70	35	2
Sorting, packing, light assembly	7.5	3.8	0.12	0.6		7	25	12.5	2
Telephone closets	—	—	0.00	0.0		—			1
Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1	1
Warehouses	10	5	0.06	0.3	B	—			2
Public Assembly Spaces									
Auditorium seating area	5	2.5	0.06	0.3		150	5	2.7	1
Places of religious worship	5	2.5	0.06	0.3		120	6	2.8	1
Courtrooms	5	2.5	0.06	0.3		70	6	2.9	1
Legislative chambers	5	2.5	0.06	0.3		50	6	3.1	1
Libraries	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies	5	2.5	0.06	0.3		150	5	2.7	1
Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3	1
Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6	1
Residential									
Dwelling unit	5	2.5	0.06	0.3	F,G	F			1
Common corridors	—	—	0.06	0.3					1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.
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C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.
F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Retail									
Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8	2
Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6	1
Barbershop	7.5	3.8	0.06	0.3		25	10	5.0	2
Beauty and nail salons	20	10	0.12	0.6		25	25	12.4	2
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8	2
Supermarket	7.5	3.8	0.06	0.3		8	15	7.6	1
Coin-operated laundries	7.5	3.8	0.12	0.6		20	14	7.0	2
Sports and Entertainment									
Gym, sports arena (play area)	20	10	0.18	0.9	E	7	45	23	2
Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0	1
Swimming (pool & deck)	—	—	0.48	2.4	C	—			2
Disco/dance floors	20	10	0.06	0.3		100	21	10.3	2
Health club/aerobics room	20	10	0.06	0.3		40	22	10.8	2
Health club/weight rooms	20	10	0.06	0.3		10	26	13.0	2
Bowling alley (seating)	10	5	0.12	0.6		40	13	6.5	1
Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6	1
Game arcades	7.5	3.8	0.18	0.9		20	17	8.3	1
Stages, studios	10	5	0.06	0.3	D	70	11	5.4	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.
B Rate may not be sufficient when stored materials include those having potentially harmful emissions.
C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.
F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

vided such value is the product of the net occupiable area of the ventilation zone and the default occupant density listed in Table 6.2.2.1.

6.2.2.2 Zone Air Distribution Effectiveness. The zone air distribution effectiveness (E_z) shall be no greater than the default value determined using Table 6.2.2.2.

Note: For some configurations, the default value depends upon space and supply air temperature.

6.2.2.3 Zone Outdoor Airflow. The zone outdoor airflow (V_{oz}), i.e., the outdoor airflow rate that must be provided to the ventilation zone by the supply air distribution system, shall be determined in accordance with Equation 6.2.2.3.

$$V_{oz} = V_{bz}/E_z \quad (6.2.2.3)$$

6.2.3 Single-Zone Systems. For ventilation systems wherein one or more air handlers supply a mixture of outdoor air and recirculated air to only one ventilation zone, the

APPENDIX P1.A3

ASHRAE 62.1-2004 OA Calculation from H.F. Lenz Company original design

H.F. LENZ
COMPANY

Subject	NASA AOB1	Date:	Jan-2010
HFL #:.	2009-0185.01	Calculated by:	CBH

ANSI/ASHRAE Standard 62.1-2004

Ventilation for Acceptable Indoor Air Quality

Ventilation Rate Procedure (VRP)

AHU-4

Zones served by system	Space type	Az	Pz	Rp	Ra	Pz*Rp	Az*Ra	Ez	Voz	Vpz	Vpzm %	Vpzm	Zp	
105A Conference Room	Conference / meeting	800	30.0	6.5	0.078	195	62.4	0.8	322	1365	30	410	0.79	
105B Conference Room	Conference / meeting	690	28.0	6.5	0.078	182	53.8	0.8	295	1235	30	371	0.80	*
										2,600				

Ps	System population, maximum simultaneious # of occupants of space served by system	64.00
D	Occupant diversity, ratio of system peak occupancy to sum of space peak occupancies, = Ps/SPz	0.91
SRp	Summation of Rp Values	377.00
SRa	Summation of Ra Values	116.22
Vou	Uncorrected outdoor air intake, = D*SRp*Pz +SRa*Az, cfm	457.88

SYSTEM EFFICIENCY

Max Zp	Max Zp	0.80			
Ev	System ventilation efficiency, Table 6.3 based on maxZp	0.60			
				Percent outdoor air intake	
Vot	Minimum outdoor air intake, Vou/Ev, cfm	763.13	CFM	**29%**	= Vot/Sum of Vpz

LEGEND

Az	Floor area of zone, ft2
Pz	Zone population, largest # of people expected to occupy zone
Rp	Area outdoor air rate from Table 6.1, cfm/ft2
Ra	People outdoor air rate from Table 6.1, cfm/person
Ez	Zone air distribution effectiveness, Table 6.2
Voz	Outdoor airflow to the zone corrected for zone air distribution effectiveness, (Pz*Rp + Az*Ra)/Ez, cfm
Vpz	Primary airflow to zone from air handler. **In VAV systems, use the design value.** cfm
Vpzm	The minimum value of the primary airflow to zone from air handler. **In CAV systems, Vpzm = Vpz.** cfm
Zp	Primary outdoor air fraction, Voz/Vpzm

APPENDIX P1.A4

ASHRAE 62.1-2013 Table 6.5 Minimum Exhaust Rates

TABLE 6.5 Minimum Exhaust Rates

Occupancy Category	Exhaust Rate, cfm/unit	Exhaust Rate, cfm/ft^2	Notes	Exhaust Rate, L/s·unit	Exhaust Rate, $L/s \cdot m^2$	Air Class
Arenas	—	0.50	B	—	—	1
Art classrooms	—	0.70		—	3.5	2
Auto repair rooms	—	1.50	A	—	7.5	2
Barber shops	—	0.50		—	2.5	2
Beauty and nail salons	—	0.60		—	3.0	2
Cells with toilet	—	1.00		—	5.0	2
Copy, printing rooms	—	0.50		—	2.5	2
Darkrooms	—	1.00		—	5.0	2
Educational science laboratories	—	1.00		—	5.0	2
Janitor closets, trash rooms, recycling	—	1.00		—	5.0	3
Kitchenettes	—	0.30		—	1.5	2
Kitchens—commercial	—	0.70		—	3.5	2
Locker/dressing rooms	—	0.25		—	1.25	2
Locker rooms	—	0.50		—	2.5	2
Paint spray booths	—	—	F	—	—	4
Parking garages	—	0.75	C	—	3.7	2
Pet shops (animal areas)	—	0.90		—	4.5	2
Refrigerating machinery rooms	—	—	F	—	—	3
Residential kitchens	50/100	—	G	25/50	—	2
Soiled laundry storage rooms	—	1.00	F	—	5.0	3
Storage rooms, chemical	—	1.50	F	—	7.5	4
Toilets—private	25/50	—	E, H	12.5/25	—	2
Toilets—public	50/70	—	D, H	25/35	—	2
Woodwork shop/classrooms	—	0.50		—	2.5	2

NOTES:

A Stands where engines are run shall have exhaust systems that directly connect to the engine exhaust and prevent escape of fumes.
B When combustion equipment is intended to be used on the playing surface additional dilution ventilation and/or source control shall be provided.
C Exhaust not required if two or more sides comprise walls that are at least 50% open to the outside.
D Rate is per water closet and/or urinal. Provide the higher rate where periods of heavy use are expected to occur, e.g., toilets in theatres, schools, and sports facilities. The lower rate may be used otherwise.
E Rate is for a toilet room intended to be occupied by one person at a time. For continuous system operation during normal hours of use, the lower rate may be used. Otherwise use the higher rate.
F See other applicable standards for exhaust rate.
G For continuous system operation, the lower rate may be used. Otherwise use the higher rate.
H Exhaust air that has been cleaned to meet Class 1 criteria from Section 5.16.1 shall be permitted to be recirculated.

6.4.3 Control and Accessibility. The means to open required operable openings shall be readily accessible to building occupants whenever the space is occupied. Controls shall be designed to properly coordinate operation of the natural and mechanical ventilation systems.

6.5 Exhaust Ventilation. The Prescriptive Compliance Path or the Performance Compliance Path shall be used to meet the requirements of this section. Exhaust makeup air may be any combination of outdoor air, recirculated air, and transfer air.

6.5.1 Prescriptive Compliance Path. The design exhaust airflow shall be determined in accordance with the requirements in Table 6.5.

6.5.2 Performance Compliance Path. The exhaust airflow shall be determined in accordance with the following subsections.

6.5.2.1 Contaminant Sources. Contaminants or mixtures of concern for purposes of the design shall be identified. For each contaminant or mixture of concern, indoor sources

APPENDIX P1.B1

ASHRAE 90.1-2013 and 2007 Table 5.5-4 Building Envelope Requirements for Climate Zone 4 (A, B, C)

Table 5.5-4 Building Envelope Requirements for Climate Zone 4 (A,B,C)*

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.032	R-30 c.i.	U-0.032	R-30 c.i.	U-0.093	R-10 c.i.
Metal Building[a]	U-0.037	R-19 + R-11 Ls or R-25 + R-8 Ls	U-0.037	R-19 + R-11 Ls or R-25 + R-8 Ls	U-0.082	R-19
Attic and Other	U-0.021	R-49	U-0.021	R-49	U-0.034	R-30
Walls, above Grade						
Mass	U-0.104	R-9.5 c.i.	U-0.090	R-11.4 c.i.	U-0.580	NR
Metal Building	U-0.060	R-0 + R-15.8 c.i.	U-0.050	R-0 + R-19 c.i.	U-0.162	R-13
Steel Framed	U-0.064	R-13 + R-7.5 c.i.	U-0.064	R-13 + R-7.5 c.i	U-0.124	R-13
Wood Framed and Other	U-0.064	R-13 + R-3.8 c.i. or R-20	U-0.064	R-13 + R-3.8 c.i. or R-20	U-0.089	R-13
Wall, below Grade						
Below Grade Wall	C-0.119	R-7.5 c.i.	C-0.092	R-10 c.i.	C-1.140	NR
Floors						
Mass	U-0.057	R-14.6 c.i.	U-0.051	R-16.7 c.i.	U-0.107	R-6.3 c.i.
Steel Joist	U-0.038	R-30	U-0.038	R-30	U-0.052	R-19
Wood Framed and Other	U-0.033	R-30	U-0.033	R-30	U-0.051	R-19
Slab-on-Grade Floors						
Unheated	F-0.520	R-15 for 24 in.	F-0.520	R-15 for 24 in.	F-0.730	NR
Heated	F-0.843	R-20 for 24 in.	F-0.688	R-20 for 48 in.	F-0.900	R-10 for 24 in.
Opaque Doors						
Swinging	U-0.500		U-0.500		U-0.700	
Nonswinging	U-0.500		U-0.500		U-1.450	

Fenestration	Assembly Max. U	Assembly Max. SHGC	Assembly Min. VT/SHGC	Assembly Max. U	Assembly Max. SHGC	Assembly Min. VT/SHGC	Assembly Max. U	Assembly Max. SHGC	Assembly Min. VT/SHGC
Vertical Fenestration, 0%–40% of Wall		(for all frame types)			(for all frame types)			(for all frame types)	
Nonmetal framing, all	U-0.35			U-0.35			U-0.51		
Metal framing, fixed	U-0.42			U-0.42			U-0.73		
Metal framing, operable	U-0.50	SHGC-0.40	1.10	U-0.50	SHGC-0.40	1.10	U-0.81	NR	NR
Metal framing, entrance door	U-0.77			U-0.68			U-0.77		
Skylight, 0%–3% of Roof									
All types	U-0.50	SHGC-0.40	NR	U-0.50	SHGC-0.40	NR	U-1.15	NR	NR

* The following definitions apply: c.i. = continuous insulation (see Section 3.2), FC = filled cavity (see Section A2.3.2.5), Ls = liner system (see Section A2.3.2.4), NR = no (insulation) requirement.

a. When using the R-value compliance method for metal building roofs, a thermal spacer block is required (see Section A2.3.2).

TABLE 5.5-4 Building Envelope Requirements For Climate Zone 4 (A,B,C)

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	**Insulation Min. R-Value**	**Assembly Maximum**	**Insulation Min. R-Value**	**Assembly Maxi-mum**	**Insulation Min. R-Value**
Roofs						
Insulation Entirely above Deck	U-0.063	R-15.0 ci	U-0.063	R-15.0 ci	U-0.218	R-3.8 ci
Metal Building	U-0.065	R-19.0	U-0.065	R-19.0	U-0.097	R-10.0
Attic and Other	U-0.034	R-30.0	U-0.027	R-38.0	U-0.081	R-13.0
Walls, Above-Grade						
Mass	U-0.151[a]	R-5.7 ci[a]	U-0.104	R-9.5 ci	U-0.580	NR
Metal Building	U-0.113	R-13.0	U-0.113	R-13.0	U-0.134	R-10.0
Steel-Framed	U-0.124	R-13.0	U-0.064	R-13.0 + R-7.5 ci	U-0.124	R-13.0
Wood-Framed and Other	U-0.089	R-13.0	U-0.089	R-13.0	U-0.089	R-13.0
Wall, Below-Grade						
Below-Grade Wall	C-1.140	NR	C-1.140	NR	C-1.140	NR
Floors						
Mass	U-0.107	R-6.3 ci	U-0.087	R-8.3 ci	U-0.322	NR
Steel-Joist	U-0.052	R-19.0	U-0.038	R-30.0	U-0.069	R-13.0
Wood-Framed and Other	U-0.051	R-19.0	U-0.033	R-30.0	U-0.066	R-13.0
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.730	NR	F-0.730	NR
Heated	F-0.950	R-7.5 for 24 in.	F-0.840	R-10 for 36 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.700		U-0.700	
Non-Swinging	U-1.450		U-0.500		U-1.450	
Fenestration	**Assembly Max. U (Fixed/ Operable)**	**Assembly Max. SHGC (All Orientations/ North-Oriented)**	**Assembly Max. U (Fixed/ Operable)**	**Assembly Max. SHGC (All Orientations/ North-Oriented)**	**Assembly Max. U (Fixed/ Opera-ble)**	**Assembly Max. SHGC (All Orientations/ North-Oriented)**
Vertical Glazing,% of Wall						
0-10.0%	U_{fixed}-0.57 U_{oper}-0.67	$SHGC_{all}$-0.39 $SHGC_{north}$-0.49	U_{fixed}-0.57 U_{oper}-0.67	$SHGC_{all}$-0.39 $SHGC_{north}$-0.49	U_{fixed}-1.22 U_{oper}-1.27	$SHGC_{all}$-NR $SHGC_{north}$NR
10.1-20.0%	U_{fixed}-0.57 U_{oper}-0.67	$SHGC_{all}$-0.39 $SHGC_{north}$-0.49	U_{fixed}-0.57 U_{oper}-0.67	$SHGC_{all}$-0.39 $SHGC_{north}$-0.49	U_{fixed}-1.22 U_{oper}-1.27	$SHGC_{all}$-NR $SHGC_{north}$NR
20.1-30.0%	U_{fixed}-0.57 U_{oper}-0.67	$SHGC_{all}$-0.39 $SHGC_{north}$-0.49	U_{fixed}-0.57 U_{oper}-0.67	$SHGC_{all}$-0.39 $SHGC_{north}$-0.49	U_{fixed}-1.22 U_{oper}-1.27	$SHGC_{all}$-NR $SHGC_{north}$NR
30.1-40.0%	U_{fixed}-0.57 U_{oper}-0.67	$SHGC_{all}$-0.39 $SHGC_{north}$-0.49	U_{fixed}-0.57 U_{oper}-0.67	$SHGC_{all}$-0.39 $SHGC_{north}$-0.49	U_{fixed}-1.22 U_{oper}-1.27	$SHGC_{all}$-NR $SHGC_{north}$NR
40.1-50.0%	U_{fixed}-0.46 U_{oper}-0.47	$SHGC_{all}$-0.25 $SHGC_{north}$-0.36	U_{fixed}-0.46 U_{oper}-0.47	$SHGC_{all}$-0.25 $SHGC_{north}$-0.36	U_{fixed}-0.98 U_{oper}-1.02	$SHGC_{all}$-NR $SHGC_{north}$NR
Skylight with Curb, Glass,% of Roof						
0-2.0%	U_{all}-1.17	$SHGC_{all}$-0.49	U_{all}-0.98	$SHGC_{all}$-0.36	U_{all}-1.98	$SHGC_{all}$-NR
2.1-5.0%	U_{all}-1.17	$SHGC_{all}$-0.39	U_{all}-0.98	$SHGC_{all}$-0.19	U_{all}-1.98	$SHGC_{all}$-NR
Skylight with Curb, Plastic,% of Roof						
0-2.0%	U_{all}-1.30	$SHGC_{all}$-0.65	U_{all}-1.30	$SHGC_{all}$-0.62	U_{all}-1.90	$SHGC_{all}$-NR
2.1-5.0%	U_{all}-1.30	$SHGC_{all}$-0.34	U_{all}-1.30	$SHGC_{all}$-0.27	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}-0.58	$SHGC_{all}$-0.36	U_{all}-1.36	$SHGC_{all}$-NR
2.1-5.0%	U_{all}-0.69	$SHGC_{all}$-0.39	U_{all}-0.58	$SHGC_{all}$-0.19	U_{all}-1.36	$SHGC_{all}$-NR

[a]Exception to A3.1.3.1 applies.

APPENDIX P1.B2

ASHRAE 90.1-2013

Table 10.8-1 Minimum Nominal Full-Load Efficiency for General Purpose Electric Motors (Subtype I), Except Fire-Pump Electric Motors

Table 10.8-2 Minimum Nominal Full-Load Efficiency for General Purpose Electric Motors (Subtype III), Except Fire-Pump Electric Motors

TABLE 10.8-1 Minimum Nominal Full-Load Efficiency for General Purpose Electric Motors (Subtype I), Except Fire-Pump Electric Motors[a]

Full-Load Efficiency, %						
	Open Drip-Proof Motors			Totally Enclosed Fan-Cooled Motors		
Number of Poles ⇒	2	4	6	2	4	6
Synchronous Speed (RPM) ⇒	3600	1800	1200	3600	1800	1200
Motor Horsepower						
1	77.0	85.5	82.5	77.0	85.5	82.5
1.5	84.0	86.5	86.5	84.0	86.5	87.5
2	85.5	86.5	87.5	85.5	86.5	88.5
3	85.5	89.5	88.5	86.5	89.5	89.5
5	86.5	89.5	89.5	88.5	89.5	89.5
7.5	88.5	91.0	90.2	89.5	91.7	91.0
10	89.5	91.7	91.7	90.2	91.7	91.0
15	90.2	93.0	91.7	91.0	92.4	91.7
20	91.0	93.0	92.4	91.0	93.0	91.7
25	91.7	93.6	93.0	91.7	93.6	93.0
30	91.7	94.1	93.6	91.7	93.6	93.0
40	92.4	94.1	94.1	92.4	94.1	94.1
50	93.0	94.5	94.1	93.0	94.5	94.1
60	93.6	95.0	94.5	93.6	95.0	94.5
75	93.6	95.0	94.5	93.6	95.4	94.5
100	93.6	95.4	95.0	94.1	95.4	95.0
125	94.1	95.4	95.0	95.0	95.4	95.0
150	94.1	95.8	95.4	95.0	95.8	95.8
200	95.0	95.8	95.4	95.4	96.2	95.8

a. Nominal efficiencies shall be established in accordance with DOE 10 CFR 431.

TABLE 10.8-2 Minimum Nominal Full-Load Efficiency for General Purpose Electric Motors (Subtype II), Except Fire-Pump Electric Motors[a]

Full-Load Efficiency, %								
	Open Drip-Proof Motors				Totally Enclosed Fan-Cooled Motors			
Number of Poles ⇒	2	4	6	8	2	4	6	8
Synchronous Speed (RPM) ⇒	3600	1800	1200	900	3600	1800	1200	900
Motor Horsepower								
1	NR	82.5	80.0	74.0	75.5	82.5	80.0	74.0
1.5	82.5	84.0	84.0	75.5	82.5	84.0	85.5	77.0
2	84.0	84.0	85.5	85.5	84.0	84.0	86.5	82.5
3	84.0	86.5	86.5	86.5	85.5	87.5	87.5	84.0
5	85.5	87.5	87.5	87.5	87.5	87.5	87.5	85.5
7.5	87.5	88.5	88.5	88.5	88.5	89.5	89.5	85.5
10	88.5	89.5	90.2	89.5	89.5	89.5	89.5	88.5
15	89.5	91.0	90.2	89.5	90.2	91.0	90.2	88.5
20	90.2	91.0	91.0	90.2	90.2	91.0	90.2	89.5
25	91.0	91.7	91.7	90.2	91.0	92.4	91.7	89.5
30	91.0	92.4	92.4	91.0	91.0	92.4	91.7	91.0
40	91.7	93.0	93.0	91.0	91.7	93.0	93.0	91.0
50	92.4	93.0	93.0	91.7	92.4	93.0	93.0	91.7
60	93.0	93.6	93.6	92.4	93.0	93.6	93.6	91.7
75	93.0	94.1	93.6	93.6	93.0	94.1	93.6	93.0
100	93.0	94.1	94.1	93.6	93.6	94.5	94.1	93.0
125	93.6	94.5	94.1	93.6	94.5	94.5	94.1	93.6
150	93.6	95.0	94.5	93.6	94.5	95.0	95.0	93.6
200	94.5	95.0	94.5	93.6	95.0	95.0	95.0	94.1

a. Nominal efficiencies shall be established in accordance with DOE 10 CFR 431.
NR—No requirement

APPENDIX P1.C

Kawneer Glass Spec Sheet for conversion of thermal properties for curtainwall systems

Thermal Transmittance [1] (BTU/hr • ft^2 • °F)

Glass U-Factor [3]	Overall U-Factor [4]
0.47	0.54
0.46	0.53
0.44	0.52
0.42	0.50
0.40	0.48
0.38	0.47
0.36	0.45
0.34	0.43
0.32	0.42
0.30	0.40
0.28	0.38
0.26	0.37
0.24	0.35
0.22	0.33
0.20	0.32
0.18	0.30
0.16	0.28
0.14	0.26
0.12	0.25
0.10	0.23

1" GLAZING WITH ALUMINUM PRESSURE PLATE

NOTE: For glass values that are not listed, linear interpolation is permitted.

1. U-Factors are determined in accordance with NFRC 100.
2. SHGC and VT values are determined in accordance with NFRC 200.
3. Glass properties are based on center of glass values and are obtained from your glass supplier.
4. Overall U-Factor, SHGC, and VT Matricies are based on the standard NFRC specimen size of 2000mm wide by 2000mm high (78-3/4" by 78-3/4").

SHGC Matrix [2]

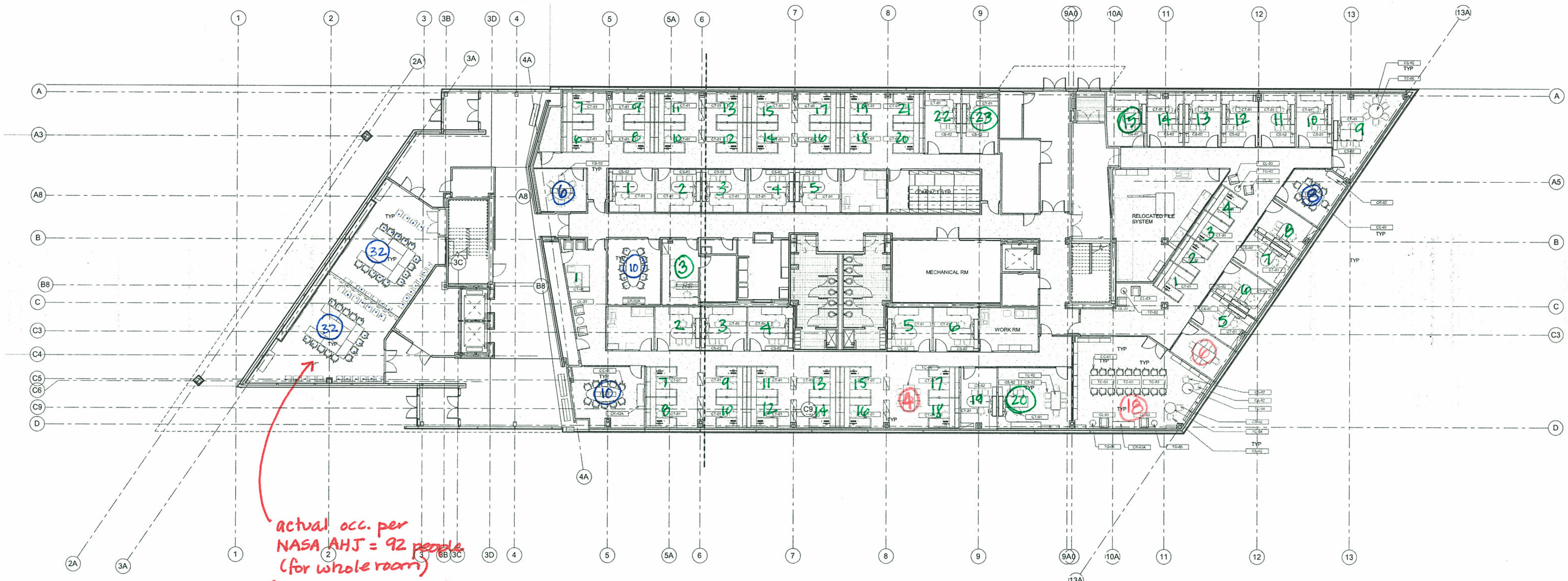
Glass SHGC [3]	Overall SHGC [4]
0.75	0.68
0.70	0.64
0.65	0.59
0.60	0.55
0.55	0.50
0.50	0.46
0.45	0.41
0.40	0.37
0.35	0.32
0.30	0.28
0.25	0.24
0.20	0.19
0.15	0.15
0.10	0.10
0.05	0.06

Visible Transmittance [2]

Glass VT [3]	Overall VT [4]
0.75	0.67
0.70	0.63
0.65	0.58
0.60	0.54
0.55	0.49
0.50	0.45
0.45	0.40
0.40	0.36
0.35	0.31
0.30	0.27
0.25	0.22
0.20	0.18
0.15	0.13
0.10	0.09
0.05	0.04

APPENDIX P1.D

Occupancy floor plans obtained from H.F. Lenz Company



actual occ. per NASA AHJ = 92 people (for whole room)
(+28 over seat count)

Chair Counts

Level 1

• = 98 (Assembly areas per NASA)
• = 61 (workstations)
• = 28 (teaming areas outside of offices)

187

all 3 levels

[284]
[257]
[95] ?

[636]
-95
= 541

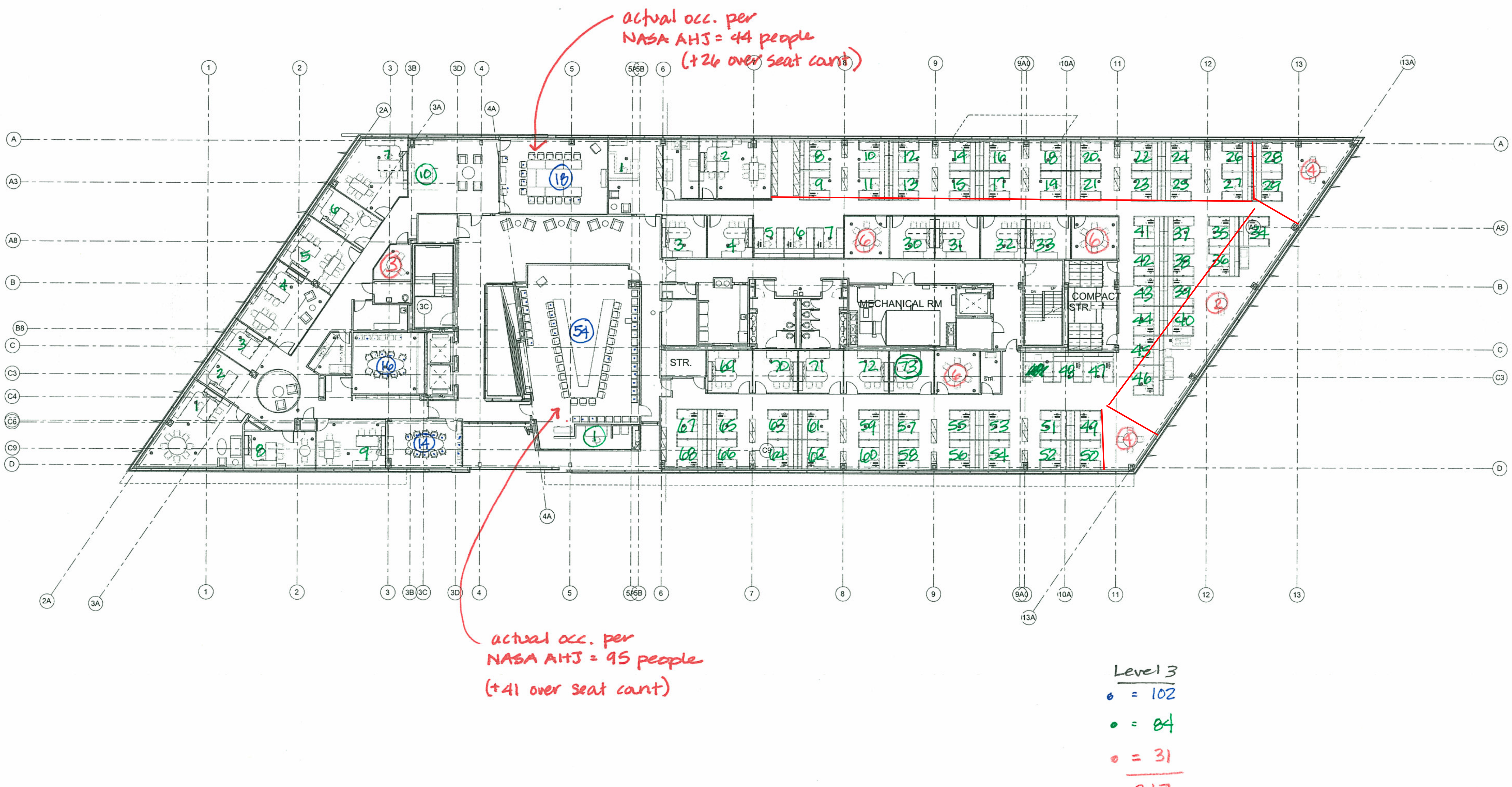
rooms w/ moveable tables
+126 over seat count

541 + 126 = 667

actual occ. per
NASA AHJ = 93 people
(for whole room)
(+31 over seat count)

Level 2
• = 84
• = 112
• = 36

232


actual occ. per
NASA AHJ = 44 people
(+26 over seat count)
MECHANICAL RM
COMPACT STR.
STR.
actual occ. per
NASA AHJ = 95 people
(+41 over seat count)
Level 3
= 102
= 84
= 31
217

APPENDIX P1.E

U.S. Department of Energy Buildings Energy Data Book: 3.3 Commercial Sector Expenditures

3.3.8 Average Annual Energy Expenditures per Square Foot of Commercial Floorspace, by Year ($2010)

Year	$/SF
1980 (1)	2.12
1981	2.22 (2)
1982	2.24
1983	2.21
1984	2.25
1985	2.20
1986	2.06
1987	2.00
1988	1.99
1989	2.01
1990	1.98
1991	1.92
1992	1.86
1993	1.96
1994	2.05
1995	2.12
1996	2.10
1997	2.08
1998	1.97
1999	1.88
2000	2.06
2001	2.20
2002	2.04
2003	2.13
2004	2.16
2005	2.30
2006	2.36
2007	2.35
2008	1.71
2009	2.43
2010	**2.44**
2011	2.44
2012	2.35
2013	2.28
2014	2.27
2015	2.29
2016	2.29
2017	2.28
2018	2.29
2019	2.29
2020	2.29
2021	2.31
2022	2.32
2023	2.32
2024	2.32
2025	2.32
2026	2.32
2027	2.33
2028	2.32
2029	2.31

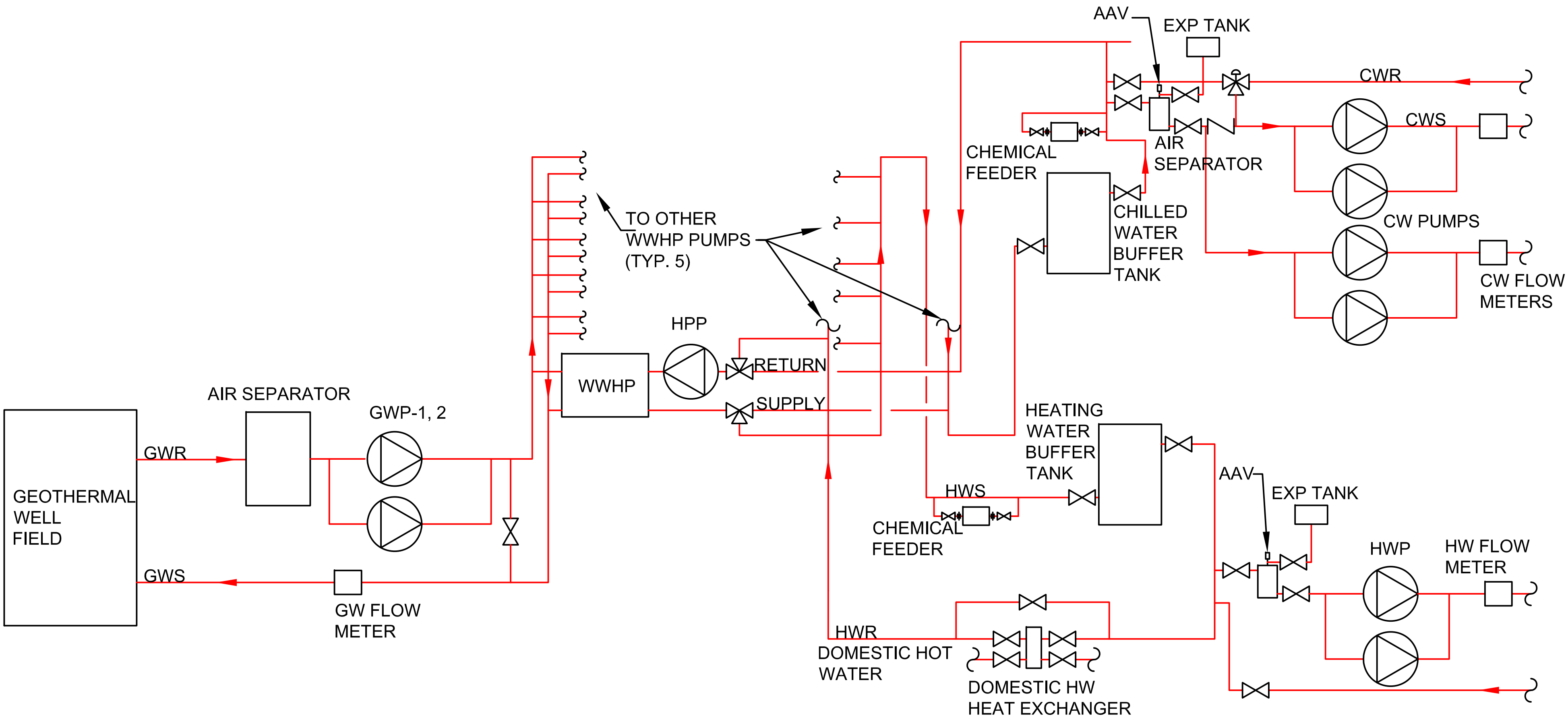
2030	2.31
2031	2.32
2032	2.35
2033	2.37
2034	2.39
2035	2.42

Note(s): 1) End of year 1979. 2) Square footage estimated for years 1981, 1982, 1984, 1985, 1987, 1988, 1990, 1991, 1993, 1994, 1996, 1997, 1998, 2000, 2001, 2002, 2004, and 2005.

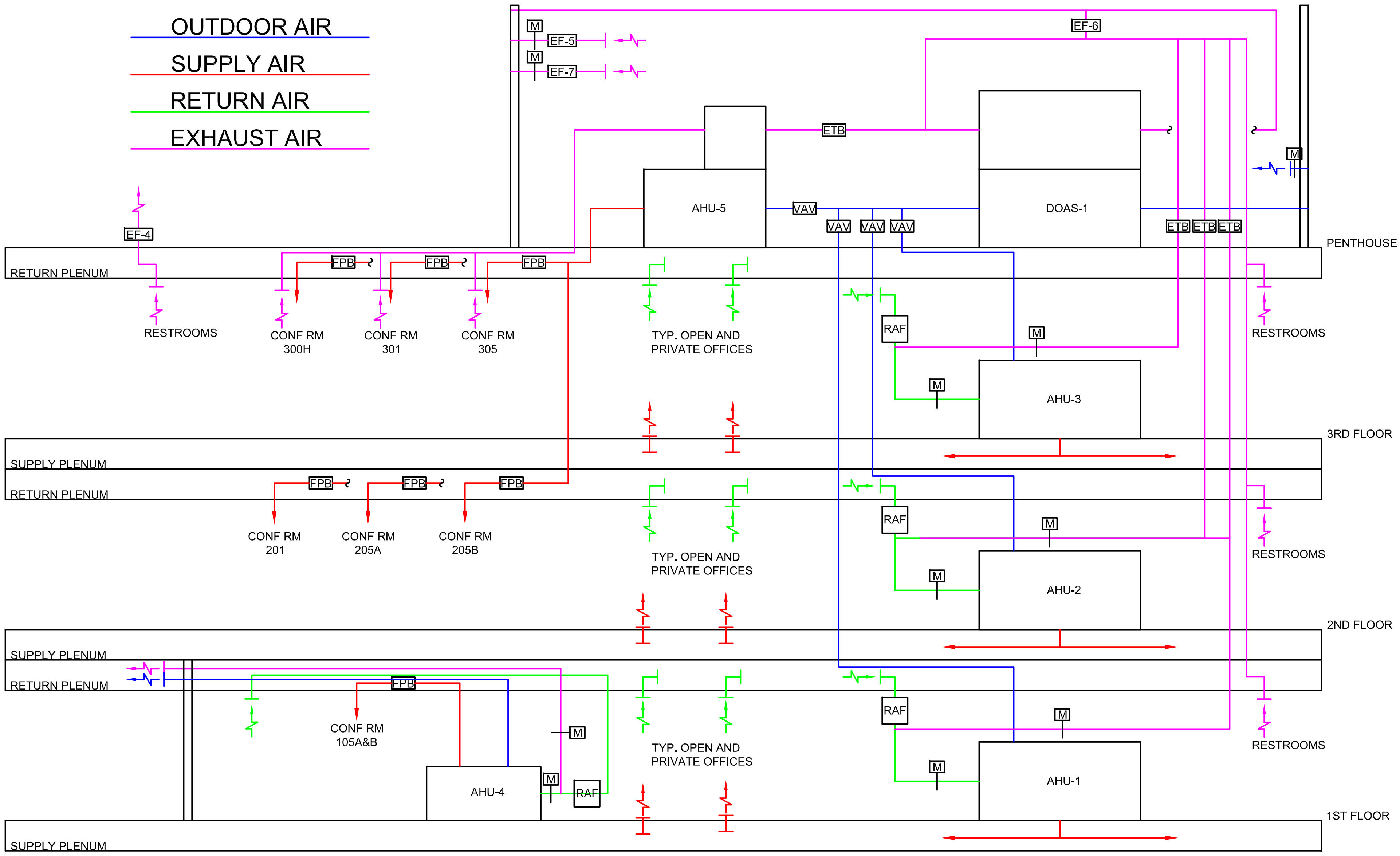
Source(s): EIA, State Energy Data Prices and Expenditures Database, June 2011 for 1980-2009; EIA, Annual Energy Outlook 2012 Early Release, Jan. 2012, Summary Reference Case Tables, Table A2, p. 3-5 and Table A5, p. 11-12 for consumption, Table A3, p. 6-8 for prices for 2008-2035; EIA, Annual Energy Review 2010, Oct. 2011, Appendix D, p. 353 for price deflators. for price deflators; EIA, AEO 1994, Jan. 1994, Table A5, p. 62 for 1990 floorspace; and PNNL for 1980 floorspace.

APPENDIX P1.F

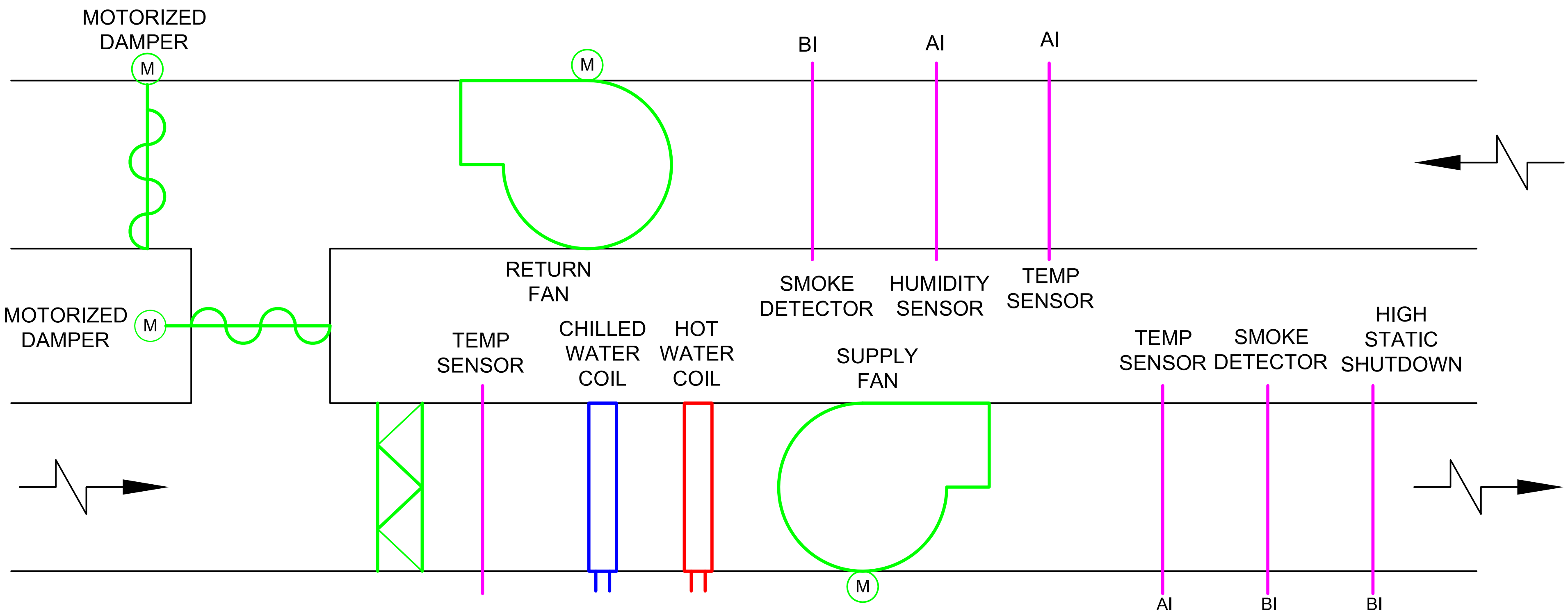
Diagrams and Schematics of building systems



Flow Diagram



Air Riser Diagram



Typical AHU Schematic

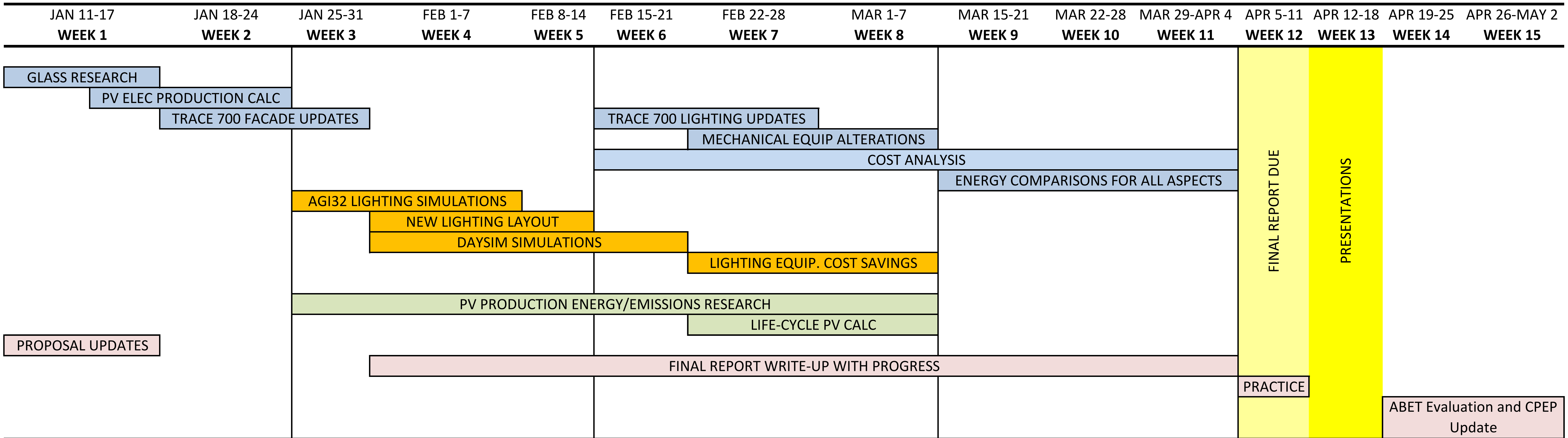
APPENDIX P2.G

Spring semester work schedule

Valerie Miller
Mechanical

Advisor: Dr. Freihaut

Spring Semester Work Schedule



MILESTONE 1 - JAN 23
(a) Windows selected for analysis
(b) PV electricity output determined
(c) Trace 700 updates started
(d) Schedule determined

MILESTONE 2 - FEB 13
(a) TRACE 700 façade updates finished
(b) AGi32 lighting simulations done, DAYSIM started
(c) Lighting layout done
(d) PV research underway

MILESTONE 3 - MAR 6
(a) Lighting breadth complete
(b) Environmental breadth complete
(c) Cost analysis underway
(d) Mechanical equipment resized

MILESTONE 4 - APR 3
(a) Final energy comparisons from depth and breadths done
(b) Cost analysis done
(c) Final report done

APPENDIX P3.H

Glass alternative equipment schedules

Original glass and lighting

EQUIP.	TOTAL CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	8728	2925	19.2	154.2
AHU-2	12707	3023	27.5	262.3
AHU-3	12842	3112	32.1	267.1
AHU-4	2387	780	5.9	44.7
AHU-5	3812	1810	18.1	101.1
DOAS		9840	36.3	273.7

Original glass and new lighting

EQUIP.	TOTAL CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	8583	2925	19.0	152.5
AHU-2	12232	3023	26.7	258.4
AHU-3	12533	3112	31.5	264.6
AHU-4	2387	780	5.9	44.5
AHU-5	3812	1810	18.1	101.1
DOAS		9840	36.3	276.4

Triple doubble low-E

EQUIP.	TOTAL CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	8317	2925	18.4	137.8
AHU-2	11876	3023	25.9	232.9
AHU-3	12037	3112	30.5	241.2
AHU-4	2361	780	5.9	43.5
AHU-5	3812	1810	18.1	101.1
DOAS			36.7	270.9

Triple double low-E + PV

EQUIP.	TOTAL CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	8317	2925	29.3	137.8
AHU-2	11003	2993	35.8	213.8
AHU-3	12037	3112	42.1	241.2
AHU-4	2361	780	5.9	43.5
AHU-5	3812	1810	18.1	101.1
DOAS			2.9	270.1

Basic glass type

EQUIP.	TOTAL CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	8728	2925	26.7	210.5
AHU-2	12707	3023	37.0	352.1
AHU-3	12842	3112	39.4	335.7
AHU-4	2387	780	5.3	41.8
AHU-5	3812	1810	18.1	101.1
DOAS		9840	45.2	357.8

Triple low-E

EQUIP.	TOTAL CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	8728	2925	19.3	148.3
AHU-2	12707	3023	27.2	249.6
AHU-3	12842	3112	31.6	255.7
AHU-4	2387	780	5.9	44.2
AHU-5	3812	1810	18.1	101.1
DOAS		9840	36.3	270.8

Original + PV

EQUIP.	TOTAL CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	8728	2925	20.0	158.3
AHU-2	12707	3023	26.0	242.8
AHU-3	12842	3112	32.0	268.6
AHU-4	2387	780	5.9	44.7
AHU-5	3812	1810	18.1	101.1
DOAS		9840	36.3	273.7

Triple low-E + PV

EQUIP.	TOTAL CFM	OA CFM	COOLING TON	HEATING MBH
AHU-1	8728	2925	20.2	154.7
AHU-2	12707	3023	26.3	236.1
AHU-3	12842	3112	32.1	261.3
AHU-4	2387	780	5.9	44.2
AHU-5	3812	1810	18.1	101.1
DOAS		9840	36.3	270.8

APPENDIX P3.I

Yearly Energy Consumption data

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total	Yearly w/ PV generation
Real monthly total														
Electric (kWh)	84258	80060	72934	76824	105927	99277	112814	80933	70668	70782	83926	99587	1,037,990	1,037,990
Original glass and lighting														
On-Pk Cons. (kWh)	84357	77631	80919	70883	73871	88146	91610	92963	78211	79641	76257	90037	984,526	984,526
Original glass and NEW lighting														
On-Pk Cons. (kWh)	82,407	75,004	79,280	68,704	72,060	86,029	89,825	90,738	76,313	77,800	74,368	87,872	960,399	960,399
Original + PV														
On-Pk Cons. (kWh)	83,292	75,602	79,514	68,601	72,133	86,039	90,188	90,757	76,768	79,082	75,129	87,270	964,375	962,924
Triple low-E														
On-Pk Cons. (kWh)	83,238	75,812	80,058	69,976	72,647	86,652	90,200	91,261	76,861	79,249	75,238	85,897	967,089	967,089
Triple low-E + PV														
On-Pk Cons. (kWh)	84,523	76,185	80,954	70,081	72,759	86,824	90,727	91,542	77,407	80,764	76,446	88,127	976,339	974,888
Triple doubble low-E														
On-Pk Cons. (kWh)	81,036	73,523	78,759	68,564	72,300	85,635	89,309	90,163	76,006	78,922	74,738	81,812	950,768	950,768
Triple double low-E + PV														
On-Pk Cons. (kWh)	80,497	73,245	78,637	68,508	72,300	85,433	89,110	89,949	75,878	78,564	74,274	81,532	948,017	946,566
Basic glass type														
On-Pk Cons. (kWh)	108,308	98,473	98,613	81,322	82,275	97,845	100,690	103,167	87,990	95,250	94,086	109,828	1,157,847	1,157,847

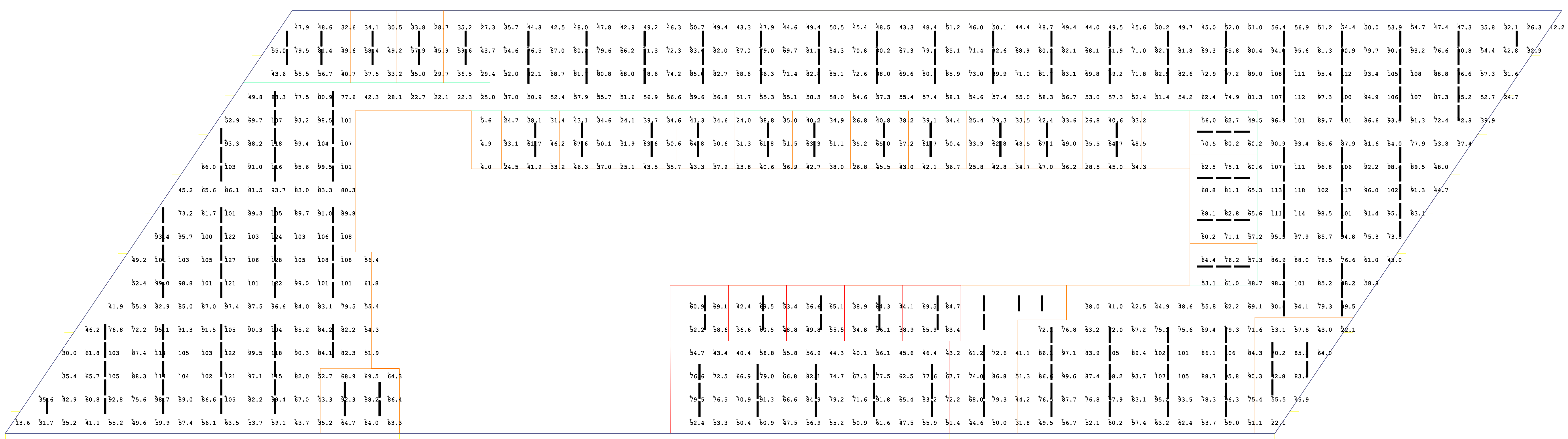
APPENDIX P3.J

Breakdown to alternative cost estimates

	AHU-1	AHU-2	AHU-3	AHU-4	AHU-5	DOAS (ton/MBh)	Energy Recovery	Total equip cost:	Glass Construction cost:	Equip + Glass cost:	1 year op cost:	Operating cost for 20 years:	20 Year Life-Cycle Cost:
Original glass and lighting													
Total SA CFM:	8728	12707	12842	2387	3812	130/1037	18085						
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000						
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**	**$320,762**	**$751,687**	**$75,808.45**	**$1,516,169**	**$2,267,856**
Original glass and NEW lighting													
Total SA CFM:	8583	12232	12533	2387	3812	129/1031	17644						
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000						
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**	**$320,762**	**$751,687**	**$73,950.74**	**$1,479,015**	**$2,230,702**
Original + PV													
Total SA CFM:	9166	11870	12813	2387	3812	130/1023	17882						
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000						
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**	**$295,927**	**$726,852**	**$74,256.85**	**$1,485,137**	**$2,211,989**
Triple low-E													
Total SA CFM:	8831	12560	12617	2374	3812	130/1004	17958						
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000						
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**	**$422,616**	**$853,541**	**$74,465.85**	**$1,489,317**	**$2,342,858**
Triple low-E + PV													
Total SA CFM:	9404	12061	12892	2374	3812	132/1027	18123						
RSMeans size used (CFM):	11500	13200	13200	3000	4000	140	20000						
Cost:	**$22,700**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$433,025**	**$373,828**	**$806,853**	**$74,570.78**	**$1,491,416**	**$2,298,269**
Triple double low-E													
Total SA CFM:	8317	11876	12037	2361	3812	127/962	17113						
RSMeans size used (CFM):	9200	13200	13200	3000	4000	140	20000						
Cost:	**$20,600**	**$26,000**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$430,925**	**$446,939**	**$877,864**	**$73,209.13**	**$1,464,183**	**$2,342,046**
Triple double low-E + PV													
Total SA CFM:	8317	11003	12037	2361	3812	125/942	16699						
RSMeans size used (CFM):	9200	11500	13200	3000	4000	140	20000						
Cost:	**$20,600**	**$22,700**	**$26,000**	**$7,400**	**$9,525**	**$311,000**	**$30,400**	**$427,625**	**$392,431**	**$820,056**	**$72,997.30**	**$1,459,946**	**$2,280,002**
Basic glass type													
Total SA CFM:	15568	21490	18130	2459	3812	163/1329	28017						
RSMeans size used (CFM):	16500	22000	19500	3000	4000	170	20000						
Cost:	**$32,200**	**$42,900**	**$27,900**	**$7,400**	**$9,525**	**$505,000**	**$30,400**	**$655,325**	**$168,742**	**$824,067**	**$89,154.20**	**$1,783,084**	**$2,607,151**

APPENDIX P3.K

AGI32 lighting plans and illuminance (fc) calculations for electric lights



Original Lighting Plan

New Lighting Plan

APPENDIX P3.L

AGI32 daylighting analysis results for south office section of second floor

Date 03 21
Time 8:00
Daylight Sa FALSE
AGi32 File New lighting plan.AGI
RGB Image 001_Mar 21 0800.jpg
Numerical Summary

Label	Desc.	Max	Avg	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		1048.484	572.91	232.0529	2.47	4.52	N.A.	N.A.

Date 03 21
Time 12:00
Daylight Sa FALSE
AGi32 File New lighting plan.AGI
RGB Image 002_Mar 21 1200.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		342.61	464.8176	172.4139	1.99	2.7	N.A.	N.A.

Date 03 21
Time 17:00
Daylight Sa FALSE
AGi32 File New lighting plan.AGI
RGB Image 003_Mar 21 1700.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		182.8	246.3688	87.4667	2.09	2.82	N.A.	N.A.

Date 03 21
Time 8:00
Daylight Sa FALSE
AGi32 File Alternative windows.AGI
RGB Image 001_Mar 21 0800.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		351.5	611.281	148.419	2.37	4.12	N.A.	N.A.

Date 03 21
Time 12:00
Daylight Sa FALSE
AGi32 File Alternative windows.AGI
RGB Image 002_Mar 21 1200.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		263.18	325.7981	141.4369	1.86	2.3	N.A.	N.A.

Date 03 21
Time 17:00
Daylight Sa FALSE
AGi32 File Alternative windows.AGI
RGB Image 003_Mar 21 1700.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		146.5	210.9798	73.1149	2	2.89	N.A.	N.A.

Date 06 21
Time 8:00
Daylight Sa FALSE
AGi32 File New lighting plan.AGI
RGB Image 004_Jun 21 0800.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		341.39	584.2779	144.2519	2.37	4.05	N.A.	N.A.

Date 06 21
Time 12:00
Daylight Sa FALSE
AGi32 File New lighting plan.AGI
RGB Image 005_Jun 21 1200.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		343.23	493.4727	160.0237	2.15	3.08	N.A.	N.A.

Date 06 21
Time 17:00
Daylight Sa FALSE
AGi32 File New lighting plan.AGI
RGB Image 006_Jun 21 1700.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		299.8	489.6951	136.9317	2.19	3.58	N.A.	N.A.

Date 06 21
Time 8:00
Daylight Sa FALSE
AGi32 File Alternative windows.AGI
RGB Image 004_Jun 21 0800.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		218.91	352.308	95.9521	2.28	3.67	N.A.	N.A.

Date 06 21
Time 12:00
Daylight Sa FALSE
AGi32 File Alternative windows.AGI
RGB Image 005_Jun 21 1200.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		253.51	327.4791	124.6796	2.03	2.63	N.A.	N.A.

Date 06 21
Time 17:00
Daylight Sa FALSE
AGi32 File Alternative windows.AGI
RGB Image 006_Jun 21 1700.jpg
Numerical Summary

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		249.01	467.3235	117.0824	2.13	3.99	N.A.	N.A.

Date	09 21
Time	8:00
Daylight Sa	FALSE
AGi32 File	New lighting plan.AGI
RGB Image	007_Sep 21 0800.jpg
Numerical Summary	

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		363.62	632.6481	152.1109	2.39	4.16	N.A.	N.A.

Date	09 21
Time	12:00
Daylight Sa	FALSE
AGi32 File	New lighting plan.AGI
RGB Image	008_Sep 21 1200.jpg
Numerical Summary	

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		342.26	475.7522	168.6108	2.03	2.82	N.A.	N.A.

Date	09 21
Time	17:00
Daylight Sa	FALSE
AGi32 File	New lighting plan.AGI
RGB Image	009_Sep 21 1700.jpg
Numerical Summary	

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		159.49	212.5249	75.8355	2.1	2.8	N.A.	N.A.

Date	09 21
Time	8:00
Daylight Sa	FALSE
AGi32 File	Alternative windows.AGI
RGB Image	007_Sep 21 0800.jpg
Numerical Summary	

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		230.5	378.6266	99.956	2.31	3.79	N.A.	N.A.

Date	09 21
Time	12:00
Daylight Sa	FALSE
AGi32 File	Alternative windows.AGI
RGB Image	008_Sep 21 1200.jpg
Numerical Summary	

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		258.97	323.191	135.4142	1.91	2.39	N.A.	N.A.

Date	09 21
Time	17:00
Daylight Sa	FALSE
AGi32 File	Alternative windows.AGI
RGB Image	009_Sep 21 1700.jpg
Numerical Summary	

Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		130.91	195.501	64.549	2.03	3.03	N.A.	N.A.

Date	12 21							
Time	8:00							
Daylight Sa	FALSE							
AGi32 File	New lighting plan.AGI							
RGB Image	010_Dec 21 0800.jpg							
Numerical Summary								
Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		262.98	475.7678	108.7084	2.42	4.38	N.A.	N.A.

Date	12 21							
Time	12:00							
Daylight Sa	FALSE							
AGi32 File	New lighting plan.AGI							
RGB Image	011_Dec 21 1200.jpg							
Numerical Summary								
Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		237.96	323.7109	123.6468	1.93	2.62	N.A.	N.A.

Date	12 21							
Time	8:00							
Daylight Sa	FALSE							
AGi32 File	Alternative windows.AGI							
RGB Image	010_Dec 21 0800.jpg							
Numerical Summary								
Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		163.53	278.885	70.0934	2.33	3.98	N.A.	N.A.

Date	12 21							
Time	12:00							
Daylight Sa	FALSE							
AGi32 File	Alternative windows.AGI							
RGB Image	011_Dec 21 1200.jpg							
Numerical Summary								
Label	Desc.	Avg	Max	Min	Avg/Min	Max/Min	DF %Over	DF Basis
CalcPts		183.66	221.2734	102.2942	1.8	2.16	N.A.	N.A.

APPENDIX P3.M

Glass catalogs

PIONEER CLADDING & GLAZING
Project Name: NASA AOB1 (20917)
Architect: DMJM Design AECOM / Cooper Carry
General Contractor: The Whiting-Turner Contracting Company
Specification Section: 08 80 00 1.6.B
Submittal: Product Data – Solar Optical Properties and Thermal Characteristics

VIRACON

"The Leader in Glass Fabrication"™

.RACON
800 PARK DRIVE
P.O. BOX 990
OWATONNA, MN 55060
507-451-9555

VIRACON

10/5/2009

SOLAR OPTICAL PROPERTIES AND THERMAL CHARACTERISTICS****

Customer: Pioneer Cladding & Glazing
Jobname: NASA Langley Research Center
GlassType: GL-2
LOW-E INSULATING LAMINATED DATA

Make-up:
1/4" (6mm) VE14-2M #2 (HS)
1/2" (13.2mm) airspace
3/16" (5mm) Clear (HS)
.030" (0.76mm) clear pvb interlayer
3/16" (5mm) Clear (HS)

Transmittance	
Visible Light:	53%
Solar Energy:	19%
Ultra-Violet:	<1%

UltraViolet defined as 300 to 380 nanometers(nm)

Reflectance	
Visible Light-Exterior:	8%
Visible Light-Interior:	10%
Solar Energy:	6%

U-Value	
NFRC Winter Conditions:	0.29 Btu/(hr x sqft x °F)
NFRC Summer Conditions:	0.26 Btu/(hr x sqft x °F)
Shading Coefficient:	0.31
Solar Factor (SHGC):	0.27
Relative Heat Gain:	66 Btu/hr x sqft

****** Centerpane Values**

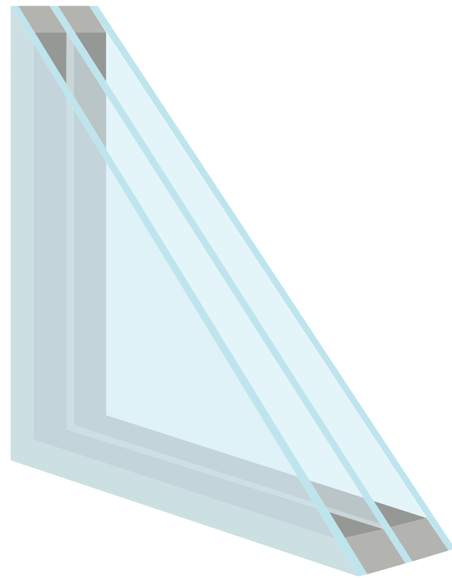
******Calculated using Windows 5.2**

TRIPLE INSULATING GLASS

The most common triple insulating glass units are constructed with three plies of glass separated by two hermetically sealed and dehydrated spaces. This construction increases the insulating value of the glass unit, thus reducing the u-value. A triple insulating glass unit is especially useful in applications where a low u-value is necessary.

While it is possible to specify a 1” triple insulating unit to coincide with a 1” dual pane insulating unit, it is not always practical. A 1” triple insulating unit is constructed with 1/8” glass plies rather than 1/4” plies used in a 1” dual pane insulating unit. The reduced glass thickness increases the potential for distortion and since the 1/8” plies are not as strong as 1/4” plies, the width and height of the glass units must also be decreased. In addition, the solar performance improvement is minimal.

More commonly, triple insulating glass units are constructed with three plies of 1/4” glass and two 1/2” spaces. Viracon’s triple insulating glass units are available with the same Low-E coatings offered with dual pane insulating glass and the Low-E coating is placed on the #2 surface.

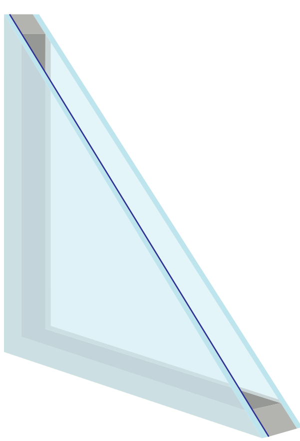


TRIPLE INSULATING KEY BENEFITS:

+ *Two spacers provide superior insulating performance*
+ *Reduces the center of glass u-value*

1" VRE1-54 INSULATING

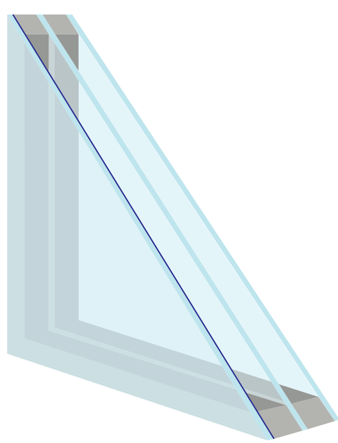
1/4" (6mm) clear with VRE-54 #2
1/2" (13.2mm) airspace
1/4" (6mm) clear



VLT	47%
Winter u-value	0.30
Summer u-value	0.27
SHGC	0.31

1" VRE1-54 TRIPLE INSULATING

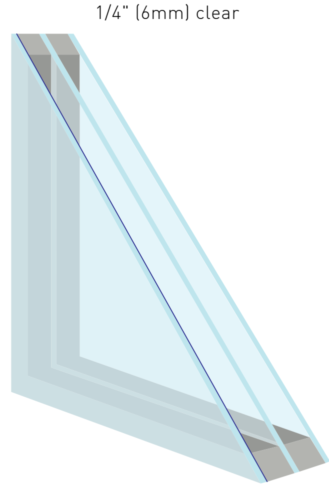
1/8" (3mm) clear with VRE-54 #2
5/16" (7.5mm) airspace
1/8" (3mm) clear
5/16" (7.5mm) airspace
1/8" (3mm) clear



VLT	44%
Winter u-value	0.27
Summer u-value	0.29
SHGC	0.29

1-3/4" VRE1-54 TRIPLE INSULATING

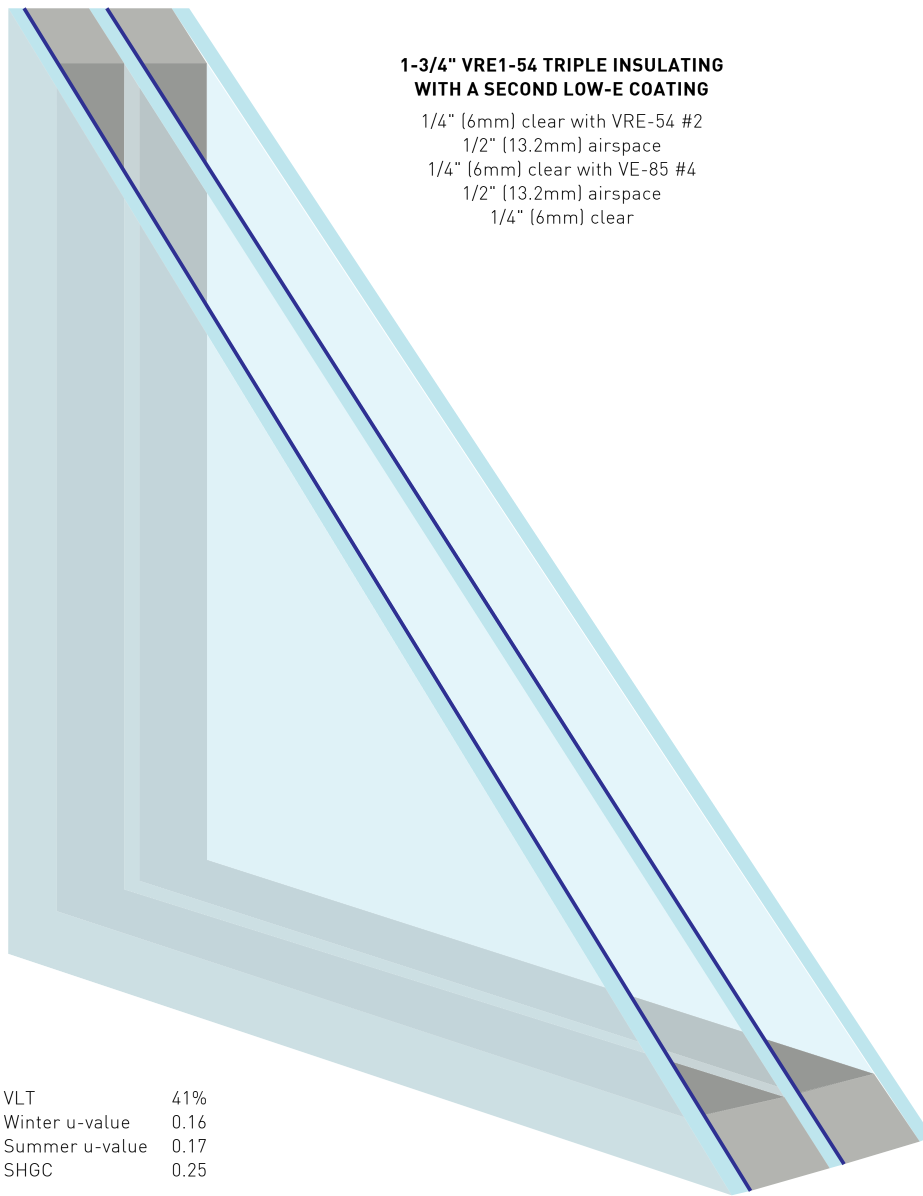
1/4" (6mm) clear with VRE-54 #2
1/2" (13.2mm) airspace
1/4" (6mm) clear
1/2" (13.2mm) airspace
1/4" (6mm) clear



VLT	42%
Winter u-value	0.22
Summer u-value	0.22
SHGC	0.28

TRIPLE INSULATING GLASS

The third ply of glass in a triple insulating unit also offers the option to add a second Low-E coating within the glass unit. The second coating is Viracon's VE-85, a highly transparent coating added to the #4 surface to further improve the solar performance without adversely affecting the appearance.



1-3/4" VRE1-54 TRIPLE INSULATING WITH A SECOND LOW-E COATING

1/4" (6mm) clear with VRE-54 #2
1/2" (13.2mm) airspace
1/4" (6mm) clear with VE-85 #4
1/2" (13.2mm) airspace
1/4" (6mm) clear

VLT	41%
Winter u-value	0.16
Summer u-value	0.17
SHGC	0.25

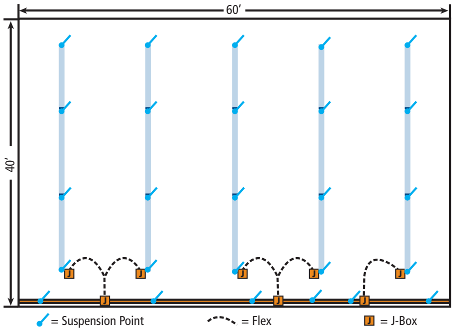
APPENDIX P3.N

Luminaire catalog cost calculation from www.finelite.com

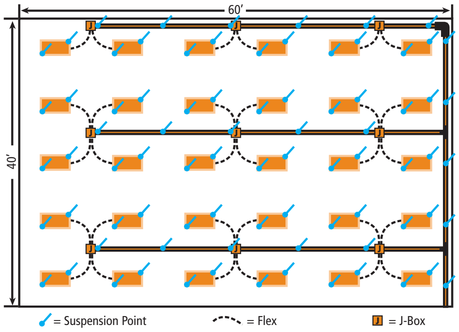
Open Office

60′ x 40′ Area
2400 ft²

Finelite Pendant: 5 - 32′ Rows, 12′ on center, 0.41 w/ft² with 1 T8, 0.78 BF



Recessed High Efficiency 2x4: 30 fixtures, 8′x10′ on center, 0.48 w/ft² with 1 T8, 1.2 BF



Building System Wiring	**Finelite Pendant**			**Recessed High Efficiency**		
Material	Unit Cost	Quantity	Total Cost		Quantity	Total Cost
Rigid metallic conduit (RMC)	$0.98/ft	60	$58.80		190	$186.20
Conduit clips	$0.77 ea	5	$3.85		21	$16.17
RMC bodies and covers	$10.05 ea	0	$0.00		3	$30.15
RMC connectors	$1.90 ea	5	$9.50		15	$28.50
J-boxes	$2.55 ea	8	$20.40		9	$22.95
Metal conduit (MC)	$0.41/ft	30	$12.30		180	$73.80
MC connectors	$1.55 ea	10	$15.50		60	$93.00
Ceiling supports	$2.05 ea	26	$53.30		81	$166.05
SUBTOTAL			**$173.65**			**$616.82**
Labor	Minutes	Quantity Minutes	Total Cost @ $65/hr		Quantity Minutes	Total Cost @ $65/hr
Start-up	45 total	45	$48.75		45	$48.75
Install RMC	2 per ft	120	$130.00		380	$411.67
Install MC	1.5 per ft	45	$48.75		270	$292.50
Rough-in ceiling supports	10 ea	260	$281.67		810	$877.50
SUBTOTAL			**$509.17**			**$1,630.42**
Luminaires						
Material	Unit Cost	Quantity	Total Cost	Unit Cost	Quantity	Total Cost
Luminaires	$35-$45/ft	160	$5,600–$7,200	$135-$250ea	30	$4,050–$7,500
SUBTOTAL			**$5,600–$7,200**			**$4,050–$7,500**
Labor	Minutes	Quantity Minutes	Total Cost @ $65/hr	Minutes	Quantity Minutes	Total Cost @ $65/hr
Install luminaires	1.5/ft	240	$260.00	45 ea	1350	$1,462.50
Make electrical conn.	15 ea	75	$81.25	15 ea	450	$487.50
Remove luminaire bags	2 ea	30	$32.50	2 ea	60	$65.00
Rough-in ceiling supports	15 tot	15	$16.25	15 tot	15	$16.25
SUBTOTAL			**$390.00**			**$2,031.25**
TOTAL			**$6,673–$8,273**			**$8,328–$11,778**
Per Ft²			**$2.78–$3.45**			**$3.47–$4.91**

Notes: All costs are presented for illustration purposes only, to show how the step-by-step Contractor Estimator process is easily applied. Building system wiring material costs are obtained from Sweets Electrical Cost Guide 2009. Luminaire costs can vary significantly depending on the specific luminaire selected and options included. Labor rates will also vary, depending on geographic location and a variety of other factors. Using the method presented and your own cost data for a specific project, an accurate job estimate will result.