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888 Boylston Street – Mechanical System Design

Major Qualifying Project

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NOMENCLATURE

ACB (Active Chilled Beam)

AHU (Air Handling Unit)

ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers)

BTUH (British Thermal Units per Hour)

CFM (Cubic-Feet per Minute)

DOAS (Dedicated Outdoor Air System)

HVAC (Heating, Ventilation, and Air Conditioning)

NFPA (National Fire Prevention Association)

SHGC (Solar Heat Gain Coefficient)

VAV (Variable Air Volume)

ABSTRACT

This project is an entry to the 2016 Architectural Engineering Institute Student Design Competition in the Mechanical category. The challenge was to design the mechanical systems for a 17-story mixed-use building at 888 Boylston Street, in Boston, Massachusetts. The team provided a comprehensive design of the HVAC, plumbing, fire protection, resiliency, lighting, and energy-generation systems, including cogeneration and active chilled beams. The design process involved calculations and simulations to optimize the energy and water consumption of each system, each of which was modeled and evaluated, and then integrated with the Bubbledeck structural system that a partner team designed.

Chapter 1.0 Executive Summary

This report analyzes the mechanical systems for sustainable and efficient operation of 888 Boylston Street. The heating, ventilation, and air conditioning (HVAC) system, as well as the other building systems, are designed in detail to achieve comfort while reducing the ASHRAE 90.1 2007's baseline energy use by 50%. Manual calculations to determine system loads, system energy use, and overall system design were completed with the assistance of Microsoft Excel (Microsoft, 2016). The software DesignBuilder (Design Builder Software Ltd., 2005) was used to validate the manual calculation, and both DesignBuilder and COMcheck-Web (COMcheck-Web, no date) were used to compare an ASHRAE 90.1 2007 compliant base case model to the newly designed model.

Cooling is provided by a combination of high performance Variable Air Volume (VAV) systems, and Active Chilled Beams (ACB) with primary air supplied by Dedicated Outdoor Air Systems (DOAS). Heating is provided by hydronic radiant flooring, with water heated by waste heat from cogeneration. A software program called LoopCAD (Avenir Software Inc., 2015) was used to determine the design heating load and the radiant tubing layout. The heating and cooling systems are designed to be modular for the flexibility to accommodate multiple occupancies on the same floor, as well as adaptable to tenant mobility.

Water use reduction and greywater reuse is important for the sustainability of the plumbing and waste systems. By using water-conscious fixtures such as pressurized faucets and waterless urinals, overall water consumption is decreased significantly.

The fire protection system is designed to meet the requirements of the NFPA 13 and 14, 2013 edition. Hydraulic calculations were performed with the HydraCalc (HydraCalc, no date) software program to secure water flow and pressure demand accuracy.

To address resiliency, sustainability, and performance during an emergency, renewable energy sources including wind turbines, solar panels, and an anaerobic digester, are located on-site. Cogeneration is another on-site energy source that significantly reduces grid reliance, and provides 888 Boylston Street with much energy-independence.

1.1 Design Goals

The following goals present the outline for designing sustainable, efficient, and integrated mechanical systems for 888 Boylston Street:

1. An adaptable and sustainable heating, ventilation, and air conditioning (HVAC) system or systems with small ductwork, low energy consumption, high efficiency, low noise levels, low cost, and accurate comfort control
2. Energy modeling that serves as the backbone of energy comparison and reduction
3. A basic plumbing system that is reliable, convenient, and sustainable, with water reduction features
4. A code compliant fire protection system
5. A sustainable, efficient, and adaptable lighting system which reduces electricity consumption due to fixture and lamp choices and utilization of natural lighting

In addition to these five overarching goals, the mechanical team also closely examined the sustainability of every building system, including the structural systems. Please refer to 4.7 Sustainability/On-Site Energy and 4.10 LEED for more details on sustainability, 4.9 Energy Use Calculations for building energy use reductions, and 4.8 Resiliency for building resiliency systems.

1.2 Team Collaboration

There are nine members in the overall competition team, three of whom worked primarily on the mechanical systems. One member designed the air conditioning and ventilation systems, calculated overall building energy efficiency, and determined possible LEED certification. This member also collaborated with a Structural team member on building sustainability and on-site energy. Another member worked on energy modeling, and designing the lighting system in collaboration with a member from the Structural team. The last member worked on the plumbing and fire protection system, and collaborated with others on resiliency and architectural design.

All three members met regularly to update each other on progress and/or any changes that were made in the mechanical discipline. Daily communication via emails, texts, and phone calls made the team's collaboration smooth. Google Drive (Google, no date) and Sharepoint (Microsoft, 2016) were the central platforms to share work and ensure immediate access to files. Additionally, a weekly nine-member meeting was used to evaluate progress, discuss new ideas, and seek guidance from advisors.

Figure 1 below represents the integration of the various mechanical systems in the building. These equipment and systems will be discussed in sections throughout the report.

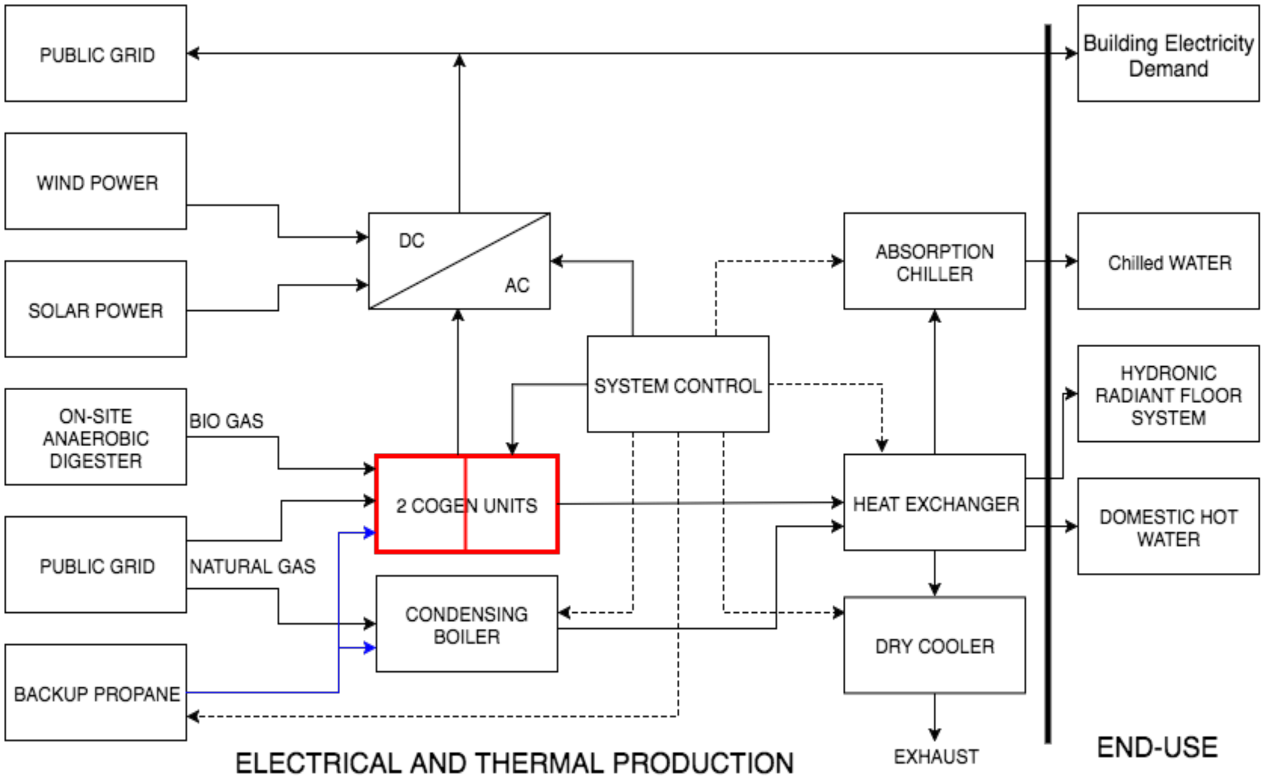

Figure 1: HVAC and Power System Diagram

1.3 Project Codes and Standards

The team extensively researched and consulted with applicable codes and standards before designing a mechanical system for 888 Boylston Street. These include:

- ASHRAE 90.1 2007: Energy Standard for Buildings except Low-Rise Residential Buildings (I-P ed)
- NFPA 54: National Fuel Gas Code (2012 ed)
- NFPA 58: National Liquefied Petroleum Gas Code (2011 ed)
- NFPA 13: Standard for the Installation of Sprinkler Systems (2013 ed)
- NFPA 14: Standard for the Installation of Standpipe and Hose System (2013 ed)
- 248 CMR 4.00: Massachusetts Fuel Gas Code (and its amendments)
- 310 CMR 15.262: Regulatory Provisions for Composting Toilets and Greywater Systems (and its amendments)

1.4 Mechanical Code-Compliance

To ensure 888 Boylston Street's compliance to the ASHRAE 90.1 2007 standard, the team assumed a base case model that would be barely compliant, to use as a point of reference while working on the much improved, proposed model. COMcheck-Web (COMcheck-Web, no date) was used to verify code compliance.

The base case model passed the code requirements by +0.1% for the envelope, +7% for the interior lighting, and +9% for the exterior lighting. The values used for the base case envelope design included 40% glass, with a glass U-value of 0.4 on the southwest façade, 0.45 on the northeast facade, and a Solar Heat Gain Coefficient (SHGC) value of 0.4; the wall U-value was 0.069, with a cavity insulation R-value of 21, and a continuous insulation R-value of 5. Varying the glass U-value for the southwest and northeast facades proved crucial to the base case model passing the code requirements where a uniform glass U-value resulted in envelope non-compliance. The lamps used for the interior lighting were 30W linear fluorescent, averaging a 0.93W/ft^2 emittance, and those used on the exterior lighting were 120W halogen, averaging a 0.25W/ft^2 emittance.

Meanwhile, the proposed model passed the code requirements by +0.29% for the envelope, +89% for the interior lighting, and +86% for the exterior lighting. The values used for the proposed model's envelope design were 99% glass, with a uniform glass U-value of 0.23, a SHGC value of 0.21, and a wall U-value of 0.2. The lamps used for the interior lighting were 8W LED, averaging 0.11W/ft^2 emittance, and exterior lamps were 120W halogen, averaging 0.04W/ ft^2 emittance.

Finally, the entire competition team decided to replace part of the curtain wall with a shadowbox system. Reducing the glass to 60% with remainder of the façade being shadowbox system, and using an R-50 shadowbox with a U-value of 0.025, resulted in an envelope code compliance equivalent to +6%, for the proposed model. Table 1 summarizes the code compliance for the base case and proposed model.

Table 1: Summary of Code Compliance

	Base Case Model	Proposed Model
Envelope	+0.1%	+6%
Interior Lighting	+7%	+89%
Exterior Lighting	+9%	+86%

CHAPTER 2.0 BACKGROUND

This chapter explores the key background research on code requirements, software selection, systems, and energy sources. The first section describes the codes that apply to the design of a multi-story office building, and form the basis for the model. The next section summarizes research completed regarding the mechanical systems in the building, including the air conditioning, ventilation, and heating systems. The third section introduces the software chosen to simulate and evaluate the mechanical aspects of the building. Finally, the challenges the team overcame, while calculating the energy loads of the building and implementing changes during development from the base case to the proposed model, are discussed.

To ensure that the new design would meet the minimum requirements in energy efficiency, the base design, from which all energy reductions are calculated, complies with the ASHRAE 90.1 2007 standard. The base case model was adjusted to a state which barely passes code requirements, and from that a much more energy efficient model was developed. To ensure a proper design for the fire protection system, the national fire protection codes NFPA 54, NFPA 58, NFPA 13, and NFPA 14 were consulted. Finally, the Massachusetts Plumbing and Gas Code, 248 CMR 4.00 code, and its amendments were consulted on fuel gas, and the Regulatory Provisions 310 CMR 15.262 was consulted on compost and greywater applications.

Calculations to determine the energy load for the entire building, and for each aspect of it separately, were extremely important; thus, it was decided to conduct manual calculations using Microsoft Excel spreadsheets, at the same time developing models to support it using other software. AutoCAD and Revit 2015 (Autodesk Inc., 2016) were chosen for fully detailed scales of the model, while COMcheck-Web was chosen for quick determination of the code requirements on envelope, interior lighting and exterior lighting. For energy simulation the DesignBuilder software was chosen, as this is the software most familiar to members of the group. DIALux 4.12 was initially used to determine the lighting output, but this then changed to its newer version, DIALux evo, as it was more advanced and achieved more accurate results (DIAL GmbH, 2016). Finally, LoopCAD 2015 was selected for simulating the radiant floor.

Throughout the design process, the team faced multiple challenges, either while using the software or when conducting manual calculations. There were moments when the simulations would give unusual results, and they would need to be restarted. There were also times when the software would misinterpret a certain unidentifiable parameter. Such a case was very common while using DesignBuilder, which often crashed under the load of our multistory building. This would render incomprehensible results or no results at all, at which point restarting the entire computer was the only safe solution. In order to verify the accuracy of the DesignBuilder results, the team manually designed and calculated the energy use of each system using the aforementioned software DIALux evo, LoopCAD 2015, and Microsoft Excel. The correct pipe and duct sizes, lamps, temperatures, equipment sizes, and all other design constraints were manually determined to assume the calculated loads.

Active Chilled Beams (ACB) supplied by Dedicated Outdoor Air Systems (DOAS) were chosen for the air conditioning and ventilation on all fifteen office floors. An ACB is essentially a heat exchanger. Primary air conditioned to dehumidify and ventilate is pushed into the space through duct in the top or side of the beam (see Figure 2). This flow of primary air induces the air in the room over a chilled water heat exchanger inside the beam, cooling the room air. The three retail floors, due to the differences in scheduling, are serviced by a separate VAV system for air conditioning and ventilation. For more information on the air conditioning and ventilation systems, see 4.1.

Figure 2: York Active Chilled Beam by Johnson Controls

The team researched various heating sources for the building, including forced air heating systems such as central VAV, and condensing boiler and furnace. A radiant floor heating system (see 4.2 Hydronic Radiant Flooring) became the team's system of choice primarily because it provides the best comfort for the occupants.

The mechanical team recommends a shadowbox system that replaces 40% of the curtain wall panels with shadowbox panels. A shadowbox panel is glass on the exterior, and insulation on the interior. From the inside it looks like a wall, from the outside it appears to be glass. The recommended shadowboxes have a U-value of 0.02, substantially decreasing rate of heat transfer through the whole façade.

A cogeneration/trigeneration system was also discussed for 888 Boylston Street. The team evaluated the possibility of grid dependence, which is not the most ideal option. The possibility of a citywide blackout due to natural disasters such as hurricanes and snowstorms is becoming more serious. Additionally, sustainability is a big concern that has to be discussed. If the proposed model is intended to be 'green,' then consuming power produced by large coal-burning plants is not an option. Therefore, a cogeneration system was chosen to efficiently generate power, heat, and cooling with the minimum use of fuel. Although cogeneration consumes natural gas, pollution is significantly reduced, and water-based cooling for the system is dramatically decreased compared with that used in coal-burning plants. For more information on the cogeneration system, refer to 4.3. The team also proposes utilizing various on-site renewable energy sources such as solar power, wind power, and anaerobic digestion as a supplement to resource use reduction. The anaerobic digester can be a benefit considering the large amount of food waste generated by the restaurant and the existing food court in the Prudential Center. Even though it does not produce enormous amounts of biogas, it is another progressive step to achieve sustainability. Renewable energy sources are further discussed in 4.7 Sustainability/On-site Energy.

The plumbing system for 888 Boylston Street was designed to be efficient, reduce overall water consumption, and reuse greywater collected in the rainwater collection tanks. The team briefly designs the pipe layouts for a typical office floor. The system processes greywater and recycles it in the building's gardens and lavatories.

CHAPTER 3.0 METHODOLOGY

The major systems explored in this project are: air conditioning, ventilation, heating, cogeneration, plumbing, fire protection, lighting, solar and wind energy collection, and resiliency. Reducing energy consumption by at least 50% according to ASHRAE 90.1 2007 while maintaining optimum comfort and convenience is of critical importance. As previously mentioned, COMcheck-Web was used to verify and validate envelope and lighting code compliance. This program allowed the team to set a generic base case design for the building and compare it to a proposed design. To precisely calculate the energy consumption of all the mechanical systems in the building, the team used Microsoft Excel. The results from these spreadsheets are then compared to the results produced by DesignBuilder, a software program that predicts the energy consumption of the building (for more information on DesignBuilder, see 3.5). LoopCAD was used simultaneously to design the hydronic radiant floor heating system as well as predict the energy consumption, supplied water temperature, and floor surface temperature.

The amount of greywater being recycled and stored by the plumbing and waste system was calculated using Microsoft Excel. The fire protection sprinkler/standpipe system is designed with HydraCalc which accurately determines water flow and pressure demand as prescribed by NFPA 13 and 14. Sustainability and resiliency do not need special software program to determine their feasibility; however, the team still follows local codes to make sure that the systems proposed are compliant.

AutoCad is used to design the mechanical systems in detailed two-dimensions including ductwork, lighting, plumbing, and sprinkler layout. Revit is used to design the HVAC system in three-dimensions and detect clashes between the systems. This allows the team to visualize how all the mechanical systems interact within the building and how they can integrate with the structural system.

3.1 Active Chilled Beam (ACB) System

The scheduling and tenant variability requires an air conditioning and ventilation system for the fifteen office floors that is separate from the retail. Two mechanical rooms, containing Dedicated Outdoor Air Systems (DOAS), on each office floor split the space in two, allowing two different tenants per floor. Individual systems for each tenant allow for more personalized environmental controls, and for complete tenant responsibility over amount of energy bought and consumed. Outside air is moved from the building exterior to each mechanical room via large duct. From the DOAS, ductwork transports the conditioned air to localized chilled-water heat exchangers called Active Chilled Beams (ACB). The conditioned air flows into the top or side of the ACB, inducing the warmer room air over a chilled-water heat exchanger, cooling the room air. The primary air operates in conjunction with CO_2 sensors, providing the correct amount of ventilation at all times. Chilled water is pumped to each ACB from the absorption chillers in the Mechanical penthouse. The ACBs sit flush with the ceiling, and the number is determined by the cooling load of the zone, and trade-offs between nozzle type and heat exchanger capacity.

By using 100% outside air, the DOAS meets winter cooling loads without compressor operation. The floor-by-floor mechanical rooms utilize a "mixing room" concept that reduces ductwork and congestion in the mechanical room, saving first cost and facilitating maintenance access. The primary air provided to each ACB in the interior spaces is designed to meet winter cooling loads. The first step in designing the ACB and DOAS systems is the calculation of cooling loads.

3.1.1 ACB Load Calculations

The typical office floor plan was divided into three zone categories: Perimeter (E), Corner (C), and Interior (I). If the zone had more than one exterior wall orientation, it was considered a Corner. The zone areas, shadowbox areas with U-value equal to 0.02, and window areas with U-value equal to 0.23, together with orientation and location values assisted in the heat transfer calculations. Final BTUH (British Thermal Units per hour), both sensible and latent, were calculated after adding values for internal heat gain, including lighting, people, and appliances. A sample of the load calculations for a typical office floor can be found in Appendix 01, and the Appliance Calculations can be found in Appendix 09.

3.1.2 Load Distribution

Due to the dual medium of the ACBs, primary air and chilled water, part of the zone thermal load is carried by the primary air, and the majority is provided by the chilled water. Because the primary air is cooled to dehumidify, as it enters the space to induce convection, the primary air also provides some cooling to the zone. The remainder of the cooling is due to heat exchanging between the room air and the chilled water. First, a calculation was made to determine which was higher: the CFM (cubic-feet per minute) of air flow required to ventilate the space, or the CFM required to dehumidify the space. Dehumidification CFM was determined to be the highest, so this became the minimum primary air CFM needed in the space. Then a calculation was done to find out how much cooling that dehumidification CFM provided. The rest of the cooling load, as determined by the load calculations in section 3.1.1 ACB Load Calculations, was the required capacity of the chilled water. To see the values for this process, please refer to the Appendix 02.

3.1.3 Active Chilled Beam Sizing

After the primary air and chilled water cooling capacity were determined, the capacities had to be balanced according to actual ACB cooling capabilities. Johnson Controls York © Overhead Active Chilled Beams were chosen for this project, based on customer reviews and the availability of copious design data.

Johnson Controls offers eight different nozzle types. The nozzle type affects the capacity of the ACB by altering the distribution patterns and velocity of the air. Also, each nozzle type has a range of primary air CFM capabilities that have to be balanced and matched. A sample of the ACB sizing process can be seen in Appendix 03. For a summary of the ACBs and their properties, see the Load Distribution in Appendix 02.

Table 2 is the ACB schedule for each of the fifteen office tenant floors. For easy layout installation and buying simplicity, each of the 1,950 ACBs is 6 feet long, 2 feet wide, and 11 ¾ inches tall, and each has ½ inch chilled water pipes. The capacity of each ACB has been uniquely matched to the capacity of each zone.

Table 2: Active Chilled Beam (ACB) Schedule

Nozzle	Count
A0	22
A1	48
B1	5
C1	20
E1	29
F1	6
G1	0
H1	0
Total	**130**
All Floors	**1,950**

3.1.4 Primary Air Ductwork Sizing

The sizing of the primary air ductwork is comparable to that of a traditional VAV duct sizing process. The CFM flow that needs to fit through those ducts, found in 3.1.3 Active Chilled Beam Sizing, is used to calculate the duct height and width, while keeping to an approximate 0.08 friction (head) loss per 100 feet of duct. At the same time, the highest pressure drop across the fittings and the lengths of straight duct needs to be calculated in order to properly size the equipment. Another important consideration is the velocity of the air in the duct. It is good practice to keep the air velocity well below 1,500 inches per minute to reduce noise to acceptable levels. To see how this was done, refer to Primary Air Ductwork Sizing for a Typical Office Floor in the Drawing D01.

In the case of this project, there was an added complication. The primary air ductwork is integrated with the structural floor system of the building, called Bubbledeck. The Bubbledeck for this design is a 20 inch concrete slab latticed with 16 inch diameter plastic bubbles and rebar. The bubbles reduce the amount of concrete and lighten the structure, as well as create open spaces suitable for duct. While the majority of the primary air duct is located inside the Bubbledeck, the duct cannot be placed inside the Bubbledeck within 9 feet of any structural column for strength reasons. This required careful placement of the primary duct with strategic exits from the Bubbledeck into the ceiling plenum, and then shorter runs of small duct inside the plenum itself. This method has the added benefit of flexibility in the placement of the ACBs. For the final ACB and Primary Air Duct Layout, as well as a 3D representation of the column complication, see Drawing D02.

3.1.5 Equipment Sizing

Each office floor has two mechanical rooms, each of which must provide the ACBs with the capacities outlined in Table 3.

Table 3: Typical Office Floor Cooling Capacities

	Primary Air Capacity (tons)	Chilled Water Capacity (tons)
Mechanical Room 1	16.43	17.36
Mechanical Room 2	14.98	18.24
Floor Totals	**31.41**	**35.59**
Office Totals	**471.15**	**533.90**

These values were used to size all the equipment for the Active Chilled Beam with Dedicated Outdoor Air systems.

3.1.6 Cooling Energy Consumption Calculations

Table 4 shows the energy consumed by all of the cooling equipment explored in 3.1.5 Equipment Sizing, for the entire office use, in kW, as well as annual consumption.

Table 4: Energy Consumed by Office Cooling Systems

Equipment Type	Number / Capacity	Energy Use (kW)	kWh/year
Absorption chillers	534 tons	1,643.4	4,272,840
Cooling towers	472 tons	661.9	1,720,966
DOAS	30	35.8	93,106
Desiccant wheels	30	-	-
Relief/spill fans	30	23.87	62,062
Exhaust fans	30	23.87	62,062
ACB	1,950	-	-
TOTAL		**2,389**	**6,211,036**

See 4.9 for the ACBs' contribution to the project's 50% energy reduction goal.

3.2 Variable Air Volume (VAV) System

The calculations for high performance VAV systems are much simpler than calculations for the office Active Chilled Beam (ACB) Systems (see 3.1 Active Chilled Beam). ACBs are a much newer technology, resulting in fewer calculation methods and less available data.

3.2.1 Load Calculations

Please refer to 3.1.1 ACB Load Calculations for load calculation methods. Retail 1/Lobby Peak Load Calculations can be found in Appendix 04.

3.2.2 VAV Duct Sizing

Duct sizing for the retail VAV is almost exactly the same as the primary air duct sizing for office (see 3.1.4 Primary Air Duct Sizing), but with fewer complications. In this case the entire load capacity is provided by changing air amounts, hence "Variable Air Volume", and all the retail VAV duct is in the plenum below the Bubbledeck (for more information, refer to 3.1.4 Primary Air Ductwork Sizing). This means that the duct is no longer restricted to 16 inches wide by 16 inches tall, and that VAV boxes are the center point for the air registers. To see sample duct sizing, refer to Drawing D01. To view the VAV ductwork layouts for Retail Level 01 and Retail Level 02, refer to drawings D08 and D09.

3.3 Hydronic Radiant Floor

3.3.1 Assessment

A removable shadowbox system is recommended for 40% of the building envelope which provides a significant reduction in U-value from 0.23 to 0.025. This allows a reduction in heat loss through the building envelope. Note that the shadowbox system occupies 40% of the building envelope at random locations. LoopCAD is an excellent tool to calculate the designed radiant load, but it does not provide enough flexibility to specify that 40% of the shadowbox system occupies the envelope at random locations. Therefore, the team approximates a U-value using this method:

$$\frac{(0.6\times 0.23)+(0.4\times 0.025)}{2} = 0.074.$$

The U-value of 0.074 is the final number that is used to determine design heating load of the radiant system, floor surface temperature, and required water temperature, which are predicted by LoopCAD software program as shown in Table 8 on page 21. This program is then used to create tubing layouts.

This U-value reduction dramatically decreases the radiant heating load. Table 8 shows that the largest heat consumer is the first floor because it has the largest floor area, and the typical office floor consumes the least. The Supplemental Heat column shows the heat required in addition to what the radiant heating can provide. No supplemental heat is needed because the radiant system provides enough heat to maintain the building at a comfortable level, with the exception of the third floor. Part of this floor requires supplemental heating due to the ceiling height in the office lobby. Heat from the third floor HVAC system will fulfill this supplemental heat. The water temperatures range from 92.8 to 114.8˚F, which is well below what the heat recovery can supply. The total flow and head loss column allows the team to select the correct pump for each manifold and for the entire building. Another important takeaway from this table is that all surface temperatures are below 85˚F, which is the design maximum allowable surface temperature. Surface temperatures above this would be uncomfortable to occupants.

3.3.2 Radiant Floor and Electrical Conduit

To ensure maximum flexibility of the space, electrical conduits are embedded in the topping concrete slab of the Bubbledeck (for more information, refer to 3.1.4 Primary Air Ductwork Sizing) so that electrical plugs can be placed strategically. These conduits also have access panels in various locations. This is important especially on the office floors where work stations are mainly away from the walls. The conduits cannot cross or interfere with the radiant tubes, thus the structural and mechanical teams collaborated to strategically place the conduits throughout the floor plan. This task is relatively simple in the design phase because the radiant tube positions are known, and they are spaced approximately nine inches from one another. The nine-inch spacing leaves enough space to add conduits between the tubes if necessary (see Figure 3).

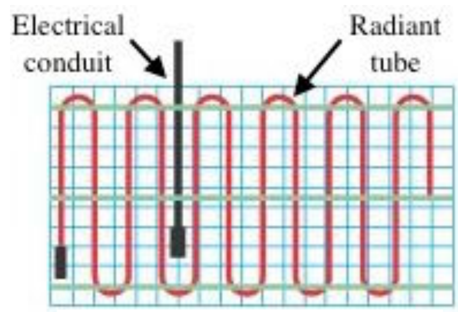

Figure 3: Electrical Conduit in Radiant Floor

3.4 Fire Protection System

The assessment of sprinkler flow and pressure demand requires the following steps:

- Determine hazard occupancy per NFPA 13, 5.2 and 5.3 (see Appendix 08)
- Classify stored commodity per NFPA 13, Table A.5.6.3 (see Appendix 08)
- Determine appropriate trim and valves (see Appendix 08)

3.4.1 Suction Pressure

This building requires a fire pump because of the head loss due to elevation. The Upper Roof is 319 feet, 7 inches above ground level, and the static loss is 0.433 psi per foot, which amounts to 138.4 psi due to total height. The city provides only 60 psi residual and 65 psi static.

The pressure (Ps) at the suction flange of the pump must be positive. The pressure at the pump suction is the pressure available from the city water supply less the losses:

- 60 psi residual pressure from city supply
- Less 15.2 psi loss due to 35 feet elevation gain from water service to the fire pump inlet on the third floor
- Less 13.23 psi loss due to pipe friction and fittings (backflow preventer, check valve, gate valve, flow switch); the Hazen-Williams formula is used to determine pressure loss per foot due to pipe friction.

This calculation leaves an acceptable 31.6 psi (60 – 15.2 – 13.23 = 31.6) of pressure available at the pump inlet.

3.4.2 Sprinkler Design

The sprinkler design is different for each occupancy type. The typical office floors are light hazard occupancy and equipped with concealed, quick response, standard coverage sprinklers with a K-factor of 5.6. A quick response sprinkler is required by NFPA 13, 8.8.3.1. It is also permitted in ordinary hazard occupancy as well, which is the case in this project. The maximum spacing for light hazard is 15 feet by 15 feet, but 12 feet by 12 feet was chosen because extra cushion is ideal. The retail spaces are ordinary hazard group II and are equipped with the same sprinklers as the office floors. The maximum coverage area per sprinkler is 130 square feet for ordinary hazard, thus the spacing is 11 feet by 11.5 feet (126.5 square feet; smaller than 130 square feet).

The storage rooms on the first and third floor are ordinary hazard group II and are equipped with concealed, quick response, standard coverage sprinklers with a K-factor of 11.2 because there tends to be more combustible materials in such spaces. The spacing remains as 11 feet by 11.5 feet. The parking levels are ordinary hazard group I and are equipped with the same sprinklers as the retail floors. The sprinkler spacing is also 11 feet by 11.5 feet. Refer to drawings D05 and D05.1 for sprinkler layouts for the Level 18 and for all three retail floors.

As per NFPA 13, 11.2.3.1.1(1), the density/area method is used. This method allows the designer to easily select the water density based on the hazard occupancy of the space from a chart as shown in Figure 4. Since most of the spacing within the design area is not uniform, more sprinklers are added into the calculation to ensure that the 1,500 square feet requirement is met. As per NFPA 13, 11.2.3.2.3.1, this sprinkler system is qualified to reduce the design area from 1,500 square feet by 35.5% and 30%, without revising density for typical office floors and retail floors, respectively. This qualified reduction is due to the satisfaction of the following conditions: wet pipe system, light or ordinary hazard occupancy, 20 foot maximum ceiling height, and the lack of unprotected ceiling pockets exceeding 32 square feet. The design area of 1,500 square feet for the parking levels are increased by 30% without revising water density as per NFPA 13, 11.2.3.2.5 to compensate for the time it takes for water to travel to the sprinkler heads in the dry pipes. Details of the design can be seen in Drawing D07.

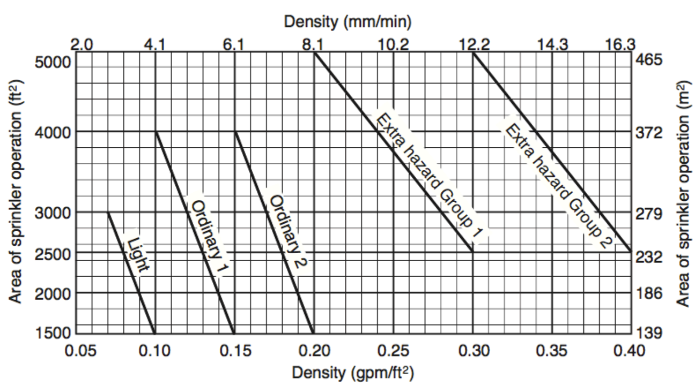

Figure 4: Density/Area Chart (NFPA 13, Section 11.2.3.1.1)

3.4.3 Hydraulic Calculations

The water and pressure demand are hydraulically calculated using HydraCalc. Table 5 displays the results of six selected floors. Floor 18 represents a typical office floor. Screenshots of the program are included in Appendix 08.

Table 5: Flow and Pressure Demand for Sprinkler System

Floor	Flow Demand (GPM)	Pressure at Floor 3 Pump Discharge Flange (PSI)
Wet Pipe System:		
18th	120	233
3rd	358	90
2nd	307	89
1st	305	43
Dry Pipe System:		
Green Mezzanine	300	31
Green Level	306	18

The system is sized for the larger of sprinkler and standpipe demand. Since the flow demand in both wet and dry pipe systems exceeds the flow requirement for standpipe of 750 to 500 GPM for remote riser and 250 GPM for additional riser, the standpipe system can sufficiently supply the sprinkler system in a combined standpipe/sprinkler system.

Inside hose allowance is not added when hydraulically calculated; however, 250 GPM of outside hose allowance is added separately to the system at the city main as per NFPA 13, Table 11.2.3.1.2. The overall flow demand is now 1,000 GPM, which is exactly what the city can supply, thus no storage tank is needed.

3.4.4 Fire Pump Selection

A fire pump rated for 750 GPM, 12 inch diameter 60 Hz model 6x4x10F-M 8100 (see Figure 5), from AC Fire Pump Systems is installed in the pump room on Floor 03 which supplies both the wet and dry pipe systems. The available suction pressure is subtracted from the greatest sprinkler system pressure demand, which is discussed below, in order to select the most efficient pump size. A city and fire pump combined curve is provided in Appendix 08. Note that the 'A' curve of the selected fire pump is used.

Figure 5: Fire Pump (AC Fire Pump)

3.4.5 Valves, Components, Trims, and Pipe Type

The system piping is carbon steel, ASTM A53 Grade B ERW, schedule 40. The grooved pipe joining method is used to join the different pipes and components in the system because it is easier and faster than welded, flanged and threaded joints. Different valves and components are approved by standards such as UL Listed and FM Approved. Below is a list of the components and valves needed for this fire protection system and can be found on both the Tyco Fire Products LP and Viking Group Inc. websites.

- Pressure gauge
- Test drain valve
- Check valve
- Listed combined pressure reducing valve, indicating control valve, and check valve
- Pressure reducing fire hose valve
- City gate valve
- Flow switch
- Fire department connection
- Driver valve riser assembly
- Relief valve
- Backflow preventer

3.5 DesignBuilder Simulations

In order to verify the manual calculations independently for each system selection, as well as collectively for the building, the team conducted simulations using DesignBuilder, a software that can recognize a 3D building model (see Figure 6), and all its components, and then render simulations on the building energy use. It does so using the stand-alone simulation program EnergyPlus, the U.S. Department of Energy building energy simulation program for energy consumption.

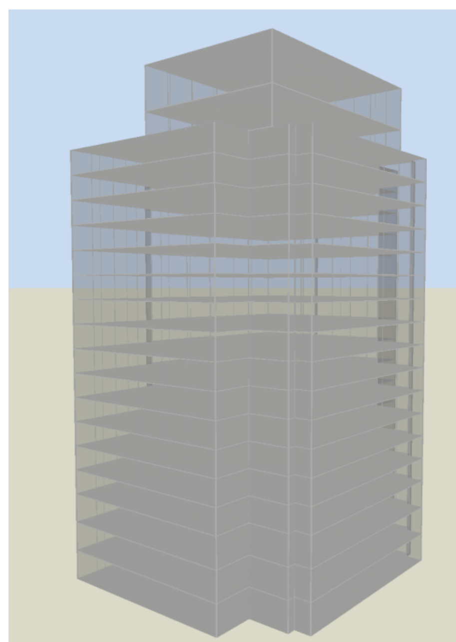

Figure 6: DesignBuilder Base Case Building Rendering

As a starting point, a base case model was created using the code-compliant values confirmed in the COMcheck base case report, and assuming the ASHRAE 90.1 2007 default settings for all the parameters under the Activity, Construction, Openings, Lighting and HVAC categories. Then, step-by-step simulations were conducted to record the progress and percent reduction in the on-site total energy use with the changing of each parameter. These parameters include the different materials used for the floors, walls and windows, the schedules of occupancy, building and equipment operation schedules, the HVAC system parameters, and the specifications of the lighting fixtures, among others. Images of the software depicting the settings that shaped the final model can be found in Appendix 13.

A summary table of the step-by-step process using DesignBuilder, indicating the net source energy outputs of the building, followed by the percent reduction in energy use that each step contributed, can be found in Appendix 07. The steps represent the effects of each of the aforementioned categories as a whole, and then sub-steps are added, representing the individual changes to each of the categories. The nature of the change is first introduced, followed by the Base Case and Final Proposal settings. The energy use in tons per hour and kBTU/ft^2 per year are presented, followed by the effect the steps and sub-steps had on the total energy use reduction percentage.

The software appeared to be problematic a number of times; it would often misinterpret changes to the settings, or even completely disregard them. This would lead to inaccurate numbers on the simulation reports, which then needed to be confirmed with other, more specific software, or manual calculations. The platform also had difficulty supporting the large file, leading to screen freezing, and requiring reboots of the computer. For this, the HVAC TAB numbers in the Appendix 07 were calculated using a Microsoft Excel and the radiant floor heating value was taken from LoopCAD (for more on this see 3.3 Hydronic Radiant Floor).

Chapter 4.0 Results

4.1 Cooling & Ventilation Systems

The overall building cooling system is divided into two larger separate systems, due to the mixed use of the space. Retail tenants occupy Floor 01 through Floor 03 with scheduling that includes weekends and weeknights. Office tenants occupy Floor 04 through Floor 18 with approximate 8AM to 5PM scheduling. By separating the retail cooling from the office cooling, there is an enormous energy use reduction during off-hours.

Each separate system is further subdivided to maintain flexibility with changing tenants. The large, open retail spaces on Levels 01, 02, and 03, excluding the office entry, food hall, and food hall entry, are divided into smaller, ceiling-mounted Variable Air Volume (VAV) systems. The food hall and both entryways are served by large air handling units (AHU) located on Level 01 in the south-center of the building. Each office floor is cooled by two Dedicated Outdoor Air Systems (DOAS); each half-floor system supplies primary air to the Active Chilled Beams (ACB) on that half, which allows each tenant to control the their environment. Due to the subsystem separation, each tenant can be made responsible, to a large extent, for their individual energy consumption by the installation of sub-meters.

Ventilation is provided year-round by the ACB primary air duct. In the winter months when no major cooling is needed, the water flow to the ACBs can be shut off, and the primary airflow can be reduced to provide ventilation only, or slight cooling where it is needed.

4.1.1 Active Chilled Beam (ACB) and Dedicated Outdoor Air (DOAS) Systems

Active Chilled Beams (ACB) provide a modular ventilation and air conditioning system, with small ductwork, energy consumption lower than a traditional VAV system, high efficiency, low noise levels, low overall cost, and accurate comfort control. The smaller ductwork allowed by ACB systems enables this project to integrate the primary air ductwork into the Bubbledeck structure (see 3.1.4 Primary Air Ductwork Sizing) of the building, effectively saving installation time and cost, reducing plenum space and floor-to-floor height, and decreasing the energy consumption of the cooling system. Using a Dedicated Outdoor Air System (DOAS) with a desiccant wheel allows “free” cooling at certain times, as well as some low-energy dehumidification.

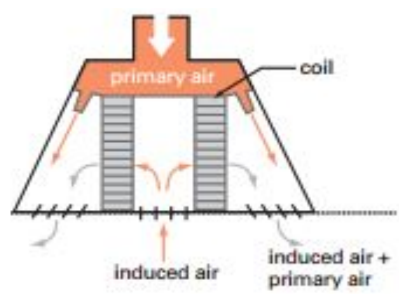

Figure 7: Active Chilled Beam (Murphy)

An ACB is essentially a localized heat exchanger (see Figure 7). The primary air, conditioned to dehumidify and ventilate, enters through a duct connection in the top of the beam. This primary flow induces room air over a chilled water heat exchanger, cooling the room air. This cooled supply air also mixes in the space, providing additional cooling.

DOASs provide the ACBs with the primary air via ductwork in the Bubbledeck. To keep each half-floor system separate, two mechanical rooms on each floor are needed. These mechanical rooms house the

DOAS, which pull the correct amount of outside air into the system via exterior-connected duct. The desiccant wheels included in the DOAS remove 20 to 25% of moisture from the outside air (Desiccant Dehumidification Wheel, 2004). The quantity of outside air varies slightly by floor. While in the DOAS, the outside air is filtered and cooled to 57°F to dehumidify to 60 grains per lb., and subsequently it is delivered through the duct to the ACBs.

On a cool day, when the outside air is cold enough, the DOAS system will simply supply the air to the ACBs, which is essentially free cooling. By using 100% outside air, the DOAS meets winter cooling loads without compressor operation. The DOAS systems will compensate to provide the amount of cooling and/or dehumidification that is necessary. Meanwhile a central, valve-controlled chilled water system based at the absorption chillers in the Mechanical Penthouse provides the chilled water to the mechanical rooms on each floor. From each location it is distributed by pump to the ACBs.

Figure 8: Precast Bubbledeck (Bubbledeck North America LLC)

Much less air is needed with ACB than with traditional VAV, reducing the fan power necessary and converting it to pump power, which is much lower. Also, floor-by-floor mechanical rooms utilize a "mixing room" concept reducing ductwork and congestion in the mechanical room, saving first cost, and facilitating maintenance access.

The ACB primary air ductwork was designed specifically to fit inside the Bubbledeck structure. As can be seen in Figure 8, the Bubbledeck slabs arrive at the site precast with the polystyrene and rebar, are lifted into place by crane, and then the finishing touches are made, including setting the duct, adding access panels and extra rebar, and then pouring the concrete on top. Integrating the primary air ductwork with the building structure allows for a reduction in plenum space and thus the addition of floor (a total of 18 occupiable floors) without altering the original height of the building.

The use of ACBs in this building design requires some special design criteria, including:

- The chilled water supply temperature needs to remain above the dew point of the space to avoid condensation in the chilled beams.
- The primary air provides ventilation, and must always be on when the space is occupied.
- The primary air duct must be less than 16 inches tall and 16 inches wide to integrate correctly with the Bubbledeck structure.
- The duct inside the Bubbledeck cannot be within 9 feet of any structural columns, due to the shear strength limitations of the Bubbledeck (illustration in Drawing D02).
- Many interior zones do not require much or any water-based cooling by the ACB; cooling is accomplished by primary air only.

Table 6 shows the Cooling Equipment Schedule for a Typical Office Floor, compared to the Total Equipment Schedule for all 15 offices floors. The cooling capacity of the primary air supplied by the cooling towers, and the cooling capacity of the chilled water is provided by the absorption chillers.

Table 6: Typical Office Floor Equipment Size

Typical Office Floor Equipment Schedule		Total Office Equipment Schedule
Equipment Type	**Number / Capacity**	**Number / Capacity**
Absorption chillers*	36 tons	534 tons
Cooling towers	32 tons	472 tons
DOAS	2	30
Desiccant wheels	2	30
Relief/spill fans	2	30
Exhaust fans	2	30
ACB	130	1,950

*Waste heat from the cogeneration system provides the "fuel" for the absorption chillers to generate chilled water

The highest capacity, 534 tons, and the highest energy use, 4,272,840 kWh per year (see Table 7), come from the absorption chillers. The absorption chillers provide the chilled water for the ACBs using waste heat from the cogeneration system (see Chapter 4.3).

The physical position of the ACB is important for aesthetic reasons and for locating around the other building systems, such as lighting and fire protection. Each of the 1,950 ACBs in 888 Boylston Street are 6 feet in length, 2 feet wide, and 11 ¼ inches in height. The ACBs sit flush with the ceiling; they fit in the lower section of the 18 inch plenum space.

The ACBs are as evenly spaced as possible within each zone. In Figure 9, the purple duct is inside the Bubbledeck structure, the green duct is under the Bubbledeck in the plenum space, the ACBs are in blue, and the zones are in red. Figure 9 is an example of part of the ACB layout each office floor.

Table 7: Energy Consumption of the Office Cooling Systems

Equipment Type	Number / Capacity	Energy Use (kW)	kWh/yr
Absorption chillers	534 tons	1,643.4	4,272,840
Cooling towers	472 tons	661.9	1,720,966
DOAS	30	35.8	93,106
Relief/spill fans	30	23.87	62,062
Exhaust fans	30	23.87	62,062
ACB	1,950	-	-
TOTAL		**2,389**	**6,211,036**

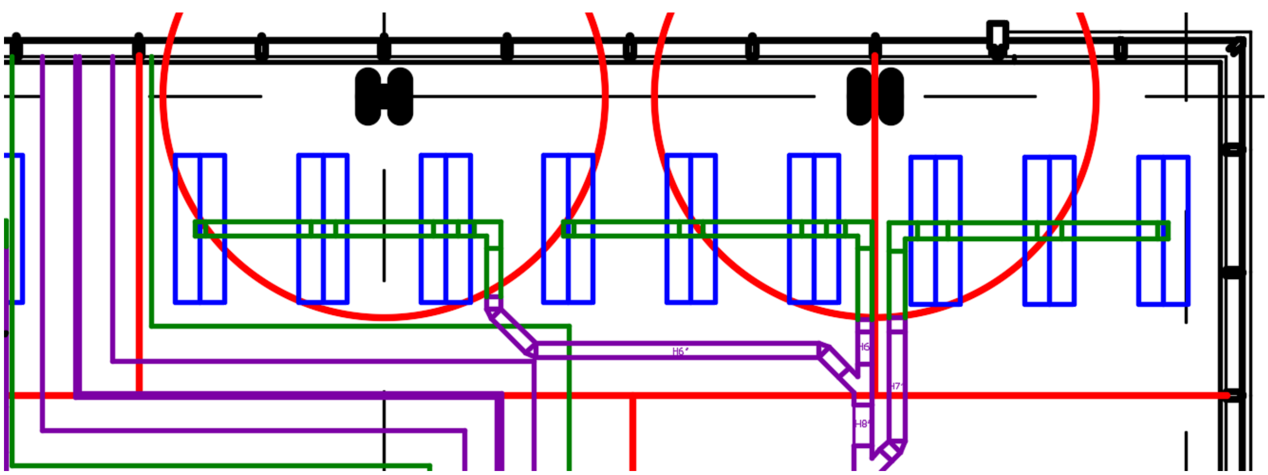

Figure 9: Typical office floor Active Chilled Beam (ACB) layout sample

The primary air ductwork itself is carefully sized to deliver the correct flow of air according to the previously determined ACB primary air loads. The system is designed to use the least amount of ductwork and have the smallest pressure drop. The pressure drop values determine the fan power needed in the DOAS system.

It is necessary for the primary air ductwork inside the Bubbledeck to avoid the 9 foot diameter around each structural column, as this area is solid concrete. Therefore, any ACB located beneath one of these areas had to receive primary air from smaller duct located in the plenum space. Only very short runs of duct were located in the plenum space. For a complete Typical Office Floor Active Chilled Beam and

Primary Air Duct Layout, see Drawing D02. Note that in the layout, the duct inside the Bubbledeck is in purple and the duct below the Bubbledeck is in green.

An Active Chilled Beam (ACB) and Dedicated Outdoor Air System (DOAS) integrated within the building structure is an excellent cooling system solution for the offices of 888 Boylston Street. The system consumes less energy due to reductions in fan power and cooling tower capacity, as well as the use of waste cogeneration heat to chill water. The noise levels are low, the system is efficient and flexible, and initial costs and maintenance costs are reduced.

4.1.2 Variable Air Volume (VAV) System

Retail Floors 01 through 03 are cooled by ceiling-mounted, high performance Variable Air Volume (VAV) systems in the general retail, and by larger, building-run VAV systems in the office entry, food entry, and food hall. Utilizing smaller, ceiling-mounted VAV systems allows the flexibility to add systems together to accommodate tenants that require more space. Modern technology allows for a reduction in power consumption with VAV systems by using sensors, controllers, and variable frequency drives (VFD).

Six ceiling-mounted units, each below 7 tons of capacity, serve the roughly 22,400 square feet of retail space on Floor 01. Likewise, five units serve the general retail area on Floor 02, and four units are utilized on Floor 03. Outside air is supplied to each of these units via insulated duct that runs straight down from the plenum space of Floor 03. Inside this plenum space the outside air duct pulls air in from the building exterior. The louvers for the outside air are well hidden in the soffit beneath the balcony on Floor 04, above the arcade, and above the occupied terrace on Floor 03. Some of these outside air ducts deliver air on Floors 02 and 03 on the way down to Floor 01, and others deliver air straight to their final destination. The office entry, food entry, food hall, and other "building-managed" spaces are cooled by larger air handling units (AHU) located in a mechanical room on Floor 01.

The space cooled by each ceiling-mounted unit is carefully determined. The possibility of renting to retail tenants that require less space necessitated a logical division of retail space that can physically be used by those tenants. For example, each tenant needs a door to the exterior or to the Prudential Center arcade. Figure 10 displays an example of a typical retail tenant space.

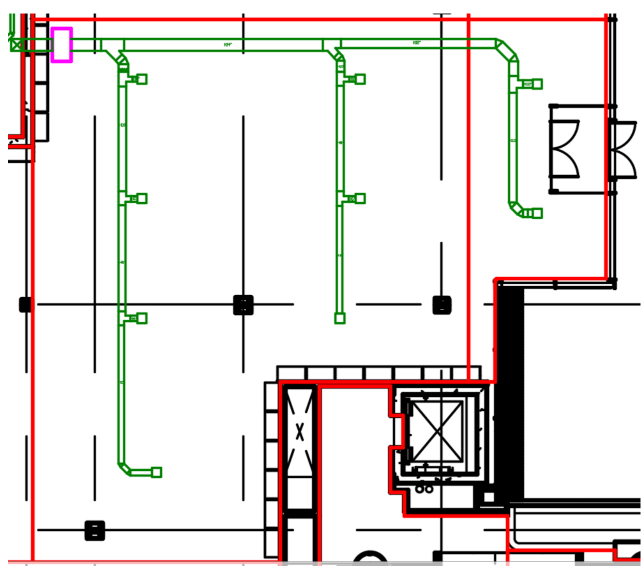

Figure 10: Sample of retail modular unit ductwork

It can be seen in Figure 10 that the duct is green, which indicates, as previously mentioned, that the ductwork is below the Bubbledeck structure (see 3.1.4 Primary Air Ductwork Sizing). Due to the size of the duct needed to deliver cooling capacity to certain locations on Floors 01 through 03 and the changing of tenants, it was not feasible or logical to place the duct within the Bubbledeck.

As with the primary air duct for the office floors, the ductwork for the retail is sized to accommodate the airflow needed to meet the load. The system design is organized to use the least amount of duct possible, and to have reasonable pressure drops.

Variable Air Volume (VAV) systems are cost effective, flexible, quiet, easy to install, and with new technology, energy efficient. They are the best solution for a changing retail environment.

4.2 Hydronic Radiant Flooring

Hydronic radiant flooring in the perimeter zones provides enough heat for the entire building. Hot water for use in the radiant floor tubing is supplied using waste heat from cogeneration. Ventilation during the winter months continues to be supplied through Variable Air Volume (VAV) systems or Active Chilled Beam (ACB) primary air duct. Radiant tubes are properly laid out to provide heat according to the calculated design load. For the entire radiant tube layout, refer to Appendix D03.

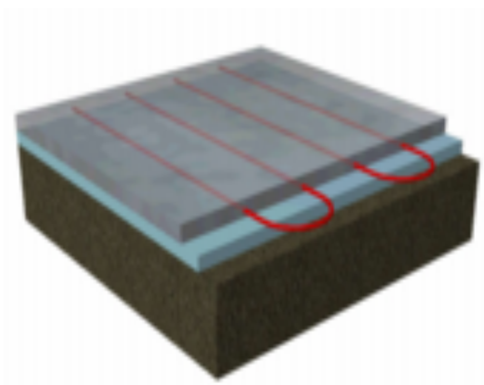

Figure 11: Typical radiant floor system (LoopCAD)

The hydronic radiant floor system turns a floor into a large area, low-temperature radiator by pumping heated water through tubes embedded in the floor concrete slab. Half-inch cross-linked polyethylene (PEX) tubes are embedded in a 2.5 inch-concrete slab on top of the Bubbledeck structure (see 3.1.4 Primary Air Ductwork Sizing). The radiant tubing and the topping slab are field installed. Extruded polystyrene insulation is placed between the Bubbledeck and the 2.5-inch concrete slab to reduce heat loss to the floor below.

The system is installed approximately 10 feet along the perimeter of each floor because the area does not lose heat. The radiant heating system compensates for heat loss through the outside walls. In addition, zoning allows water temperature to vary, offering high flexibility for maintaining different temperatures in different spaces and for allowing differential heat delivery to spaces with and without solar heat gain. Table 8 below shows the design-heating load and water temperature, among other values, produced by LoopCAD.

Table 8: Radiant Floor LoopCAD Results

Space	Design Load (BTUH)	Radiant Heating (BTUH)	Radiant Back Loss 5% (BTUH)	Supplemental Heating (BTUH)	Water Temp. (F)	Surface Temp. (F)	Total Flow Rate (GPM)	Total Head Loss (ft. w.)
Floor 01	163,497	155,711	7,786	0	107.2	71	27.7	13.1
Floor 02	117,153	111,574	5,579	0	100.8	78	23.51	11.8
Floor 03	110,110	93,868	5,243	10,999	114.8	77	17.19	11.8
Typical Office	70,598	67,236	3,362	0	92.8	74	14.84	5.3

Control methods, such as thermostats, are integrated with the system to ensure optimal comfort, to maximize energy performance, and to give occupants complete control to regulate heat in their space.

The use of half-inch PEX tubes permits a maximum length of 350 feet in each zone to avoid excessive pressure drop and resulting pump size. Multiple manifolds are placed throughout the building to ensure there are no loops that exceed the 350-foot limit and that no manifold exceeds its 12 GPM flow limit. Each manifold has a Grundfos pump, ½ horsepower model UPS 32-80/2, to pump water into a zone when a thermostat control calls for more heat.

The whole building is equipped with two Taco pumps (Taco HVAC-Pump Selection App, 2015). A pump, model FI5009C 10.69BHP, is located on the Mechanical PH floor to serve the entire building and is fed by a heat exchanger. Another pump, model FI4075 6.54BHP, is located on Floor 08 to serve all floors below and is fed by another heat exchanger on the same floor (pump curves are included in Appendix D05). This second heat exchanger keeps system pressures on the lower floors well within the range of the schedule 40 piping system that is installed. The heat exchangers use recovered waste heat from the cogeneration system.

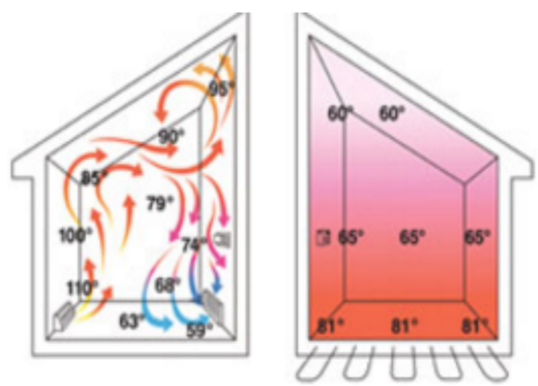

Figure 12: Comparison between forced air and radiant flooring heating systems (Uponor)

To ensure optimum comfort, the maximum design floor surface temperature is 85˚F. This design recognizes 5% as radiant back loss, which is inherent in an in-floor heating system, and a 10˚F water temperature differential. Radiant heat loss is the reason why the tubing is placed around the perimeter of the floor area, to avoid 'wasting' back loss heat to the interior spaces of the floor below.

Due to the thermal mass of the concrete slab, it takes time for water to heat the slab to a comfortable surface temperature. Hence, scheduling is programmed into the system for office floors and retail floors individually based on normal hours of occupancy. During unoccupied hours, the system is still programmed to run, but at a lower capacity so the spaces do not get too cold, especially at night.

A hydronic radiant floor heating system was chosen to fill criteria for comfort, energy efficiency, and sustainability. It surpasses others by a significant margin. All air systems directly control only air temperature, but radiant systems with a separate ventilation system control two parameters - air and mean radiant temperature. The floor provides heat in an even and steady manner allowing our whole body to comfortably stay warm as depicted in Figure 12. Other perks are that it is draft-free and nearly silent.

4.3 Cogeneration / Trigeneration

The electrical grid is becoming increasingly less reliable as large storms become more frequent, such as Hurricane Sandy or Katrina that left hundreds of buildings with no power for days or even weeks. There are also other unexpected issues that may arise during the life cycle of the building that can halt its operation and profit. Thus, removing grid-reliance is much more desirable. This leads to the implementation of a combined heat and power (CHP) system, or cogeneration, in the Mechanical Penthouse. Absorption chillers can produce chilled water with waste heat from the cogeneration units, thus creating what is called a trigeneration system.

The total electric power consumption of the building is approximately 3,244 kW (refer to Drawing D01). To accommodate this demand, two Jenbacher Type 6 Gas Engines, Model J612, from General Electric are selected, as can be seen in Figure 13. Each engine produces 1,979 kW of electricity and 1,960 kW of thermal output, respectively. These two units supply all electricity, chilled water, and heating demand (only 461 kBTUH (135 kW)). This system is equipped with an automatic transfer switch to sense the power source has gained or lost power. The cogeneration unit technical information is in Appendix 06.

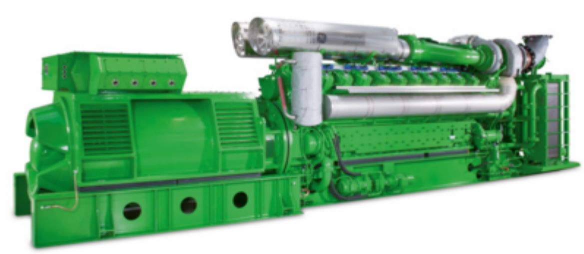

Figure 13: Jenbacher Type 6 Cogeneration Unit, (General Electric)

Two smaller units are chosen in the place of one larger unit to create power security and redundancy. Firstly, equipping cogeneration units eliminates reliance on the electrical grid; therefore, 888 Boylston Street is relatively immune to city blackouts. Secondly, when a unit is shut down for maintenance, the other unit can still supply enough power to operate at least the most critical mechanical, electrical, and telecommunications equipment. In the case of accidental damage to the unit, installing two cogeneration units reduces the possibility of building blackout by half. Another line of defense is a backup condensing boiler model FB-5000 from manufacturer Lochinvar. Its thermal output is 4,650 kBTUH, enough to supply the entire building's radiant floor load and some extra heat for domestic hot water. The specifications for the FB-5000 are in Appendix 06.

4.3.1 Backup Fuel Source

The cogeneration units still consume natural gas from the grid and biogas from the onsite anaerobic digester (refer to Figure 1: HVAC and Power System Diagram). Even though the biogas from the anaerobic digester helps offset the overall natural gas consumption, it is not enough to supply the two cogeneration units alone if the city gas pipeline is down for any reason. The estimated emergency and standby load is 9,000 MBH and propane is 90 MBTU/gallon, so full burn rate is 100 gallons of propane an hour. To sustain operation for 48 hours, the total amount of required propane is 4,800 gallons. A common 1,000-gallon tank can hold only 800 gallons of liquid to allow for gas expansion, which translates to 6 tanks in total. Each tank is 3.5 feet tall, 3.5 feet wide, and 16 feet long (see Figure 14), requiring about 30 feet by 16 feet of space to store the six tanks horizontally.

Figure 14: Propane Storage Tank (Eastern)

Another factor to consider before implementing these tanks is the probability of gas pipeline malfunction. An article (The Christian Science Monitor) addressing issues concerning natural gas reports that according to the Department of Transportation, roughly twenty-seven serious incidents are reported yearly that cause casualties, injuries, and millions of dollars of property damage. The same article also reports a study done in 2012 found 3,000 leaks in Boston, and six exceed the threshold above which an explosion can occur. Gas leaks and explosion incidents are low-probability, but high-impact events so they must be considered seriously, especially when the gas pipeline infrastructure in Boston is at least decades old. Therefore, six propane tanks are installed underground beneath the Green Level. A vaporizer is also installed so that 100% of gas in the tanks can be utilized. This system ascertains that 888 Boylston Street can be self-sufficient for 48 hours in the event of gas-line shutdown. Refer to Drawing D04 for location details.

According to Massachusetts' Consumer Affairs and Business Regulation, the 248 CMR 4.00: Massachusetts Fuel Gas Code adopts NFPA 54: National Fuel Gas Code (2012 edition) and NFPA 58: National Liquefied Petroleum Gas Code (2011 edition) with local amendments.

4.4 Plumbing

Water consumption by fixtures in the building is carefully analyzed. Three major solutions to this challenge are: efficient fixtures, a greywater recycling system, and a rainwater harvesting system. A detail diagram of these systems can be found in Drawing D06.

4.4.1 Efficient Water Fixtures

The use of efficient water fixtures is an essential way to help keep water consumption low. Examples of efficient water fixtures are low flow shower heads, faucets, waterless urinals, and dual-function toilets. Please refer to Appendix 14 for more details.

4.4.2 Greywater Recycling System

A greywater recycling system is a sustainable choice for any building, large or small. Greywater is collected from water fountains, showers, and sinks throughout the building. The water is then piped to the two-stage filtration system (see Figure 15) as per the Regulatory Provisions 310 CMR 15.262 for Composting Toilets and Greywater Systems. Then, the water is pumped to the greywater/rainwater storage tank. This greywater is used for flushing toilets and for watering the gardens and plants in the plaza. The black water from the urinals and toilets cannot be easily recycled, so it flows to the public sewage system for treatment. If there is not enough rainwater and recycled greywater, the city water will supply the remaining deficiency as a redundancy. This system is supplied by Wahaso Water Harvesting Solutions.

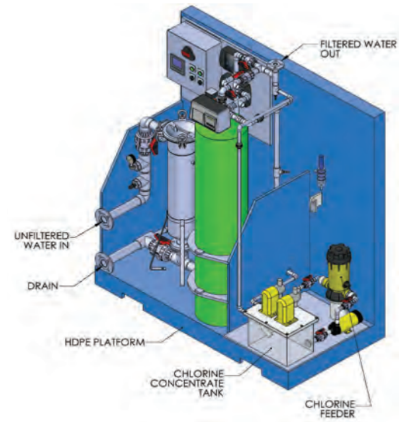

Figure 15: Greywater filtration system (Wahaso Water Harvesting Solutions)

Valves and an overflow pipe leading to the sewage system are installed in case of heavy rainfall. The tank size is 65,000 gallons and is located on the Green Level as seen in Appendix 15 and Drawing D04.

4.4.3 Rainwater Harvesting System

Rainwater is collected through a series of drains and channels on the roof. There are also floor drains on the balconies on Floors 04 and 05, as well as a trench system along the outside facade of the building on grade level. A first flush system is designed to collect initial water runoff. Then, the water is diverted to a 2-stage filtration system (see Figure 15) located on the Green Level before being collected in a greywater/rainwater collection tank nearby. Refer to appendices 04 and 06 for a schematic diagram of the system.

4.5 Fire Protection

The fire protection system designed for 888 Boylston Street comfortably exceeds the minimum code requirements as per NFPA 13 and 14 (2013 Edition). Two combined standpipe/sprinkler systems are installed in the building - one for all floors above grade and the other for the parking levels. This combination of systems dramatically reduces installation costs. The shared distribution piping does not compromise the reliability of the system, and it reduces system maintenance by combining two separate riser systems to one. The sprinkler system for floors above grade is a wet pipe system while the system for the parking levels is a dry pipe system, as the garage is not conditioned. The software program HydraCalc was used to perform hydraulic calculations for the Green Mezzanine, the Green Level, and Floors 01, 02, 03, and 18, to ensure that accurate flow and pressure can be achieved. Additionally, this building is a high rise enveloped mostly by glass. Therefore, it requires Type I (332) construction as per NFPA 220, Table A.4.1.1. To cross-reference with IBC, the building is Type IA as per Table 503.

Two Class I standpipe risers – a 500 GPM remote riser and a 250 GPM additional riser - are installed as specified by NFPA 14. Combination standpipe/sprinkler systems include control valves, check valves, and flow alarm devices as part of the overall installation requirements as per NFPA 14, 6.3.5 and NFPA 13, 8.17.5.2.2(1). NFPA 13 has an additional requirement for pressure reducing valves where combination standpipe/sprinkler system pressures exceed 175 psi. Pressure reducing valves are also required per NFPA 13, 8.15.1.2. Pressure reducing valves listed as a combination indicating control valve, pressure reducing valve, and check valve are used to avoid the multiple redundancies in control valve and check valve arrangements required by NFPA 13 and 14. For a schematic drawing of the piping arrangement of standpipe/sprinkler system, refer to Drawing D07.

As this is a combined system, the risers have to be sized at a minimum of 6 inches. Where a building requires a standpipe system and a sprinkler system, and the standpipe risers are used to supply the sprinkler system, the requirements of NFPA 14, 7.10.1.3 and NFPA 13, 11.1.5.6 apply. In this case, the system demand requirements from NFPA 14 are compared to the sprinkler system and hose stream requirements of NFPA 13, and the final system demand is the larger of the two values. As discussed previously, the standpipe system requires 750 gpm while the largest sprinkler system requires only 358 gpm. This means that the final demand is sized to meet 750 gpm.

4.6 Lighting System

4.6.1 Daylighting

Rendering daylighting simulations using DesignBuilder for an overcast day provided our team insight on the amount of light each floor accepted. As seen in Appendix 07, the lux levels on Retail 01 and Retail 02 are approximately 450 to 1,000 lux near the North and South windows, sometimes even reaching 1,500 lux on the North wall, while 20 to 30 feet further into the building, the number goes down to around 200 to 400 lux. There was no need to investigate the lux levels further in, as the core stops any transmittance. The lower light levels of the East and West sides were attributed to the existence of adjacent buildings.

The values on the proposed floor were examined (now 5th floor above ground level). Here, the values are ranging from 300 to 900 lux near the North, West and South windows, sometimes even reaching 1,100 lux. The floor area near the East facade has slightly lower values, as the adjacent building on the East side is slightly taller than the building on the West side, thus preventing more sunlight from entering. About 20 to 30 feet further into the building, the light range is closer to around 200 to 300 lux.

Finally, on Floor 16, the offices around the core will be lit at values ranging from 200 to 500 lux, while the open office space is at a range of 400 to 1,200 lux in the 20 to 30 foot wide perimeter area near the windows. In particular, on the West, North and East sides, the sunlight exceeds 1,500 lux. This is attributed to the fact that the Prudential Tower blocks sunlight on the South facade of the building, while the other three sides are open to sunlight.

Due to the placement of the building on the Boston map, the south facade theoretically would accept the most sunlight throughout the year. However, the much taller Prudential Tower to the South of 888 Boylston Street prevents most of the direct sunlight from entering. The front façade of 888 Boylston

Street is oriented to the Northeast by about 20 degrees. This allows more sunlight to hit the building diagonally, from the Southwest, as can be seen in the rendering of Floor 16 in Appendix 12.

In general, a range of 200 to 500 lux is ideal for the performance of visual tasks of high contrast or large size, whereas a range 500 to 1,000 lux is ideal for the performance of visual tasks of medium contrast or small size. Thus, judging by the values found on a cloudy day, the team is confident to say that the office will be very well lit; conclusively, during a clear summer day, the office will accept excessive light near the windows.

To prevent excessive sunlight from entering the building, shadowboxes with a U-value of 0.025 (equivalent to an R-value of 50), were chosen to replace 40% of the facade. Shadowboxes were discussed previously in Chapter 2.0 Background. For those areas along the perimeter that would not need a shadow box, the team decided to use a double pane glass insulated with room-side low-e VUE which has a visible light transmittance of 40% but still maintains a SHGC of 0.21. This will drop the light transmittance along that perimeter during the daytime.

The daylighting and envelope team collaborated to consider daylight harvesting strategies to help further reduce the energy consumption. Fiber optic daylight harvesting options such as Parans (Mayhoob, 2014) do just what the team wanted; however, all their shapes and sizes are not compliant with being flush to the facade. Also these harvesters are meant to be on the roof or protrude out from the facade which is not aesthetically pleasing.

4.6.2 Artificial Lighting

The lighting fixtures that the team decided to use were chosen in compliance with the LEED point system. In an effort to integrate lighting with the fire safety system, the team chose to take a simultaneous approach. For this, the lighting design team collaborated with the fire protection team to ensure the strategic placement of the lighting fixtures, in full accordance with the development of the sprinkler system. Images and specifications of each fixture can be found in Appendix 11.

The lighting output was measured in foot-candles (fc); in general, a range of 20 to 50fc is ideal for the performance of visual tasks of high contrast or large size, whereas a range 50 to 100fc is ideal for the performance of visual tasks of medium contrast or small size. Indeed, the typical office floor lighting was designed for a general lighting average of 27, with the task lighting achieving values of 83 when on.

All the fixtures that are used in this building are waterproofed while the lamps are attached. All fixtures have built-in LED lights, with a CRI of 80 or 85, and a rated life of at least 24,000 hours. A layout of a typical office floor lighting design can be found in Appendix 11, along with a rendering indicating the luminance values in the area. The fixtures chosen to cover the General Lighting requirements are the Modular Vaeder (Modular Vaeder, 2016) and the Modular Spock series fixtures (Modular Spock, 2016); the Vaeder fixtures are suspended 12 feet from the ceiling, while the Spock series fixtures are either attached to the walls or the ceiling. For Task Lighting, we found that the Artemide Tolomeo (Artemide 2009) performs ideally, with its dimming and multi-positioning capabilities. A typical office floor is expected to have 156 Spock fixtures, 171 Vaeder fixtures, and 188 Tolomeo fixtures. In the Conference Rooms, the Tunto LED40 (Tunto, 2015) fixtures are used, creating suspended geometric shapes, when pieced together. Finally, we suggest that the Modular Trapz LED fixture (Modular Trapz, 2016) is used as Accent/Decorative Lighting, while frosted glass diffusers with internal LED strips are used to highlight corridors, stairs and railings, as well as parts of the Retail space.

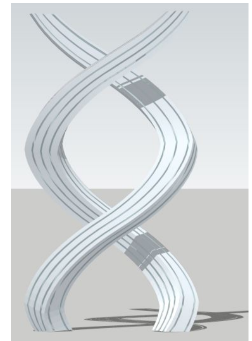

Figure 16: Eight-shaped Column

Finally, even though it would not affect our typical office lighting calculations, the lighting design team worked on the exterior lighting of the building, as part of the Integration Category of the AEI Competition requirements. Since the building at 888 Boylston is an important landmark in the Back Bay area and will hold a symbolic role in the future, the team decided, to remove the 2'-6" transfer truss below the fifth floor, rearrange the column layout to provide better and more discreet support to the upper floors, and add an exterior iconic symbol, that would serve solely aesthetic purposes.

This iconic symbol has the form of three, figure-eight-shaped, architectural columns on the front of the building facing Boylston Street, as depicted in the figure on the left. These columns were modelled in SketchUp and then imported into the Revit file of the building. They are designed to be comprised of stainless steel and frosted Plexiglas strips, while each of the columns has waterproof LED strip lights in its interior. The columns can be programmed to emit light in a variety of colors, to match the mood of a special day, or simply add to the character of the building on any day. Additionally, the bottom columns hide three outside air intake registers for the retail floors, behind them.

Figure 17: Rendering of 888's in Front Facade

4.7 Sustainability / On-site Energy

4.7.1 Photovoltaic (PV) Panel

888 Boylston Street adopts both traditional rooftop and building integrated photovoltaic panels to harvest solar power. The rooftop houses (232) PV panels, at a size of 1,560 mm (5 feet, 1.44 inches) long, 1,050 mm (3 feet, 5.28 inches) wide, and 50 mm (1.97 inches) thick, and a rated capacity of 327 watts each. These panels are adjustable from a central control unit to accommodate the changing angle of the sun throughout the year, which maximizes their performance. The rooftop panels are responsible for the production of 62,234 kWh annually as seen in Appendix 16. This value varies every month according to environmental factors such snow coverage and radiation path.

4.7.2 Wind Turbine

There are fourteen UGE 9M (rated output of 14,500 kWh/year each) vertical wind turbines located on roof (see Figure 18). These wind turbines were chosen to maximize energy production, efficiency, and minimize weight. The curved blade shape provides increased swept area for each blade and minimizes noise generated. Noise is minimized with this design because the tip speed of each blade is less than that for more traditional turbine blades. The vertical turbines can catch wind coming from any direction, and still create the same amount of energy. In total, the turbines are generating approximately 127,461 kWh average, annually (refer to Appendix 16).

Figure 18: Wind Turbine (UGE)

4.7.3 Anaerobic Digester

The sustainability and resiliency teams studied the feasibility of including an anaerobic digester onsite. The 2,000 gallon digester plant is located on the Green Level. Food waste from the restaurant and garden waste from the community gardens and front plaza are collected to operate the plant. Human waste from the building is not suitable because its water content is too high. It was estimated that 115 pounds of food waste can be fed to the plant daily, which can be converted to 15 gallons of biogas.

The biogas is mostly methane, thus, it can be burned to run the cogeneration system while the digestate is used as fertilizer for the sky gardens on each office floor and for the plants in the plaza. Having this production plant is sustainable; however, to make the plant economically desirable the average temperature has to be 60 to 68^{o}F in order for the reaction to produce a substantial amount of methane. Since the garage is not conditioned, it is important to maintain sufficient temperature for the plant. The solution is to place the plant in an insulated room and utilize waste heat from cogeneration. Cogeneration produces more heat than the radiant floor, domestic hot water, and absorption chillers require, especially during the summer months. Once the required temperature range is provided, the compost will start undergoing mesophilic digestion which is expected to process the input waste in about 30 to 45 days. The biogas is stored in storage tanks located in a room on the Green Mezzanine directly above the digester room before it is transferred to the cogeneration units. The digestate is transferred to de-watering equipment to reduce the water content before transportation. A diagram of this system is in Appendix D04. The energy and gas output of a typical plant can be seen in Table 9.

Table 9: Energy Production from Anaerobic Digester

Output	Amount
Energy	6kWh/m^3
Fuel	0.61 L diesel fuel/m^3
Biogas	0.4 m^3 gas/m^2 digester volume per day

4.8 Resiliency

888 Boylston Street is located in the Boston Back Bay Architectural District, an area highly prone to storms and flooding. The Environmental Protection Agency (EPA) provides a Storm Surge Inundation Map, which shows the possibility of different intensity storms hitting a specific area of the country. The building is located in the yellow shape on the map, which indicates that the mean water height could reach over 7.5 feet in large storms during high tide. The different color shaped areas indicate the cultural districts in the City of Boston. To limit and prevent building damage and human injury due to these natural disasters, multiple mitigation strategies were developed and implemented in the design.

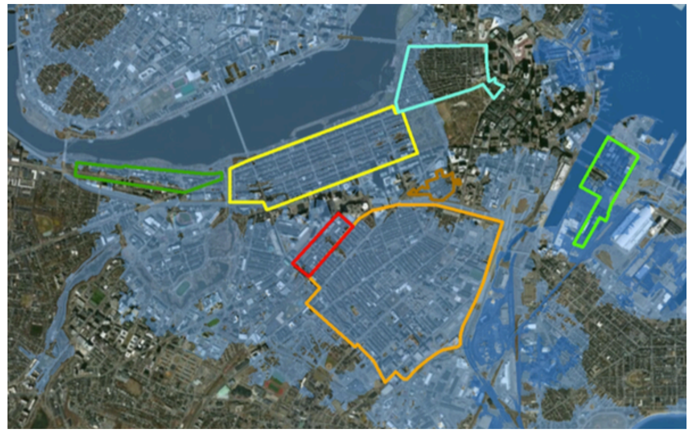

Figure 19: Flood Map in Boston (Climate Ready Boston)

4.8.1 Additional Floor

The most important measure to improve building resilience is moving the grade and sub-grade mechanical and electrical rooms above the threat of flooding. Due to the limited space in the Mechanical Penthouse, moving this electrical and mechanical equipment into the main building area would take away approximately 3,400 square feet of rentable space from the owner. However, through collaboration of the mechanical and structural teams, a solution was developed that allows for the addition of an entirely new floor, without increasing the overall height of the building, that would house this equipment and add even more usable space. The Bubbledeck structure is a precast concrete floor system, which makes floor slabs lighter and stronger by incorporating large, hollow plastic balls in a lattice of steel. The use of this system allowed the air conditioning and ventilation ductwork to be imbedded in the Bubbledeck, reducing the plenum height, and thus the overall floor height. As a result, an additional floor can be added without exceeding the original building height. The new floor is located between the previously designed fourth and fifth floors. Not only does this solution provide a safer space for critical equipment to be located, it also provides an additional 10,000 square feet of leasable space, as well as several extra parking spaces in the garage.

4.8.2 Flood Proofing

Though the critical mechanical and electrical equipment is no longer located in a flood prone area of the building, another form of flood protection is to be installed outside the building. While a flood will no longer shut down the building, it could still cause serious damage to the lower floors of the structure, where all the retail merchandise is located. A vehicular retractable FloodBreak floodgate (FloodBreak: Revolutionary Flood Control), as shown in Figure 20, is to be implemented around the exposed perimeter of the building. When idle, the wall is flush with the pavement, but when water threatens to flood the building, the four-foot wall automatically and under its own power rises to hold back the water. From the production description on the FloodBreak website, "the concept is simple – the rising floodwater creates the hydrostatic pressure to float the buoyant aluminum beam and activate the self-sealing rubber gaskets. The higher the water rises, the higher the flood barrier is lifted until it reaches 90 degrees and is held closed by the flood water. When the water recedes, the flood barrier returns to its recessed location in front of the entry way, allowing vehicle and pedestrian passage to resume," (FloodBreak: Vehicle Gate, 2011). This concept allows the device to be self-sustaining, not requiring any power or human interaction to be functional. All materials in the product are coated to protect the flood gate from rust and corrosion.

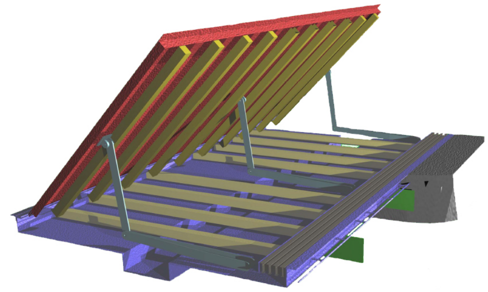

Figure 20: Retractable Floodgate (FloodBreak)

Additional measures are designed to assist in the protection of the lower floors from water damage. Equipment, such as sump pumps and sewage backflow valves, quickly remove any water that has accumulated in the garage and prevents water from backing up the building's sewage system. The Resiliency team also proposes to install the retractable floodgate at other entrances to the parking lot, such as entrances from the Prudential Center, to avoid flooding into the garage from other locations.

4.9 Energy Use Calculations

Using the ASHRAE 90.1 2007 base case values from the DesignBuilder simulations (see 3.5 DesignBuilder Simulations) and the values from the new project design, a comparison was made to determine the decrease in energy use. All power loads on the building were considered, including energy consumption and energy production. The result was a 51.1% reduction in energy use.

It is important to note the differences in the two building designs. The base case utilized Variable Air Volume (VAV) cooling and heating, which is a traditional system choice, as well as alternative lighting fixtures. The new design is cooled with Active Chilled Beam (ACB) and Dedicated Outdoor Air Systems (DOAS) as well as VAV, heated with hydronic radiant flooring, utilizes LED lighting, and includes several onsite power sources. For more information on lighting and onsite power, see Chapters 4.3, 4.6, and 4.7. Other important differences are that the new design includes one extra floor, and it reduces the heat gain with shadowboxes (refer to 3.0 Methodology). Refer to Drawing D01 for a breakdown of the energy use reduction calculations.

4.10 LEED

The new design for 888 Boylston Street earns over 80 points in the LEED (Leadership in Energy and Environmental Design) rating system, which is enough to achieve a LEED Platinum certification for New Construction and Major Renovations. 80+ points is a definite challenge. Table 10 shows the point category, the total points possible in that category, and lastly the amount of points that the new design earns. As can be seen here, the largest number of points is in the Energy & Atmosphere category, and the new 888 Boylston Street design is able to earn most of them.

Table 10: LEED Points Earned By Category

Credit Category	Points Possible	Points Earned
Integrative Process	1	1
Location & Transportation	16	12
Sustainable Sites	10	9
Water Efficiency	11	7
Energy & Atmosphere	33	31
Materials & Resources	13	5
Indoor Environmental Quality	16	13
Innovation	6	3
Regional Priority	4	0
Total	**110**	**81**

CHAPTER 5.0 CONCLUSIONS

Modularity is a prime challenge that the mechanical team carefully addressed. Separating the air conditioning and ventilation systems of the typical office floors from those of the retail floors significantly reduces energy consumption during off-peak hours. Modularizing these systems facilitates large areas to be split into smaller rentable areas to accommodate multiple tenants sharing the same floor. Active Chilled Beams (ACB) with Dedicated Outdoor Air Systems (DOAS), Variable Air Volume (VAV) systems, hydronic radiant floor systems, lighting systems, plumbing systems, and energy production systems all contribute to energy conservation. The use of ACB provides efficient cooling to the space, low noise levels, low maintenance costs, smaller ductwork, and a reduction in energy consumption. The DOASs not only use outside air to reduce energy use, they use desiccant wheels to reduce the amount of necessary dehumidification. The team was also able to modularize the VAV, ACB and DOAS ductwork to a great extent, which follows the main intent of this project. A hydronic radiant floor heating system was chosen because it provides optimum comfort, when compared to other heating systems, with much lower energy consumption.

These innovative HVAC systems must integrate well and compliment the other mechanical and structural systems. For instance, the ducts were accurately sized and strategically placed to enable imbedding in the Bubbledeck system without compromising its structural integrity. Across the board, every single system in the building had to be the most energy efficient it could be in order to achieve energy reduction by at least 50% when using ASHRAE 90.1 2007 as a baseline. Some big players in this equation were the use of ACBs, the recommendation for shadowboxes and blinds, and the use of LED lighting. The structural, mechanical, and architectural teams worked together to ensure that all systems work seamlessly together. An excellent example of this collaboration is in the design of the shadowbox system; the structural team designed supports and connections, the mechanical team determined the needed U-value for energy efficiency, and the architectural team made it look good. With the efforts of both the structural team and the mechanical team, a beautiful, functional, efficient, environmental icon was designed for 888 Boylston Street.

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MECHANICAL SUBMITTAL APPENDIX LIST

APPENDIX 01: Typical Office Floor Load Calculations

Typical Office Floor Cooling Load Calculations

ZONE PEAK		Susp'd Ceil'g?:	No	Glass U:	0.23	Supply Air Temp:	56 F
Peak OSA Temp for -- Boston, MA (Logan Airport)		Indoor Temp:	76 F	Roof U:	0.039	Return Plenum:	No
40	Degrees N. Lat	Daily Range:	16 F	SHGC:	0.4	Recessed lights to plenum:	No
		Wall Height:	13 ft	Wall U:	0.02	h out:	37.4 Btu/lb
Office Light Allowance (W/sqft):	0.12					h in:	28.7 Btu/lb

By calculating the load without the shadowboxes, the option is maintained to either use the shadowboxes or not use the shadowboxes. It becomes a owner decision, not a design decision.

ZONE	Orientation	Glass Area	Room Area	Overhang	Peak Month	Peak Hour	Glass BTUHs	Total S&T	Lighting Watts	Appliance BTUHs	Occupants BTUHs	Room Sens BTUHs	CFM	Total BTUHs	Heat Loss BTUHs
C51	N	260	250	165	6	18	5,370	5,370	30	1,720	2	18,971	860	19,371	9,798
C51	W	195			6	18	11,279	11,279							
C52	N	260	250	165	6	18	5,370	5,370	30	1,720	2	12,387	565	12,787	9,798
C52	E	195			6	18	4,695	4,695							
C53	N	130	1,180	50	6	18	2,685	2,685	142	8,601	10	22,094	1,005	24,094	9,402
C53	E	325			6	18	7,824	7,824							
C54	N	189	218	73	6	10	3,061	3,061	26	1,720	2	15,875	720	16,275	8,029
C54	E	195			6	10	10,504	10,504							
C55	S	189	218	0	2	13	12,512	12,512	26	1,720	2	21,286	970	21,686	7,780
C55	E	195			2	13	6,464	6,464							
C56	S	189	218	0	3	17	7,927	7,927	26	1,720	2	21,809	990	22,209	7,780
C56	W	195			3	17	11,573	11,573							
C57	N	189	218	73	6	17	3,727	3,727	26	1,720	2	17,509	795	17,909	8,029
C57	W	195			6	17	11,473	11,473							
C58	N	130	1,180	50	4	17	1,943	1,943	142	8,601	10	33,317	1,515	35,317	9,402
C58	W	325			4	17	19,790	19,790							
E51	N	585	675	450	6	18	12,083	12,083	81	6,021	7	20,130	915	21,530	13,415
E52	N	585	675	450	6	18	12,083	12,083	81	10,198	7	24,307	1,105	25,707	13,415
E53	E	520	580	0	4	10	28,987	28,987	70	6,881	8	38,105	1,730	39,705	10,549
E54	E	520	580	0	4	10	28,987	28,987	70	6,881	8	38,105	1,730	39,705	10,549
E55	S	585	675	0	1	14	41,508	41,508	81	5,160	6	48,444	2,200	49,644	11,867
E56	S	390	450	150	1	14	27,672	27,672	54	0	5	30,742	1,395	31,742	9,746
E56	E	65			1	14	1,636	1,636							
E57	S	390	450	150	1	14	27,672	27,672	54	0	5	30,650	1,395	31,650	9,746
E57	W	65			1	14	1,544	1,544							
E58	S	585	675	0	1	14	41,508	41,508	81	5,160	6	48,444	2,200	49,644	11,867
E59	W	650	725	0	4	17	39,581	39,581	87	8,601	10	50,979	2,315	52,979	13,186
E510	W	390	435	0	4	17	23,748	23,748	52	5,160	6	30,587	1,390	31,787	7,912
I51	0	0	1,513	0	6	18	0	0	182	18,062	21	23,931	1,090	28,131	0
I51a	0	0	139	0	6	18	0	0	17	1,562	1	1,869	85	2,069	0
I51b	0	0	139	0	6	18	0	0	17	1,562	1	1,869	85	2,069	0
I51c	0	0	139	0	6	18	0	0	17	1,562	1	1,869	85	2,069	0
I51d	0	0	139	0	6	18	0	0	17	1,562	1	1,869	85	2,069	0
I52	0	0	1,557	0	6	18	0	0	187	18,062	21	23,950	1,090	28,150	0

APPENDIX 02: Typical Office Floor Load Distribution

				VENTILATION		DEHUMIDIFICATION			CHILLED WATER LOAD				ACB					
	ZONE	#		VENT.		TOT OCCUP.	DEHUM.		ZONE	PRIMARY	CHILL. WATER		ACT. WATER	ACT. PRIMARY	FINAL	# OF ACB PER	SIZE	NOZZLE
ZONE	AREA	OCCUP.		CFM		BTUHl	CFM		BTUHs	BTUHs	BTUHs		BTUHs	BTUHs	CFM	ZONE		
C51	250	2		25		400	83		18,971	1,731	17,240		13,104	5,867	281	3	6'	E1
C52	250	2		25		400	83		12,387	1,731	10,656		8,736	3,651	175	2	6'	B1
C53	1,180	10		121		2,000	414		22,094	8,654	13,440		13,308	8,786	420	3	6'	F1
C54	218	2		23		400	83		15,875	1,731	14,144		12,387	3,488	167	3	6'	B1
C55	218	2		23		400	83		21,286	1,731	19,555		13,104	8,182	391	3	6'	E1
C56	218	2		23		400	83		21,809	1,731	20,078		12,741	9,068	434	3	6'	F1
C57	218	2		23		400	83		17,509	1,731	15,778		13,104	4,405	211	3	6'	E1
C58	1,180	10		121		2,000	414		33,317	8,654	24,663		21,840	11,477	549	5	6'	E1
E51	675	7		76		1,400	290		20,130	6,058	14,072		13,104	7,026	336	3	6'	E1
E52	675	7		76		1,400	290		24,307	6,058	18,249		17,472	6,835	327	4	6'	E1
E53	580	8		75		1,600	331		38,105	6,923	31,182		30,458	7,647	366	8	6'	A0
E54	580	8		75		1,600	331		38,105	6,923	31,182		30,458	7,647	366	8	6'	A0
E55	675	6		71		1,200	248		48,444	5,193	43,251		40,950	7,494	359	10	6'	A1
E56	450	5		52		1,000	207		30,742	4,327	26,415		24,570	6,172	295	6	6'	A1
E57	450	5		52		1,000	207		30,650	4,327	26,323		24,570	6,080	291	6	6'	A1
E58	675	6		71		1,200	248		48,444	5,193	43,251		38,383	10,061	481	10	6'	A1
E59	725	10		94		2,000	414		50,979	8,654	42,325		40,231	10,748	516	10	6'	A1
E510	435	6		56		1,200	248		30,587	5,193	25,394		24,160	6,427	310	6	6'	A1
I51	1,513	21		196		4,200	870		23,931	18,174	5,757		5,757	18,174	870	3	6'	C1
I51a	139	1		13		200	41		1,869	865	1,004		0	1,869	89	1	6'	E1
I51b	139	1		13		200	41		1,869	865	1,004		0	1,869	89	1	6'	E1
I51c	139	1		13		200	41		1,869	865	1,004		0	1,869	89	1	6'	E1
I51d	139	1		13		200	41		1,869	865	1,004		0	1,869	89	1	6'	E1
I52	1,557	21		198		4,200	870		23,950	18,174	5,776		5,776	18,174	870	3	6'	C1
I52a	127	1		13		200	41		1,864	865	999		999	865	41	1	6'	A0
I52b	130	1		13		200	41		1,865	865	1,000		1,000	865	41	1	6'	A0
I52c	148	1		14		200	41		1,873	865	1,008		1,008	865	41	1	6'	A0
I52d	108	2		16		400	83		9,104	1,731	7,373		7,361	1,743	83	1	6'	C1
I53	1,268	8		116		1,600	331		9,400	6,923	2,477		2,477	6,923	331	1	6'	C1
I53a	293	8		58		1,600	331		4,430	6,923	-2,493		-2,493	6,923	331	1	6'	C1
I54	752	8		85		1,600	331		9,189	6,923	2,266		2,266	6,923	331	1	6'	C1
I54a	148	1		14		200	41		311	865	-554		-554	865	41	1	6'	A0
I55	626	6		68		1,200	248		6,916	5,193	1,723		1,723	5,193	248	2	6'	E1
I55a	131	6		38		1,200	248		3,864	5,193	-1,329		-1,329	5,193	248	1	6'	C1
I55b	221	1		18		200	41		1,903	865	1,038		1,038	865	41	1	6'	A0
I55c	222	1		18		200	41		1,903	865	1,038		1,038	865	41	1	6'	A0
I56	1,134	5		93		1,000	207		6,015	4,327	1,688		0	6,015	288	2	6'	C1
I56a	215	1		18		200	41		1,900	865	1,035		0	1,900	91	1	6'	E1
I56b	238	1		19		200	41		1,910	865	1,045		0	1,910	91	1	6'	E1
I57	2,299	17		223		3,400	704		19,813	14,712	5,101		0	19,813	948	3	6'	C1
I57a	135	6		38		1,200	248		3,865	5,193	-1,328		0	3,865	185	1	6'	C1
I57b	145	2		19		400	83		3,120	1,731	1,389		0	3,120	149	1	6'	C1
I57c	181	2		21		2,493	516		21,277	10,788	10,489		8,379	12,898	617	2	6'	C1
Total:	21,797	224		2,428		46,893	9,709		689,621	202,912	486,709		427,123	262,498	12,564	130		

Indoor Air Temperature:	76	F		latent load/person:	200	BTUHl	gr/lb room:	67 gr/lb
Supply Air Temperature:	57	F		sensible load/person:	250	BTUHs	gr/lb SA:	60 gr/lb

APPENDIX 03: Active Chilled Beam Sizing

Zones C51	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 83 CFM	21-47	A0	11,568	3	141	354	17.00	6.00
	28-53	A1	12,285	3	159	320	18.00	6.00
	42-76	B1	12,387	3	228	315	26.00	7.00
	117-345	C1	12,897	3	1035	291	31.00	7.00
	81-131	E1	13,104	3	393	281	33.00	7.00
	93-161	F1	13,308	3	483	271	37.00	9.00
	114-182	G1	13,410	3	546	266	41.00	9.00
	153-254	H1	13,716	3	762	251	46.00	7.00
Capacity balance:	81-131	E1	13,104	3	393	281	33.00	7.00

Zones C52	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 83 CFM	21-47	A0	7,712	2	94	224	17.00	6.00
	28-53	A1	8,190	2	106	201	18.00	6.00
	42-76	B1	8,258	2	152	198	26.00	7.00
	117-345	C1	8,598	2	690	181	31.00	7.00
	81-131	E1	8,736	2	262	175	33.00	7.00
	93-161	F1	8,872	2	322	168	37.00	9.00
	114-182	G1	8,940	2	364	165	41.00	9.00
	153-254	H1	9,144	2	508	155	46.00	7.00
Capacity balance:	81-131	E1	8,736	2	262	175	33.00	7.00

Zones C53	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 414 CFM	21-47	A0	11,568	3	141	504	17.00	6.00
	28-53	A1	12,285	3	159	469	18.00	6.00
	42-76	B1	12,387	3	228	464	26.00	7.00
	117-345	C1	12,897	3	1035	440	31.00	7.00
	81-131	E1	13,104	3	393	430	33.00	7.00
	93-161	F1	13,308	3	483	420	37.00	9.00
	114-182	G1	13,410	3	546	416	41.00	9.00
	153-254	H1	13,716	3	762	401	46.00	7.00
Capacity balance:	93-161	F1	13,308	3	483	420	37.00	9.00

Zones C54	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 83 CFM	21-47	A0	11,568	3	141	206	17.00	6.00
	28-53	A1	12,285	3	159	172	18.00	6.00
	42-76	B1	12,387	3	228	167	26.00	7.00
	117-345	C1	12,897	3	1035	142	31.00	7.00
	81-131	E1	13,104	3	393	133	33.00	7.00
	93-161	F1	13,308	3	483	123	37.00	9.00
	114-182	G1	13,410	3	546	118	41.00	9.00
	153-254	H1	13,716	3	762	103	46.00	7.00
Capacity balance:	42-76	B1	12,387	3	228	167	26.00	7.00

Zones C55	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 83 CFM	21-47	A0	11,568	3	141	465	17.00	6.00
	28-53	A1	12,285	3	159	431	18.00	6.00
	42-76	B1	12,387	3	228	426	26.00	7.00
	117-345	C1	12,897	3	1035	401	31.00	7.00
	81-131	E1	13,104	3	393	391	33.00	7.00
	93-161	F1	13,308	3	483	382	37.00	9.00
	114-182	G1	13,410	3	546	377	41.00	9.00
	153-254	H1	13,716	3	762	362	46.00	7.00
Capacity balance:	81-131	E1	13,104	3	393	391	33.00	7.00

Zones C56	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 83 CFM	21-47	A0	11,568	3	141	490	17.00	6.00
	28-53	A1	12,285	3	159	456	18.00	6.00
	42-76	B1	12,387	3	228	451	26.00	7.00
	117-345	C1	12,897	3	1035	426	31.00	7.00
	81-131	E1	13,104	3	393	417	33.00	7.00
	93-161	F1	13,308	3	483	407	37.00	9.00
	114-182	G1	13,410	3	546	402	41.00	9.00
	153-254	H1	13,716	3	762	387	46.00	7.00
Capacity balance:	93-161	F1	12,741	3	436	434	34.23	7.00

Zones C57	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 83 CFM	21-47	A0	11,568	3	141	284	17.00	6.00
	28-53	A1	12,285	3	159	250	18.00	6.00
	42-76	B1	12,387	3	228	245	26.00	7.00
	117-345	C1	12,897	3	1035	221	31.00	7.00
	81-131	E1	13,104	3	393	211	33.00	7.00
	93-161	F1	13,308	3	483	201	37.00	9.00
	114-182	G1	13,410	3	546	196	41.00	9.00
	153-254	H1	13,716	3	762	181	46.00	7.00
Capacity balance:	81-131	E1	13,104	3	393	211	33.00	7.00

Zones C58	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 414 CFM	21-47	A0	19,280	5	235	672	17.00	6.00
	28-53	A1	20,475	5	265	614	18.00	6.00
	42-76	B1	20,645	5	380	606	26.00	7.00
	117-345	C1	21,495	5	1725	566	31.00	7.00
	81-131	E1	21,840	5	655	549	33.00	7.00
	93-161	F1	22,180	5	805	533	37.00	9.00
	114-182	G1	22,350	5	910	525	41.00	9.00
	153-254	H1	22,860	5	1270	500	46.00	7.00
Capacity balance:	81-131	E1	21,840	5	655	549	33.00	7.00

Zones E51	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 290 CFM	21-47	A0	11,568	3	141	410	17.00	6.00
	28-53	A1	12,285	3	159	375	18.00	6.00
	42-76	B1	12,387	3	228	370	26.00	7.00
	117-345	C1	12,897	3	1035	346	31.00	7.00
	81-131	E1	13,104	3	393	336	33.00	7.00
	93-161	F1	13,308	3	483	326	37.00	9.00
	114-182	G1	13,410	3	546	322	41.00	9.00
	153-254	H1	13,716	3	762	307	46.00	7.00
Capacity balance:	81-131	E1	13,104	3	393	336	33.00	7.00

Zone E10	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 248 CFM	21-47	A0	23,136	6	282		17.00	6.00
	28-53	A1	24,570	6	318	248	18.00	6.00
	42-76	B1	24,774	6	456		26.00	7.00
	117-345	C1	25,794	6	2070		31.00	7.00
	81-131	E1	26,208	6	786		33.00	7.00
	93-161	F1	26,616	6	966		37.00	9.00
	114-182	G1	26,820	6	1092		41.00	9.00
	153-254	H1	27,432	6	1524		46.00	7.00
Capacity balance:	28-53	A1	24,160	6	310	307	Yes	6.00

Zone I51	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 870 CFM	21-47	A0	11,568	3	141		17.00	6.00
	28-53	A1	12,285	3	159		18.00	6.00
Need beams to	42-76	B1	12,387	3	228		26.00	7.00
provide	117-345	C1	12,897	3	1035	870	31.00	7.00
dehumidification and	81-131	E1	13,104	3	393		33.00	7.00
ventilation.	93-161	F1	13,308	3	483		37.00	9.00
	114-182	G1	13,410	3	546		41.00	9.00
	153-254	H1	13,716	3	762		46.00	7.00
Capacity balance:	117-345	C1	12,395	3	870	552	28.54	6.18

Zone I51a	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 41 CFM	21-47	A0	3,856	1	47		17.00	6.00
	28-53	A1	4,095	1	53		18.00	6.00
	42-76	B1	4,129	1	76		26.00	7.00
Beams meet full load	117-345	C1	4,299	1	345		31.00	7.00
with primary CFM.	81-131	E1	4,368	1	131	89	33.00	7.00
	93-161	F1	4,436	1	161		37.00	9.00
	114-182	G1	4,470	1	182		41.00	9.00
	153-254	H1	4,572	1	254		46.00	7.00
Capacity balance:	81-131	E1	3,583	1	89	-82	22.67	5.67

Zones I51b-d same as Zone I51a

Zone I52	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 870 CFM	21-47	A0	11,568	3	141		17.00	6.00
	28-53	A1	12,285	3	159		18.00	6.00
Need beams to	42-76	B1	12,387	3	228		26.00	7.00
provide	117-345	C1	12,897	3	1035	870	31.00	7.00
dehumidification and	81-131	E1	13,104	3	393		33.00	7.00
ventilation.	93-161	F1	13,308	3	483		37.00	9.00
	114-182	G1	13,410	3	546		41.00	9.00
	153-254	H1	13,716	3	762		46.00	7.00
Capacity balance:	117-345	C1	12,395	3	870	553	28.54	6.18

Zones I52a-c same as Zones I51a-d

Zone I52d	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 83 CFM	21-47	A0	3,856	1	47		17.00	6.00
	28-53	A1	4,095	1	53		18.00	6.00
Need beams to	42-76	B1	4,129	1	76		26.00	7.00
provide	117-345	C1	4,299	1	345	83	31.00	7.00
dehumidification and	81-131	E1	4,368	1	131		33.00	7.00
ventilation.	93-161	F1	4,436	1	161		37.00	9.00
	114-182	G1	4,470	1	182		41.00	9.00
	153-254	H1	4,572	1	254		46.00	7.00
Capacity balance:	117-345	C1	4,002	1	250	244	26.65	6.00

Zone I53	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 331 CFM	21-47	A0	3,856	1	47		17.00	6.00
	28-53	A1	4,095	1	53		18.00	6.00
Need beams to	42-76	B1	4,129	1	76		26.00	7.00
provide	117-345	C1	4,299	1	345	331	31.00	7.00
dehumidification and	81-131	E1	4,368	1	131		33.00	7.00
ventilation.	93-161	F1	4,436	1	161		37.00	9.00
	114-182	G1	4,470	1	182		41.00	9.00
	153-254	H1	4,572	1	254		46.00	7.00
Capacity balance:	117-345	C1	4,299	1	345	244	31.00	7.00

Zone I53a	6' CFM range	nozzle	achieved capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 331 CFM	21-47	A0	3,856	1	47		17.00	6.00
	28-53	A1	4,095	1	53		18.00	6.00
Need beams to	42-76	B1	4,129	1	76		26.00	7.00
provide	117-345	C1	4,299	1	345	331	31.00	7.00
dehumidification and	81-131	E1	4,368	1	131		33.00	7.00
ventilation.	93-161	F1	4,436	1	161		37.00	9.00
	114-182	G1	4,470	1	182		41.00	9.00
	153-254	H1	4,572	1	254		46.00	7.00
Capacity balance:	117-345	C1	4,299	1	345	6	31.00	7.00

Zone I54	6' CFM range	nozzle	achieved capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 331 CFM	21-47	A0	3,856	1	47		17.00	6.00
	28-53	A1	4,095	1	53		18.00	6.00
Need beams to	42-76	B1	4,129	1	76		26.00	7.00
provide	117-345	C1	4,299	1	345	331	31.00	7.00
dehumidification and	81-131	E1	4,368	1	131		33.00	7.00
ventilation.	93-161	F1	4,436	1	161		37.00	9.00
	114-182	G1	4,470	1	182		41.00	9.00
	153-254	H1	4,572	1	254		46.00	7.00
Capacity balance:	117-345	C1	4,299	1	345	234	31.00	7.00

Zone I54a	6' CFM range	nozzle	achieved capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 41 CFM	21-47	A0	3,622	1	41	41	17.00	6.00
	28-53	A1	4,095	1	53	91	18.00	6.00
Need beams to	42-76	B1	4,129	1	76	86	26.00	7.00
provide	117-345	C1	4,299	1	345	62	31.00	7.00
dehumidification and	81-131	E1	4,368	1	131	52	33.00	7.00
ventilation.	93-161	F1	4,436	1	161	42	37.00	9.00
	114-182	G1	4,470	1	182	37	41.00	9.00
	153-254	H1	4,572	1	254	22	46.00	7.00
Capacity balance:	21-47	A0	3,622	1	41	-158	17.00	6.00

Zones E52	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 290 CFM	21-47	A0	15,424	4	188	425	17.00	6.00
	28-53	A1	16,380	4	212	379	18.00	6.00
	42-76	B1	16,516	4	304	373	26.00	7.00
	117-345	C1	17,196	4	1380	340	31.00	7.00
	81-131	E1	17,472	4	524	327	33.00	7.00
	93-161	F1	17,744	4	644	314	37.00	9.00
	114-182	G1	17,880	4	728	308	41.00	9.00
	153-254	H1	18,288	4	1016	288	46.00	7.00
Capacity balance:	81-131	E1	17,472	4	524	327	33.00	7.00

Zones E53	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 331 CFM	21-47	A0	30,848	8	376	331	17.00	6.00
	28-53	A1	32,760	8	424		18.00	6.00
	42-76	B1	33,032	8	608		26.00	7.00
	117-345	C1	34,392	8	2760		31.00	7.00
	81-131	E1	34,944	8	1048		33.00	7.00
	93-161	F1	35,488	8	1288		37.00	9.00
	114-182	G1	35,760	8	1456		41.00	9.00
	153-254	H1	36,576	8	2032		46.00	7.00
Capacity balance:	21-47	A0	30,458	8	366	366	Yes	6.00

Zones E54	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 331 CFM	21-47	A0	30,848	8	376	331	17.00	6.00
	28-53	A1	32,760	8	424		18.00	6.00
	42-76	B1	33,032	8	608		26.00	7.00
	117-345	C1	34,392	8	2760		31.00	7.00
	81-131	E1	34,944	8	1048		33.00	7.00
	93-161	F1	35,488	8	1288		37.00	9.00
	114-182	G1	35,760	8	1456		41.00	9.00
	153-254	H1	36,576	8	2032		46.00	7.00
Capacity balance:	21-47	A0	30,458	8	366	366	Yes	6.00

Zones E55	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 248 CFM	21-47	A0	38,560	10	470	473	17.00	6.00
	28-53	A1	40,950	10	530	359	18.00	6.00
	42-76	B1	41,290	10	760	342	26.00	7.00
	117-345	C1	42,990	10	3450	261	31.00	7.00
	81-131	E1	43,680	10	1310	228	33.00	7.00
	93-161	F1	44,360	10	1610	195	37.00	9.00
	114-182	G1	44,700	10	1820	179	41.00	9.00
	153-254	H1	45,720	10	2540	130	46.00	7.00
Capacity balance:	28-53	A1	40,950	10	530	359	18.00	6.00

Zones E56	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 207 CFM	21-47	A0	23,136	6	282	364	17.00	6.00
	28-53	A1	24,570	6	318	295	18.00	6.00
	42-76	B1	24,774	6	456	286	26.00	7.00
	117-345	C1	25,794	6	2070	237	31.00	7.00
	81-131	E1	26,208	6	786	217	33.00	7.00
	93-161	F1	26,616	6	966	197	37.00	9.00
	114-182	G1	26,820	6	1092	188	41.00	9.00
	153-254	H1	27,432	6	1524	158	46.00	7.00
Capacity balance:	28-53	A1	24,570	6	318	295	18.00	6.00

Zones E57	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 207 CFM	21-47	A0	23,136	6	282	360	17.00	6.00
	28-53	A1	24,570	6	318	291	18.00	6.00
	42-76	B1	24,774	6	456	281	26.00	7.00
	117-345	C1	25,794	6	2070	232	31.00	7.00
	81-131	E1	26,208	6	786	213	33.00	7.00
	93-161	F1	26,616	6	966	193	37.00	9.00
	114-182	G1	26,820	6	1092	183	41.00	9.00
	153-254	H1	27,432	6	1524	154	46.00	7.00
Capacity balance:	28-53	A1	24,570	6	318	291	18.00	6.00

Zones E58	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 248 CFM	21-47	A0	38,560	10	470	473	17.00	6.00
	28-53	A1	40,950	10	530	359	18.00	6.00
	42-76	B1	41,290	10	760	342	26.00	7.00
	117-345	C1	42,990	10	3450	261	31.00	7.00
	81-131	E1	43,680	10	1310	228	33.00	7.00
	93-161	F1	44,360	10	1610	195	37.00	9.00
	114-182	G1	44,700	10	1820	179	41.00	9.00
	153-254	H1	45,720	10	2540	130	46.00	7.00
Capacity balance:	28-53	A1	38,383	10	480	481	18.00	6.00

Zone E59	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 414 CFM	21-47	A0	38,560	10	470	641	17.00	6.00
	28-53	A1	40,950	10	530	481	18.00	6.00
	42-76	B1	41,290	10	760	458	26.00	7.00
	117-345	C1	42,990	10	3450	344	31.00	7.00
	81-131	E1	43,680	10	1310	298	33.00	7.00
	93-161	F1	44,360	10	1610	253	37.00	9.00
	114-182	G1	44,700	10	1820	230	41.00	9.00
	153-254	H1	45,720	10	2540	161	46.00	7.00
Capacity balance:	28-53	A1	40,231	10	516	514	Yes	6.00

Zone I55	6' CFM range	nozzle	achieved capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 248 CFM	21-47	A0	7,712	2	94		17.00	6.00
	28-53	A1	8,190	2	106		18.00	6.00
Need beams to	42-76	B1	8,258	2	152		26.00	7.00
provide	117-345	C1	8,598	2	690		31.00	7.00
dehumidification and	81-131	E1	8,736	2	262	248	33.00	7.00
ventilation.	93-161	F1	8,872	2	322		37.00	9.00
	114-182	G1	8,940	2	364		41.00	9.00
	153-254	H1	9,144	2	508		46.00	7.00
Capacity balance:	81-131	E1	8,736	2	262	-87	33.00	7.00

Zone I55a	6' CFM range	nozzle	achieved capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 248 CFM	21-47	A0	3,856	1	47		17.00	6.00
	28-53	A1	4,095	1	53		18.00	6.00
Need beams to	42-76	B1	4,129	1	76		26.00	7.00
provide	117-345	C1	3,996	1	248	248	31.00	7.00
dehumidification and	81-131	E1	4,368	1	131		33.00	7.00
ventilation.	93-161	F1	4,436	1	161		37.00	9.00
	114-182	G1	4,470	1	182		41.00	9.00
	153-254	H1	4,572	1	254		46.00	7.00
Capacity balance:	117-345	C1	3,996	1	248	-6	31.00	7.00

Zones I55b & c same as Zones I51a-d

Zone I56	6' CFM range	nozzle	achieved capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 207 CFM	21-47	A0	7,712	2	94		17.00	6.00
	28-53	A1	8,190	2	106		18.00	6.00
	42-76	B1	8,258	2	152		26.00	7.00
Beams meet full load	117-345	C1	8,598	2	690	288	31.00	7.00
with primary CFM.	81-131	E1	8,736	2	262		33.00	7.00
	93-161	F1	8,872	2	322		37.00	9.00
	114-182	G1	8,940	2	364		41.00	9.00
	153-254	H1	9,144	2	508		46.00	7.00
Capacity balance:	117-345	C1	7,007	2	288	-47	Yes	7.00

Zone I56a	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 41 CFM	21-47	A0	3,856	1	47		17.00	6.00
	28-53	A1	4,095	1	53		18.00	6.00
	42-76	B1	4,129	1	76		26.00	7.00
Beams meet full load	117-345	C1	4,299	1	345		31.00	7.00
with primary CFM.	81-131	E1	4,368	1	131	91	33.00	7.00
	93-161	F1	4,436	1	161		37.00	9.00
	114-182	G1	4,470	1	182		41.00	9.00
	153-254	H1	4,572	1	254		46.00	7.00
Capacity balance:	81-131	E1	3,634	1	91	-83	23.33	5.83

Zones I56b same as Zone I56a

Zone I57	6' CFM range	nozzle	achieved capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 704 CFM	21-47	A0	11,568	3	141		17.00	6.00
	28-53	A1	12,285	3	159		18.00	6.00
	42-76	B1	12,387	3	228		26.00	7.00
Beams meet full load	117-345	C1	12,897	3	1035	948	31.00	7.00
with primary CFM.	81-131	E1	13,104	3	393		33.00	7.00
	93-161	F1	13,308	3	483		37.00	9.00
	114-182	G1	13,410	3	546		41.00	9.00
	153-254	H1	13,716	3	762		46.00	7.00
Capacity balance:	117-345	C1	12,632	3	948	948	29.70	6.57

Zone I57a	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 248 CFM	21-47	A0	3,856	1	47		17.00	6.00
	28-53	A1	4,095	1	53		18.00	6.00
	42-76	B1	4,129	1	76		26.00	7.00
Beams meet full load	117-345	C1	4,299	1	345	185	31.00	7.00
with primary CFM.	81-131	E1	4,368	1	131		33.00	7.00
	93-161	F1	4,436	1	161		37.00	9.00
	114-182	G1	4,470	1	182		41.00	9.00
	153-254	H1	4,572	1	254		46.00	7.00
Capacity balance:	117-345	C1	3,730	1	185	6	22.08	6.00

Zone I57b	6' CFM range	nozzle	achieved water capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 83 CFM	21-47	A0	3,856	1	47		17.00	6.00
	28-53	A1	4,095	1	53		18.00	6.00
	42-76	B1	4,129	1	76		26.00	7.00
Beams meet full load	117-345	C1	4,299	1	345	149	31.00	7.00
with primary CFM.	81-131	E1	4,368	1	131		33.00	7.00
	93-161	F1	4,436	1	161		37.00	9.00
	114-182	G1	4,470	1	182		41.00	9.00
	153-254	H1	4,572	1	254		46.00	7.00
Capacity balance:	117-345	C1	3,534	1	149	-20	Yes	5.70

Zone I57c	6' CFM range	nozzle	achieved capacity	#	Chart Primary CFM	Primary CFM Needed	NC<20?	Temp (F)
Dehum. 516 CFM	21-47	A0	7,712	2	94		17.00	6.00
	28-53	A1	8,190	2	106		18.00	6.00
2 beams to supply	42-76	B1	8,258	2	152		26.00	7.00
dehumidification	117-345	C1	8,598	2	690	607	31.00	7.00
CFM	81-131	E1	8,736	2	262		33.00	7.00
	93-161	F1	8,872	2	322		37.00	9.00
	114-182	G1	8,940	2	364		41.00	9.00
	153-254	H1	9,144	2	508		46.00	7.00
Capacity balance:	117-345	C1	8,379	2	618	617	29.39	6.46

APPENDIX 04: Retail 1 / Lobby Peak Load Calculations

Sample Retail Floor Cooling Load Calculations

ZONE PEAK	Susp'd Ceil'g?:	No	Glass U:	0.23	Supply Air Temp:	56 F
Peak OSA Temp for -- Boston, MA (Logan Airport)	Indoor Temp:	76 F	Roof U:	0.039	Return Plenum:	No
40 Degrees N. Lat	Daily Range:	16 F	SHGC:	0.4	Recessed lights to plenum:	No
	Wall Height:	16.625 ft	Wall U:	0.02	h out:	37.4 Btu/lb
Office Light Allowance (W/sqft): 0.12					h in:	28.7 Btu/lb

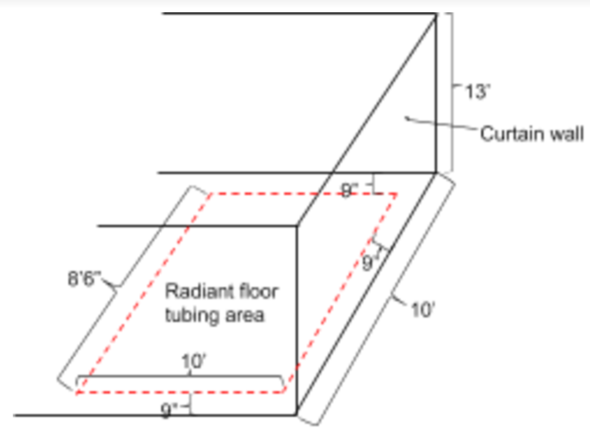
By calculating the load without the shadowboxes, the option is maintained to either use the shadowboxes or not use the shadowboxes. It becomes a owner decision, not a design decision.

ZONE	Orientation	Glass Area	Zone Area	Peak Mnth	Peak Hour	Zone S & T	Glass BTUHs	Lighting Watts	Occupants BTUHs	Room Sens BTUHs	CFM	TOTAL BTUH	Ht Loss Btuh*
R11	N	898	863	6	18	18,543	18,543	104	29	40,570	1,845	46,370	23,271
R11	W	249		6	18	14,424	14,424						
R21	N	449	660	6	18	9,271	9,271	79	22	43,890	1,995	48,290	19,224
R21	W	499		6	18	28,848	28,848						
R31	N	449	360	6	18	9,271	9,271	43	12	19,228	875	21,628	12,478
R31	E	83		6	18	2,001	2,001						
R31	W	83		6	18	4,808	4,808						
R41	N	482	390	6	18	9,958	9,958	47	13	20,177	915	22,777	13,153
R41	E	83		6	18	2,001	2,001						
R41	W	83		6	18	4,808	4,808						
R51	N	682	515	6	18	14,079	14,079	62	18	28,914	1,315	32,514	19,426
R51	E	173		6	18	4,163	4,163						
R51	W	103		6	18	5,962	5,962						
R61	N	707	1,208	6	18	14,594	14,594	145	41	80,228	3,645	88,428	34,569
R61	E	83		6	18	2,001	2,001						
R61	W	914		6	18	52,888	52,888						
R71	N	183	165	6	18	3,777	3,777	20	6	5,345	245	6,545	3,710
R81	0	0	2,160	6	18	0	0	259	72	18,884	860	33,284	0
R91	0	0	200	6	18	0	0	24	1	332	15	532	0
R101	0	0	513	6	18	0	0	62	18	4,710	215	8,310	0
R111	0	0	1,380	6	18	0	0	166	46	12,065	550	21,265	0
R121	0	0	2,463	6	18	0	0	296	83	21,759	990	38,359	0
R131	0	0	3,101	6	18	0	0	372	104	27,270	1,240	48,070	0
R141	0	0	3,303	6	18	0	0	396	12	4,353	200	6,753	0
R151	0	0	3,270	6	18	0	0	392	11	4,089	185	6,289	0
R161	0	0	2,919	6	18	0	0	350	98	25,696	1,170	45,296	0
R171	0	0	3,920	6	18	0	0	470	131	34,355	1,560	60,555	0
R181	0	0	5,518	6	18	0	0	662	19	7,010	320	10,810	0
R191	0	0	2,767	6	18	0	0	332	93	24,383	1,110	42,983	0
R201	0	0	1,029	6	18	0	0	123	35	9,171	415	16,171	0
R211	0	0	1,864	6	18	0	0	224	7	2,513	115	3,913	0
Totals		**6,203**	**38,566**			**201,397**	**201,397**	**4,628**	**871**	**434,942**	**19,780**	**609,142**	**125,830**

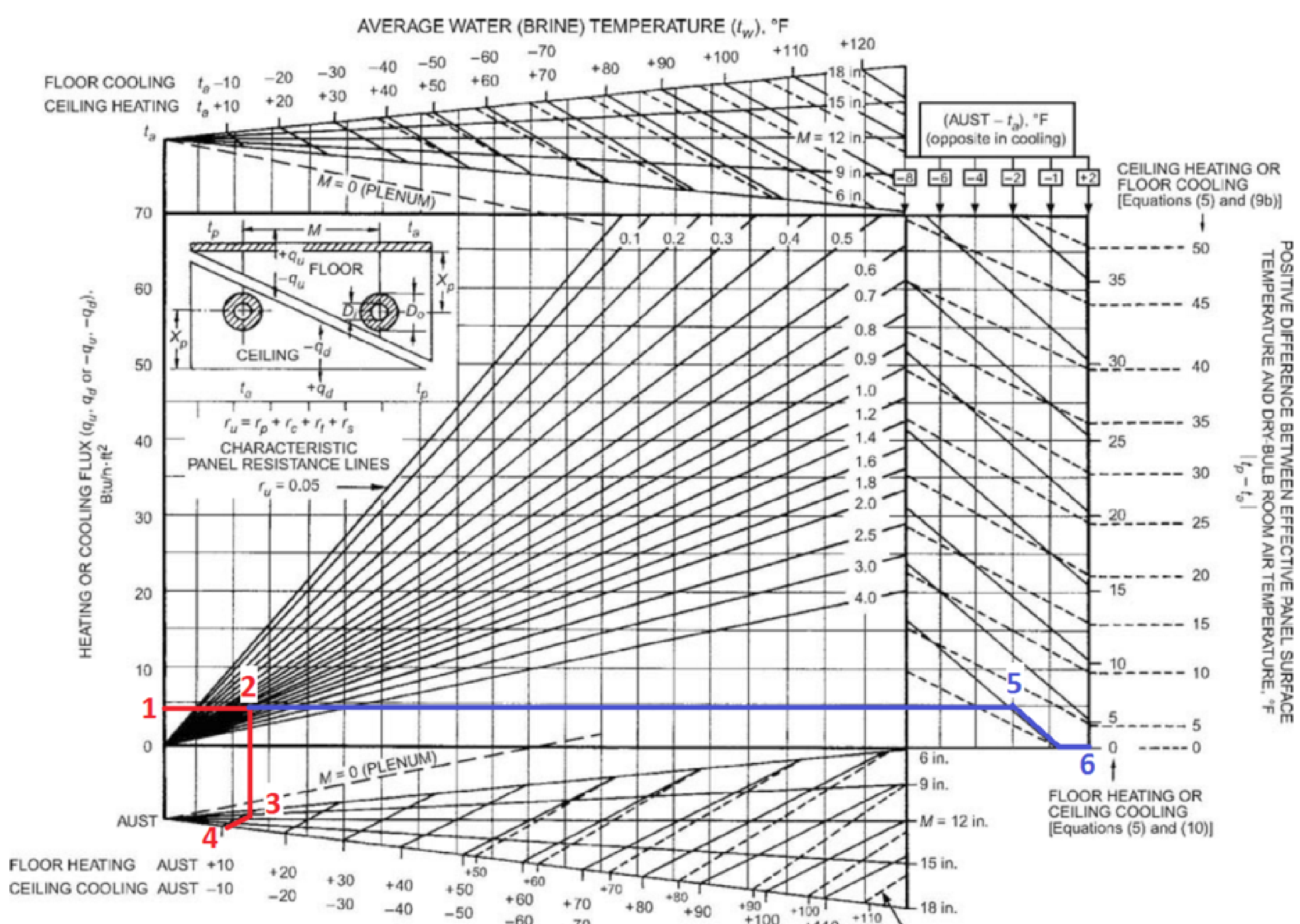
APPENDIX 05: Radiant Floor

Radiant Floor Heating Verification

The radiant panel design chart on page 6.6 of the 2012 ASHRAE Handbook – HVAC Systems and Equipment verified and validated the results from LoopCad. LoopCad predicts 34.7 kBTU/H as the design load for a typical office floor and water temperature around 118F. Our design places tubing in a 10ft wide band along the perimeter of the floor, providing an area of about 8200 ft2 of heated floor surface. The unit load is then 4.2 BTUH/ft2.



Consider a 10 foot zone as shown above representing a typical office space with tubes placed 9 inches away from any wall to avoid unexpected punctures during construction. The area of the curtain wall is then 130 ft2 (10ftx13ft high). The glass U-value for our project is 0.23. The design temperature is 70F inside and 0F outside. The total energy Q = U.A.dT = 0.025x130x70 =228 BTUH. 100 BTUH is a good approximation for exfiltration. The total Q now is 2200 BTUH. The floor area of radiant tubing is 8.5ftx10ft = 85ft2. This yields a unit load of 3.9 BTUH/f2 (328/85 = 3.9). This unit load very closely agrees with the 4.2 BTUH/ft2 unit load calculated with LoopCad with only a 7% difference. With this unit load value, we can use the radiant panel design chart from ASHRAE to verify other values that LoopCad predicts.



1. The unit load is 25.9 or 26 BTUH/ft2. The line is drawn straight to the right to meet the panel R-value line at point 2.
2. The combined R-value of the PEX tube (0.028), 2.5" concrete slab (0.475), and light carpet (0.6) is around 1.1. The line is then drawn vertically down to meet at line at point 3.
3. Our tubing is placed 9 inches on center. The line is then drawn to meet at point 4.
4. At point 4, the required average water temperature is about 48F higher than room temperature or 118F for a 70F room. This result perfectly validates the average water temperature produced by LoopCad for a typical office floor. To validate the surface temperature of radiant slabs not exceeding 85F, the straight line from point 1 is extended to meet a line at point 5.
5. The temperature difference here is -2F (AUST - Ta = 68F - 70F = -2F).
6. At point 6, the average slab temperature is 13F above room temperature or 83F for a 70F room. This result also validates our set temperature to be 85F maximum for surface temperature.

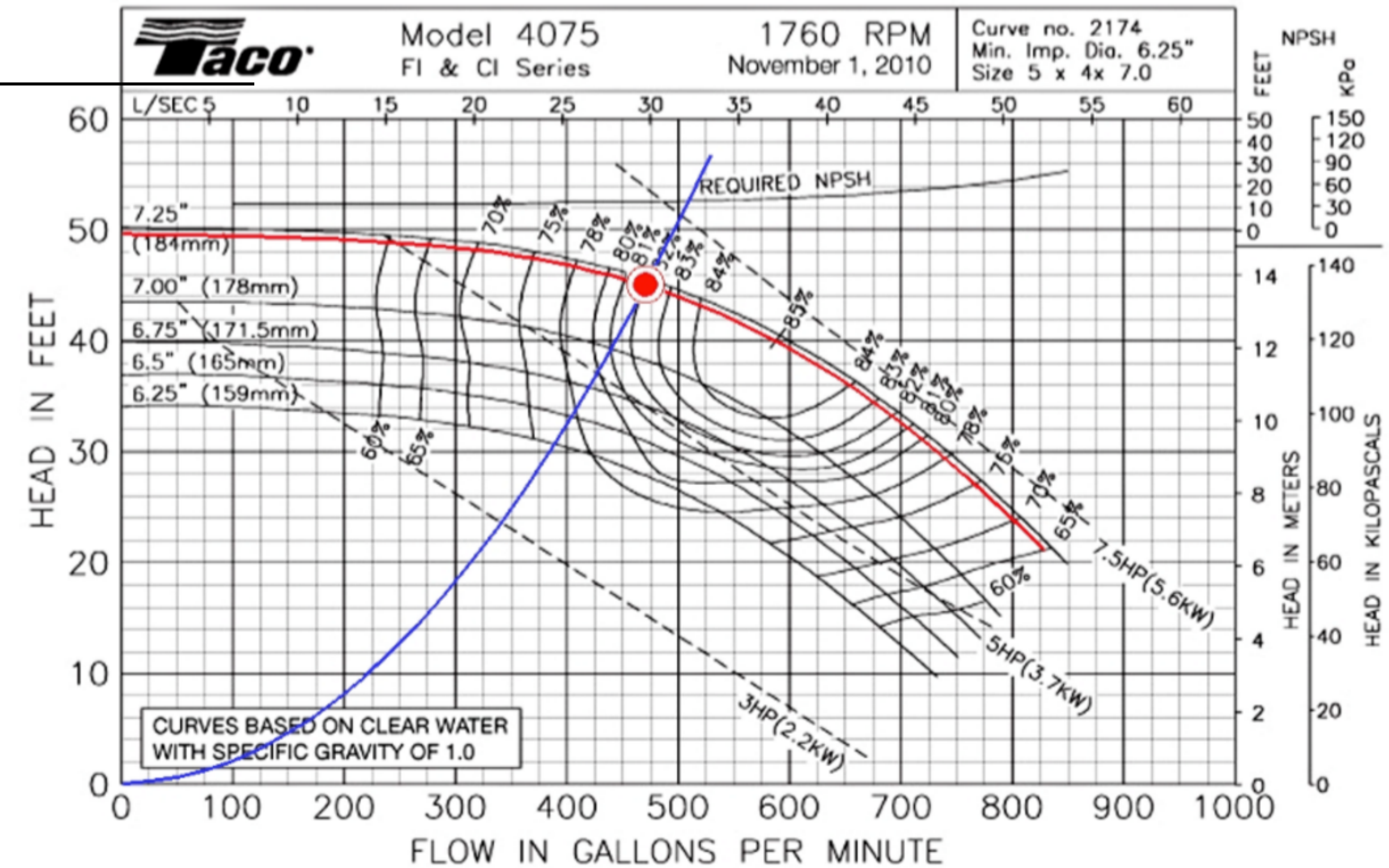


Table 1: Radiant Floor Pump Curve for the first 8 floors

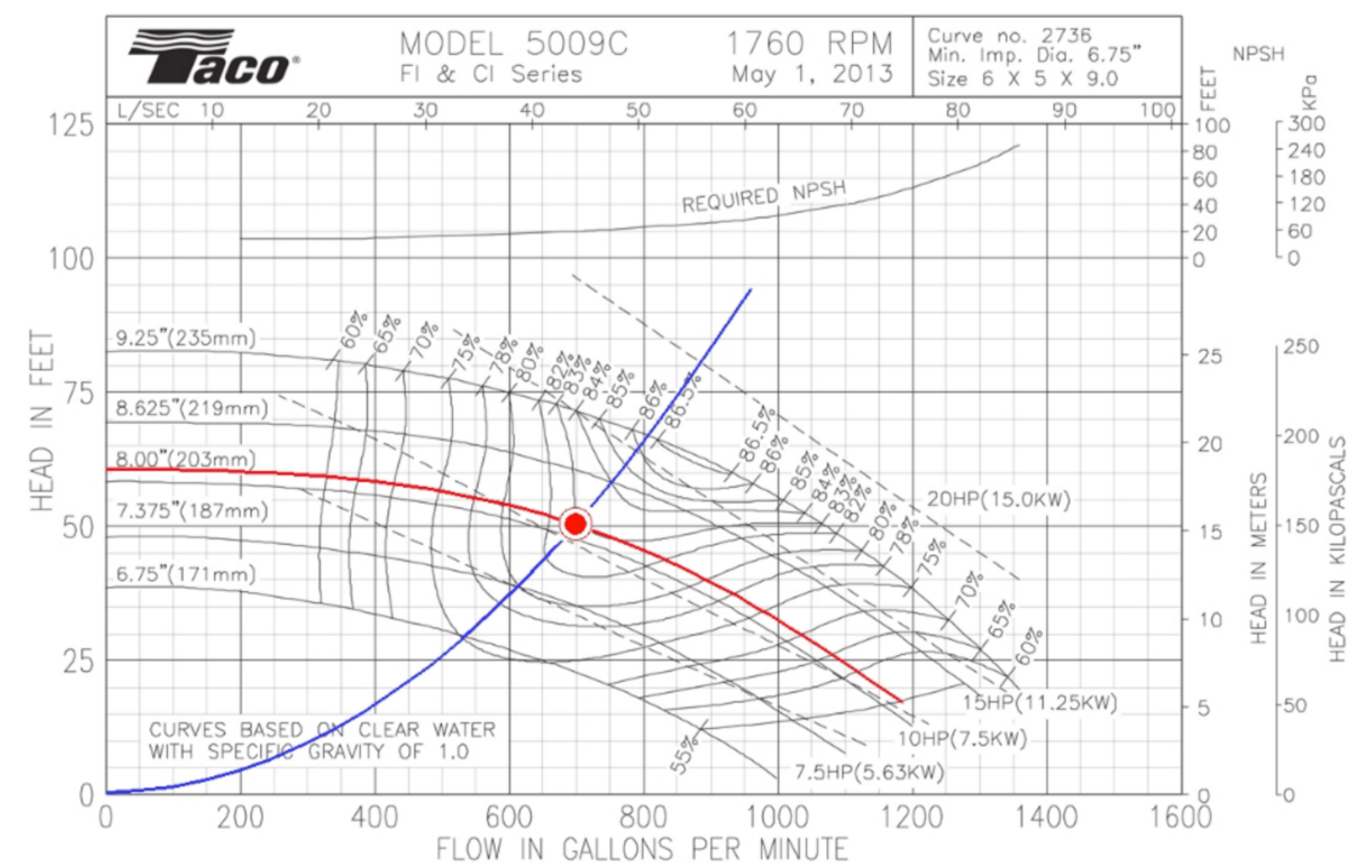


Table 2: Radiant Floor Pump Curve For The Entire Building

APPENDIX 05: Radiant Floor (Continue)

Additional information regarding radiant floor system

	Typical Office	3rd Floor	2nd Floor	1st Floor
# of zones	40	48	19	43
# of manifolds	5	8	6	10
# of circuits	44	48	41	84
Tube spacing (in)	8, 9, 12	8, 9, 10, 12	8, 9, 12	8, 9 10
Total tube length (ft)	13,555	12,554	11,509	19,145

APPENDIX 06: Cogeneration/Trigeneration Equipment Sizing

Table 1: Cogeneration Unit Energy Output and Efficiency - GE Jenbacher Type 6 Gas Engine, Model J612

Electrical Output	Thermal Output	Energy Input	Exhaust Gas Temperature	NOx	Thermal Efficiency	Electrical Efficiency	Total Efficiency
1,979 kW	1,960 kW	4,142 kW	120 C	500	43.80%	44.20%	88%

Table 2: 600-Nominal Tons Thermachill Two-Stage Direct-Fired Absorption Chiller - Trane

Model	Capacity (tons)	COP		Cooling Duty Fuel Consumption (MBH)		Heating Performance
		Std.Effi. Unit (HHV)	High.Effi. Unit (HHV)	Std.Effi. Unit (HHV)	High.Effi. Unit (HHV)	Capacity (MBH)
ABDL-600	576	0.97	1.03	7146	6717	6595

Table 3: Condensing Boiler Model FB-3500 - Lochinvar

	Water Capacity (gallon)	Max. Flow rate (gpm)	Min. Flow Rate (gpm)	Max. Pressure (psi)	Gas Input (kBTUH)	Gas Output (kBTUH)	Horse Power (HP)
FB-3500	215	350	45	160	3,500	3,220	105

APPENDIX 07: Design Builder Step-by-step Simulations

		change made	basecase	proposed	tons per Hr	kBtu/sqft per Yr	Full step cumulative (tons per Hr)	% reduction (substep)	% reduction (cumulative)
step00	STEP 00	none yet	-	-	1,227.06	224.44	1,227.06	0.00	0.00
step 01		**ACTIVITY TAB**					826.02		32.68
	STEP 01.1	density (ppl/ft2)	0.01	0.012	1,233.15	225.55		-0.50	
		schedule	ASHRAE 90.1 occupancy- office	888 occupants					
	STEP 01.2	computers	0.4645	0.2	1,183.58	216.48		4.04	
		comp. schedule	ASHRAE 90.1 occupancy- office	888 occupants					
	STEP 01.3	office equipment	2.14	0.2	826.02	151.08		29.14	
		eqpt. schedule	ASHRAE 90.1 occupancy- office	888 occupants					
step 02		**OPENINGS TAB**					931.28		24.10
	STEP 02.1	glass type	ASHRAE 90.1 single	888 copy od dbl loe (u=0.2)	831.01	152		-0.41	
	STEP 02.2	% glass	40%	99%	931.28	170.34		-8.17	
step 03		**LIGHTING TAB**					592.76		51.69
	STEP 03.1-03.2	template	common space 12W	888 LED w/linear control	584.26	106.86		28.28	
		W/sqft	0.88	0.11					
	STEP 03.3	schedule	ASHRAE 90.1 occupancy- office	888 lights	592.76	108.42		-0.69	
step 04		**HVAC TAB**					535.95		56.32
	STEP 04.1	template	VAV	chilled beams noDOAS	535.95	98.03		4.63	
step 05		**CONSTRUCTION TAB**					518.47		57.75
	STEP 05.1	internal floor	intermediate 4in concrete	888 Bubble slab	518.47	94.83		1.42	
step 06		**LAYOUT TAB**					465.21		62.09
	STEP 06.1	floor addition- height change	17 floors	18 floors	465.21	85.09		4.34	
step 07		**SHADOW BOX**					378.278		69.17
	STEP 07.1	change 40% wall value-R50	0.4	0.025	378.278	69.19		7.08	

Table: Step-by-step Simulations: Energy use reduction

APPENDIX 08: Fire Protection System

Table 1: Occupancy Classification

Space	Hazard occupancy classification	Descriptions
Office floors, restaurant seating area, arcade entrance, and main lobby	Light hazard	NFPA 13, A.5.2 specifies that such spaces are of light hazard occupancy due to low combustible materials, which may include office supplies, chairs, light wall decorations, etc.
Parking garages	Ordinary hazard group I	NFPA 13, A.5.3.1 prescribes that automobile parking is Ordinary hazard group I. Motor vehicles can produce a relatively substantial fire with liquid gas or oil in the car and seats.
The three retail floors	Ordinary hazard group II	NFPA 13, A.5.3.2 prescribes that such spaces be defined as ordinary hazard group II. These floors contain a wide range of combustible materials from Commodities class I to Plastic Group A. There are also stock rooms that contain storage merchandise. The stockrooms are assumed to be ordinary hazard II. It is assumed that there is no rack storages in the stock rooms and not exceed 8ft.

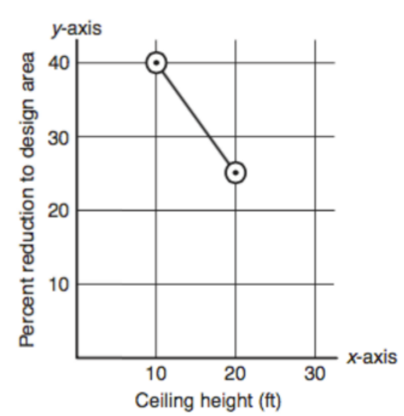
The percentage of design area reduction is based a graph in NFPA 13, 11.2.3.2.3.1.
For a typical office floor with a ceiling height of roughly 13 ft, the percent reduction to design area is y=-3132+55=35.5%.

To initially determine the number of sprinklers in the 1,500 ft2 design area, the following formulae are used. Take a typical office floor as an example.

#sprinkler=Design Area/Area per sprinkler=1500 ft/2144 ft2=10.4 or 11 sprinklers.

#sprinkler on a branch line = 1.2sqrt(design area)/(Distance between sprinklers on branch line)=1.21500 ft212 ft=3.8 or 4 sprinklers

Since the system is qualified to reduce the design area to 968 ft2, the new total number of sprinkler that must be hydraulically calculated decreases. In addition, the fact that sprinkler spacing is not uniform and the design area is slightly irregular also affect the total number of sprinklers in the revised design area. As shown in the floor plan xxx, the final total number of sprinkler is 8.



Note: $y = \frac{-3x}{2} + 55$

For ceiling height ≥10 ft and ≤20 ft, $y = \frac{-3x}{2} + 55$
For ceiling height <10 ft, $y = 40$
For ceiling height >20, $y = 0$
For SI units, 1 ft = 0.31 m.

Table 2: Commodity Classification

Space	Classification	Descriptions (NFPA 13, Table A.5.6.3)
Office floors, restaurant seating area, arcade entrance, main lobby	Class I-IV	These spaces contain office supplies, paper products, chairs, wood chopsticks, tables, wood furniture with plastic coverings, plastic posters, plants, etc.
The three retail floors, parking floors	Class I-IV, Plastic Group A	There are various merchandise such as carton boxes, plastic wraps, textiles, wood furniture with foam plastic cushioning, synthetic products, etc. In the parking floors there are rubber tires, batteries, car seats, etc.

Table 3: More Details on Sprinkler Design

Space	Sprinkler type in designed area	Hazard classification and density	Spacing (ft2)	Min. design area after modification (1500ft2 original)	#Sprinkler in design area	Flow (GPM)	Pressure (PSI)
18th floor	K-5.6	Light hazard, 0.1 gpm/ft2	12'x12'	968ft2 (35.5% reduction)	8	120	233
3rd floor	K-5.6	Ordinary hazard II, 0.2 gpm/ft2	11'x11.5'	1049ft2 (30% reduction)	13	358	90
2nd floor	K-5.6	Ordinary hazard II, 0.2 gpm/ft2	11'x11.5'	1049ft2 (30% reduction)	10	307	89
1st floor	K-11.2	Ordinary hazard II, 0.2 gpm/ft2	11'x11.5'	1049ft2 (30% reduction)	9	305	43
Gree Mezzanine	K-5.6	Ordinary hazard I, 0.15 gpm/ft2	11'x11.5'	1950 ft2 (30% increase)	15	300	31
Green Level	K-5.6	Ordinary hazard I, 0.15 gpm/ft2	11'x11.5'	1950 ft2 (30% increase)	15	306	18

PreCalculation Lines
Job - 888 - 18th floor
File name - C:\Users\Desktop\888-18th floor.WXF
Date - 01/28/16
Time - 20:25:08

K = 5.600 Pt = 7.000

Node	Dia	Length	Fit.	KFact	Qa.	Pf.	Pe.	Pt.	Vel.
HD1	1.049	8	E	5.600	14.82	0.75	106.5	7.00	5.50

DP1 K = 1.386 Qt = 14.82 Pt = 114.29

===

K = 5.600 Pt = 7.000

Node	Dia	Length	Fit.	KFact	Qa.	Pf.	Pe.	Pt.	Vel.
HD2	1.049	8.96	T	5.600	14.82	1.04	106.5	7.00	5.50

DP2 K = 1.384 Qt = 14.82 Pt = 114.59

****

General Calculation Program

Job - 888 - 18th floor Date - 01/28/16
File - C:\Users\Desktop\888-18th floor.WXFTime - 20:25:09

AREA CALCULATED - HEAD FLOW SUMMARY

ID	K-Factor	Actual Flow	Req. Flow	Delta Flow.	Actual Press.		Req. Press.	Delta Press
1	1.386	14.83	14.82	0.01	114.511	Pt	114.290	0.221
2	1.384	14.82	14.82	0.00	114.585	Pt	114.585	0.000
3	1.384	14.84	14.82	0.02	114.884	Pt	114.585	0.298
4	1.384	14.88	14.82	0.06	115.516	Pt	114.585	0.930
5	1.384	14.97	14.82	0.16	116.997	Pt	114.585	2.411
9	1.384	15.21	14.82	0.39	120.711	Pt	114.585	6.125
10	1.384	15.21	14.82	0.40	120.818	Pt	114.585	6.232
11	1.384	15.22	14.82	0.41	120.987	Pt	114.585	6.402

Total K Factors. . . . 8
Total Fixed Flows. . . 0
Sum Actual Flow. . . . 119.98
Sum Required Flow. . . 118.53
Sum Delta Flow 1.45
Max Delta Flow 0.41
Max Delta Pressure . . 6.402

AREA CALCULATED - COMPLETE SUMMARY

Start Point		Finish Point	Diam.	Start Pres.	Normal Pres.	Pf	Elev/Fixed Pres.	Flow	Vel
1	<-	2	1.610	114.511		0.074	0.000	14.83	2.34
2	<-	3	1.610	114.585		0.298	0.000	29.65	4.67
3	<-	4	1.610	114.884		0.632	0.000	44.48	7.01
4	<-	5	1.610	115.516		1.481	0.000	59.36	9.35
5	<-	6	1.610	116.997		4.337	0.000	74.33	11.71
7	->	8	1.610	120.711		-0.000	0.000	-0.00	-0.00
8	->	9	1.610	120.711		-0.000	0.000	-0.00	-0.00
9	<-	10	1.610	120.711		0.107	0.000	15.21	2.40
10	<-	11	1.610	120.818		0.170	0.000	30.42	4.79
11	<-	12	1.610	120.987		0.372	0.000	45.65	7.19
6	<-	12	4.026	121.334		0.025	0.000	74.33	1.87
12	<-	TOR	4.026	121.359		1.311	3.000	119.98	3.02
TOR	<-	BOR	6.065	125.670		0.146	85.754	119.98	1.33
BOR	<-	TPUM	6.065	211.570		0.106	0.000	119.98	1.33
TPUM	<-	TEST	6.065	211.675		0.008	20.789	119.98	1.33

Pipe with highest velocity: 5 - 6 (11.714)
Water Supply Summary @ Point TEST
Total Flow From Water Supply Curve 119.975
Pressure From Water Supply Curve 64.901
System Pressure Demand At Supply Curve 232.473
WARNING Demand Exceeds Available Pressure by 167.571

Table 5: More Details on Sprinkler Design

File Options Edit View Utilities Help

English / Metric - Bar / Metric - kPa — Project Name: 888 - 17th floor — Project Date: — Co Number: 1 — Your Company Name — Comm Elev: 0 — Auto Incr Value: 1 — Max Velocity: 32

System Piping | **Equivalent K Piping** | Check Line Piping

	Node 1	Node 2	Dia.	Pipe Type	Len.	Fit's	C Fact.	Input Type	Num Hds.	K / Flow	Den	Area	Press	Elev	Flow	Calc'd Pf.	Vel
1	HD1	DP1	1	SCHED-40	8	1E	120	Drop	1	5.6	0.1	144	7	246	14.816	0.747	5.5
2	HD2	DP2	1	SCHED-40	8.958	1T	120	Drop	1	5.6	0.1	144	7	246	14.816	1.043	5.5
3																	

Table 4: Performance curve of fire pump

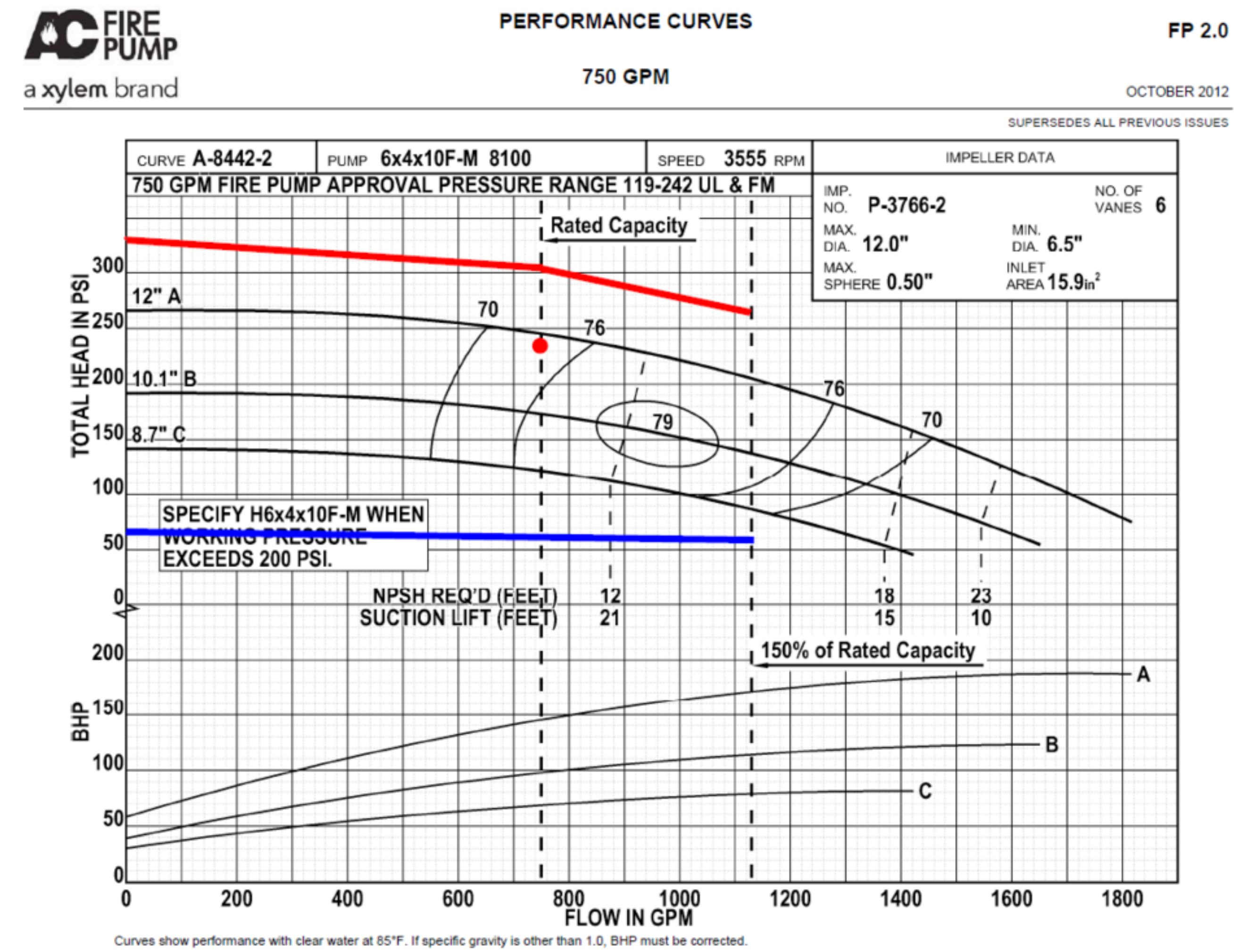


Table 6:More Details on Sprinkler Design (continued)

File Options Edit View Utilities Help

English / Metric - Bar / Metric - kPa — Project Name: 888 - 17th floor — Project Date: — Co Number: 1 — Your Company Name — Comm Elev: 0 — Auto Incr Value: 1 — Max Velocity: 32

System Piping | Equivalent K Piping | Check Line Piping

	Node 1	Node 2	Dia.	Pipe Type	Len.	Fit's	C Fact.	Input Type	Num Hds.	K / Flow	Den	Area	Press	Elev	Flow	Calc'd Pf.	Vel
1	*LINE1																
2	1	2	1.5	SCHED-40	8		120	Ln-S	1	=DP1				246	14.83	0.074	2.337
3	2	3	1.5	SCHED-40	8.917		120	Ln-S	2	=DP2				246	29.647	0.298	4.672
4	3	4	1.5	SCHED-40	8.917		120	Ln-S	3	=DP2				246	44.482	0.632	7.01
5	4	5	1.5	SCHED-40	12.250		120	Ln-S	4	=DP2				246	59.358	1.481	9.354
6	5	6	1.5	SCHED-40	7.667	2T	120	Ln-S	5	=DP2				246	74.33	4.337	11.714
7	*LINE2																
8	7	8	1.5	SCHED-40	8.917		120	Ln-S	1					246	0	0	0
9	8	9	1.5	SCHED-40	8.917		120	Ln-S	2					246	0	0	0
10	9	10	1.5	SCHED-40	11		120	Ln-S	3	=DP2				246	15.207	0.107	2.397
11	10	11	1.5	SCHED-40	4.833		120	Ln-S	4	=DP2				246	30.421	0.17	4.794
12	11	12	1.5	SCHED-40	5		120	Ln-S	5	=DP2				246	45.645	0.372	7.193
13	*XMAIN																
14	6	12	4	SCHED-40	12		120	Mn-S						246	74.33	0.025	1.873
15	12	TOR	4	SCHED-40	181	4E1Fsp35	120	Mn-S						246	119.975	1.311	3.024
16	TOR	BOR	6	SCHED-40	210		120	Riser						246	119.975	0.146	1.332
17	BOR	TPUM	6	SCHED-40	108	1E1T	120	Mn-S						48	119.975	0.106	1.332
18	TPUM	TEST	6	SCHED-40	12		120	Riser						48	119.975	0.008	1.332
19	TEST																

APPENDIX 09: Appliance Calculations

OFFICE APPLIANCES
FLOORS 04, 06-18,
DOUBLE-TENANT

wrkdys/yr:	260	**wrkhrs/yr:**	2,600	**total hrs/yr:**	8,736	**Operational hrs:**

Appliance	#	$BTUH_s$	$BTUH_l$	Total BTUH	YEARLY BTU	Avg BTUH
computers	190	853	0	162,118	421,505,500	48,249
phones	190	7	0	1,297	11,330,068	1,297
projectors	2	1,450	0	2,900	3,016,000	345
printers/copier	4	940	0	3,760	32,847,360	3,760
printers (small)	10	702	0	7,020	1,825,200	209
fridges	2	488	73	1,122	9,800,045	1,122
microwaves	2	8,970	0	17,940	4,664,400	534
drink vending	2	1,423	15	2,876	25,121,259	2,876
food vending	2	72	0	143	1,252,271	143
coffee makers	2	3,750	1,910	11,320	11,772,800	1,348
coffee warmer	2	230	110	680	1,768,000	202
paper shredders	2	680	0	1,360	353,600	40
water coolers	2	6,000	0	12,000	104,832,000	12,000
TOTAL:	**412**	**25,565**	**2,107**	**224,535**	**630,088,502**	**72,126**

TYPICAL OFFICE,	SINGLE TENANT, BY ZONE					
Zone	Description	BTUHs	BTUHl	Total BTUH	YEARLY BTU	Avg BTUH
C51	2 computers, 2 phones	1,720	0	1,720	4,472,395	512
C52	2 computers, 2 phones	1,720	0	1,720	4,472,395	512
C53	10 computers, 10 phones	8,601	0	8,601	22,361,976	2,560
C54	2 computers, 2 phones	1,720	0	1,720	4,472,395	512
C55	2 computers, 2 phones	1,720	0	1,720	4,472,395	512
C56	2 computers, 2 phones	1,720	0	1,720	4,472,395	512
C57	2 computers, 2 phones	1,720	0	1,720	4,472,395	512
C58	10 computers, 10 phones	8,601	0	8,601	22,361,976	2,560
E51	7 computers, 7 phones	6,021	0	6,021	15,653,383	1,792
E52	7 computers, 7 phones	10,198	0	10,198	26,514,233	3,035
E53	8 computers, 8 phones	6,881	0	6,881	17,889,581	2,048
E54	8 computers, 8 phones	6,881	0	6,881	17,889,581	2,048
E55	6 computers, 6 phones	5,160	0	5,160	13,417,186	1,536
E56	-		0	0	0	0
E57	-		0	0	0	0
E58	6 computers, 6 phones	5,160	0	5,160	13,417,186	1,536
E59	10 computers, 10 phones	8,601	0	8,601	22,361,976	2,560
E510	6 computers, 6 phones	5,160	0	5,160	13,417,186	1,536
I51	21 computers, 21 phones	18,062	0	18,062	46,960,150	5,375
I51a	1 computer, 1 phone, 1 printer (small)	1,562	0	1,562	4,061,398	465
I51b	1 computer, 1 phone, 1 printer (small)	1,562	0	1,562	4,061,398	465
I51c	1 computer, 1 phone, 1 printer (small)	1,562	0	1,562	4,061,398	465
I51d	1 computer, 1 phone, 1 printer (small)	1,562	0	1,562	4,061,398	465
I52	21 computers, 21 phones	18,062	0	18,062	46,960,150	5,375
I52a	1 computer, 1 phone, 1 printer (small)	1,562	0	1,562	4,061,398	465

LEED v4 for BD+C: New Construction and Major Renovation

Project Checklist

Project Name: 888 Boylston Street, Boston MA

Date: February, 2016

Y	?	N	Type	Credit	Points
1			Credit	Integrative Process	1

Y	?	N		Location and Transportation	16
12	0	4		**Location and Transportation**	**16**
			Credit	LEED for Neighborhood Development Location	16
1			Credit	Sensitive Land Protection	1
		2	Credit	High Priority Site	2
4		1	Credit	Surrounding Density and Diverse Uses	5
4		1	Credit	Access to Quality Transit	5
1			Credit	Bicycle Facilities	1
1			Credit	Reduced Parking Footprint	1
1			Credit	Green Vehicles	1

Y	?	N		Sustainable Sites	10
9	0	1		**Sustainable Sites**	**10**
Y			Prereq	Construction Activity Pollution Prevention	Required
1			Credit	Site Assessment	1
2			Credit	Site Development - Protect or Restore Habitat	2
1			Credit	Open Space	1
2		1	Credit	Rainwater Management	3
2			Credit	Heat Island Reduction	2
1			Credit	Light Pollution Reduction	1

Y	?	N		Water Efficiency	11
7	0	4		**Water Efficiency**	**11**
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
1		1	Credit	Outdoor Water Use Reduction	2
3		3	Credit	Indoor Water Use Reduction	6
2			Credit	Cooling Tower Water Use	2
1			Credit	Water Metering	1

Y	?	N		Energy and Atmosphere	33
31	0	2		**Energy and Atmosphere**	**33**
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
6			Credit	Enhanced Commissioning	6
18			Credit	Optimize Energy Performance	18
1			Credit	Advanced Energy Metering	1
2			Credit	Demand Response	2
1		2	Credit	Renewable Energy Production	3
1			Credit	Enhanced Refrigerant Management	1
2			Credit	Green Power and Carbon Offsets	2

Y	?	N		Materials and Resources	13
5	0	8		**Materials and Resources**	**13**
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
1		4	Credit	Building Life-Cycle Impact Reduction	5
1		1	Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
1		1	Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
1		1	Credit	Building Product Disclosure and Optimization - Material Ingredients	2
1		1	Credit	Construction and Demolition Waste Management	2

Y	?	N		Indoor Environmental Quality	16
13	0	3		**Indoor Environmental Quality**	**16**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
1		1	Credit	Enhanced Indoor Air Quality Strategies	2
3			Credit	Low-Emitting Materials	3
1			Credit	Construction Indoor Air Quality Management Plan	1
2			Credit	Indoor Air Quality Assessment	2
1			Credit	Thermal Comfort	1
2			Credit	Interior Lighting	2
1		2	Credit	Daylight	3
1			Credit	Quality Views	1
1			Credit	Acoustic Performance	1

Y	?	N		Innovation	6
3	0	3		**Innovation**	**6**
2		3	Credit	Innovation	5
1			Credit	LEED Accredited Professional	1

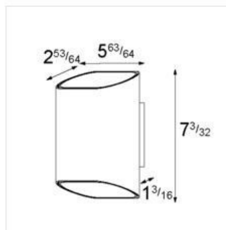
Y	?	N		Regional Priority	4
0	0	4		**Regional Priority**	**4**
		1	Credit	Regional Priority: Specific Credit	1
		1	Credit	Regional Priority: Specific Credit	1
		1	Credit	Regional Priority: Specific Credit	1
		1	Credit	Regional Priority: Specific Credit	1

Y	?	N			
81	0	29	**TOTALS**	Possible Points:	**110**

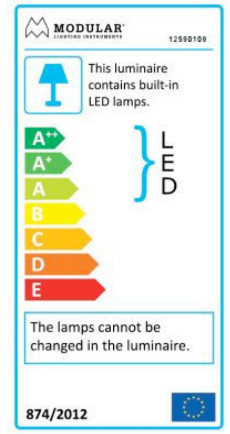
Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

APPENDIX 11: Light Fixtures

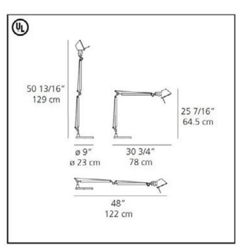
Modular Trapz



Lamp	2x LED Array 230V 4.3W
Gear / Transfo	transfo/gear not required
Power supply	120V
Weight	2.64 lbs
Min. Distance	4 in.
Glow Wire Test	960°
Source lifetime	35000 hrs
CRI	80
Lumen	590 lm
Efficacy	69 lm/W
Remark	! dry locations only ! including back plate 4"x4" - plaster finish



Artemide Tolomeo



UL Listed.

Dimensions

- 30.75"W X 27.4"H; 50.8125" max height
- Base: 9"D

Material(s)
Aluminum, steel

Lamp Type
LED

Bulbs
1 X 10W 120V LED module; 3000K, 80 CRI (included)

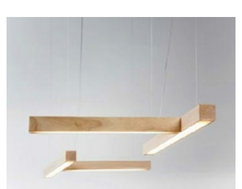
Listing
CUL, UL

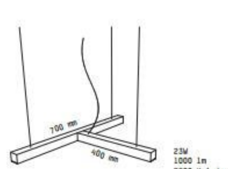
Manufacturer Specifications
Click to download specifications.

Item Number
ART-TOLCLS-T-LED

Model(s)
TOL0005

Tunto LED40 Modular





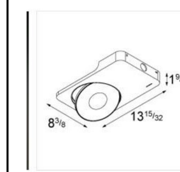
Drivers / Power Box

700 mA	0-10V / PWM (standard)	LCM40	700 mA	TRIAC	UL model	PCD40
	DALI, PUSH DIM	LCM40DA		ANALOG DIM		PLM40
	CASAMBI DIM	LCM40CAS				

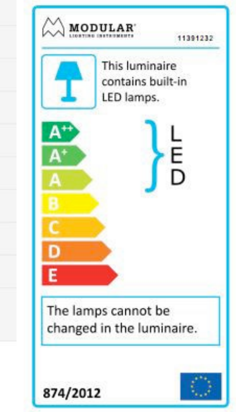
Rated Power	23-30W	Kelvin	2800 K
Voltage	220-240V 50/60 Hz, UL model 110-295V	Lumen	1000-1300 lm
Output	10-52V 700 mA	CRI	85 Typ
Cord Length	Pendant, standard 2 m, transparent. Max 20 m.	Package Size	custom made
Power Box	White ceiling cup 220 x 100 x 35 mm RAL 9016 fine efekt	Package Weight	custom made

INDOOR USE ONLY NON-USER REPLACEABLE LIGHT SOURCE IP20 CE

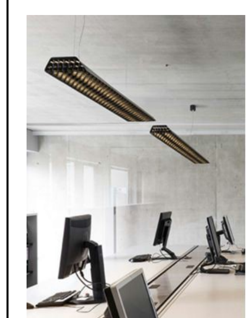
Modular Spock Series (Wall & Ceiling Track, LED GI)

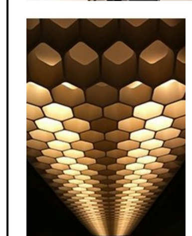


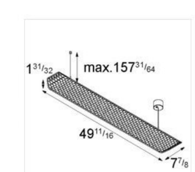
Lamp	1x LED disc 18W
Gear / Transfo	LED gear incl.
Power supply	120-277V
Adjustability	h 359° v -10°/+45°
Weight	4.8 lbs
Min. Distance	4 in.
IP	dry locations
Glow Wire Test	960°
Source lifetime	50000 hrs
CRI	80
Lumen	766 lm
Efficacy	37 lm/W
Remark	! dry locations only ! including back plate 4"x4" - plaster finish



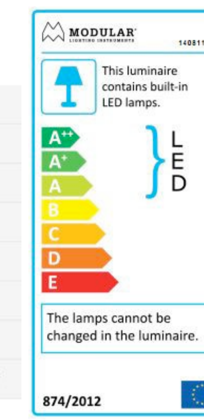
Modular Vaeder Suspension 0-10V GI







Lamp	8x LED Line 4W
Power supply	120V
Weight	10.34 lbs
Glow Wire Test	960°
CRI	80
Lumen	2681 lm
Efficacy	74 lm/W
Remark	! dry locations only



APPENDIX 11: Light Fixtures

<table>
<tr>
<td>Frosted glass diffusers with internal LED Strip Lights</td>
<td>examples

</td>
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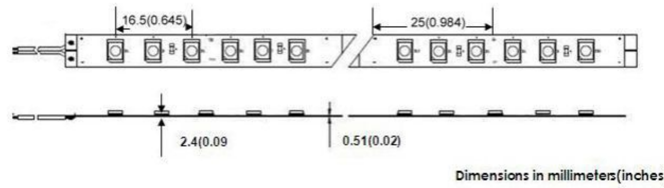

Item No.	HK-F3528X30-X-X-X	HK-F3528X60-X-X-X	HK-F5050X15-X-X-X	HK-F5050X30-X-X-X
Dimension	5000*8*2.4mm	5000*8*2.4mm	5000*10*2.0mm	5000*10*2.0mm
LED Quantity	SMD3528,300leds	SMD3528,600leds	SMD5050,150leds	SMD5050,300leds
Input Voltage	DC12V	DC12V	DC12V	DC12V
Power Consumption	<24W	<48W	<36W	<72W
Current Consumption	<2A	<4A	<3A	<6A
Viewing Angle	120°			
Operating Temperature	-30℃~85℃			
Storage Temperature	-40℃~85℃			
Protection Class	Non-waterproof, waterproof IP65, IP67, IP68 are available *(see Apendix Ⅰ)			

Contruction of the model no.
Eg. HK - F 3528 $X^1$30 – X^2 – X^3 – X^4
HK -- Abbreviation of HUAKE OPTOELECTRONICS(AISA) CO., LIMITED
F -- Short for flexible
3528 -- led chip model, SMD3528, SMD5050 and SMD335
X^1 -- CCT, ww(warm white), pw(pure white),R(red), B(blue), G(green), Y(yellow) and RGB
30 -- leds QTY. per 50cm
X^2 -- N for nonwaterproof; SI(surface injection) IP65; ST (silicone tube)IP67; WI (whole injection)IP68
X^3 -- the color of PCB broad. Y for yellow broad, W for white board, B for black board.
X^4 -- DC12V
</td>
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<tr>
<td>DesignLED Light Tiles</td>
<td></td>
<td>

- 90% optical efficiency
- Low power consumption
- Colour temperature range, from warm to cool white (2,700K - 7,000K)
- Spatial dimming capability
- Power consumption, 7 W - 100 W/m2
- Modular, Dimmable
- No Heat sink required
- Low profile, easily surface mounted to walls ceilings or other architectural surfaces
- Multiple mechanical fixing options

</td>
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Figure: Typical Ofice Floor Lighting Design Layout

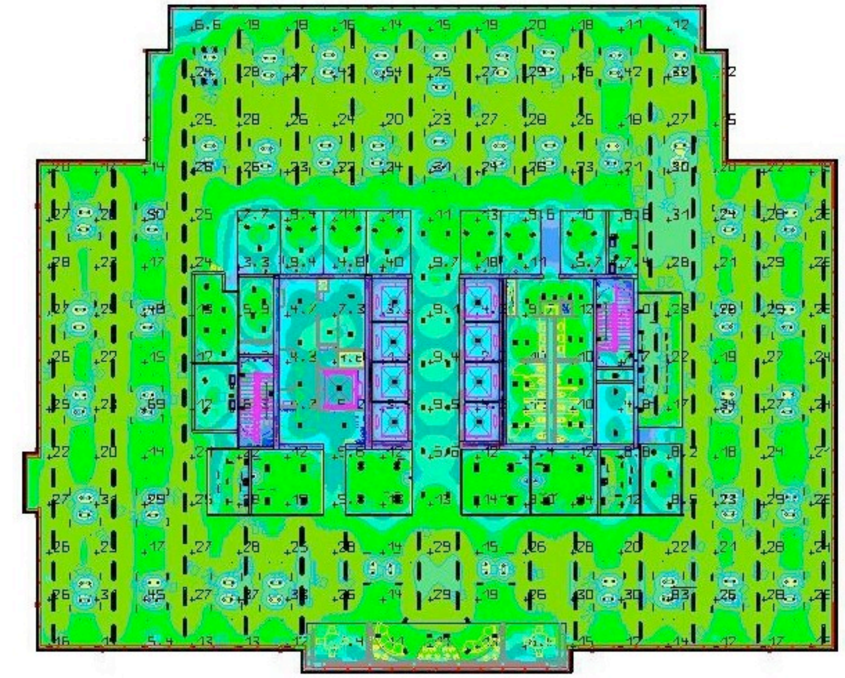
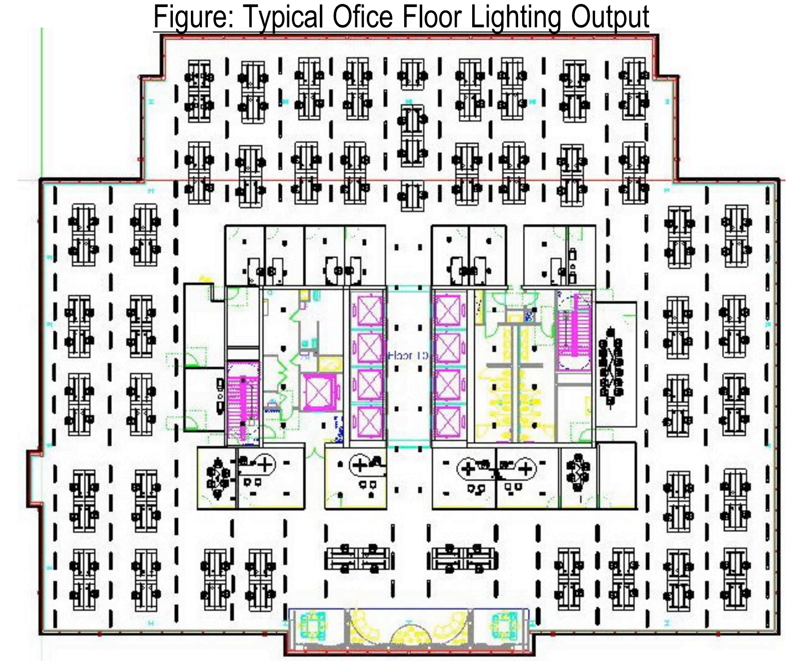


Figure: Typical Ofice Floor Lighting Output



APPENDIX 12: Daylighting Simulation

Figure: Daylighting Simulation - Retail 1

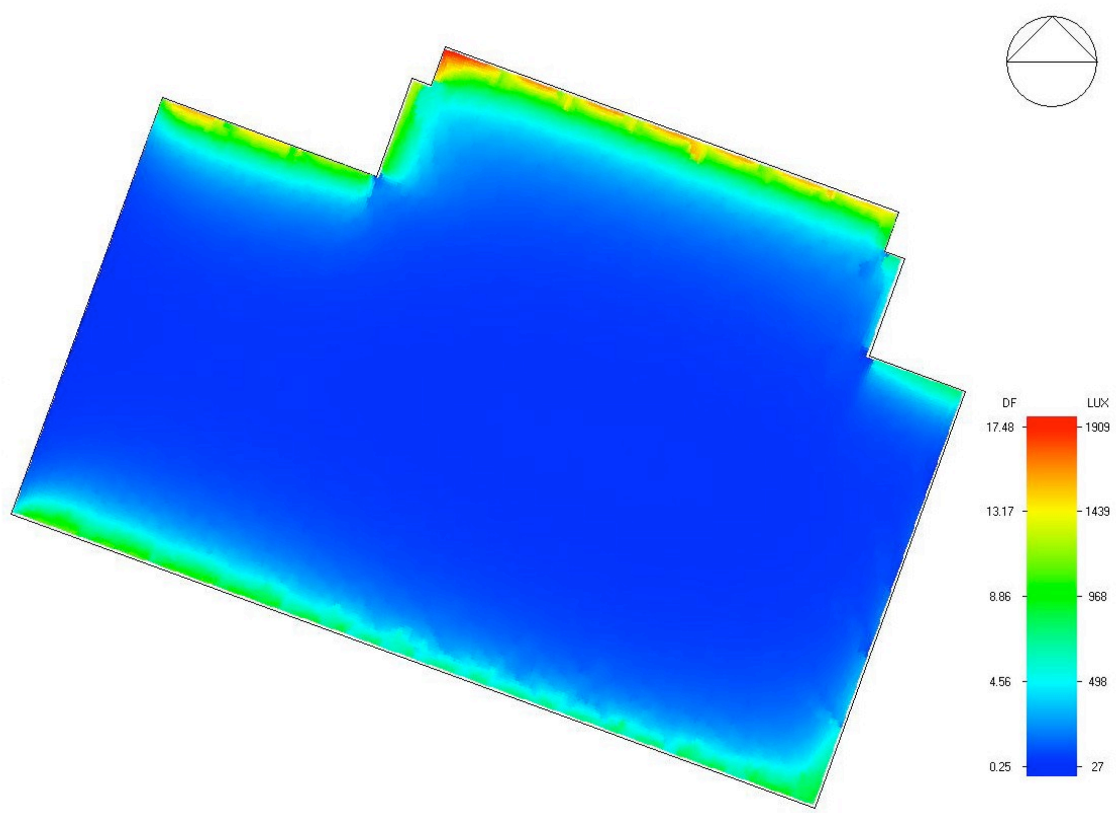


Figure: Daylighting Simulation - New Floor

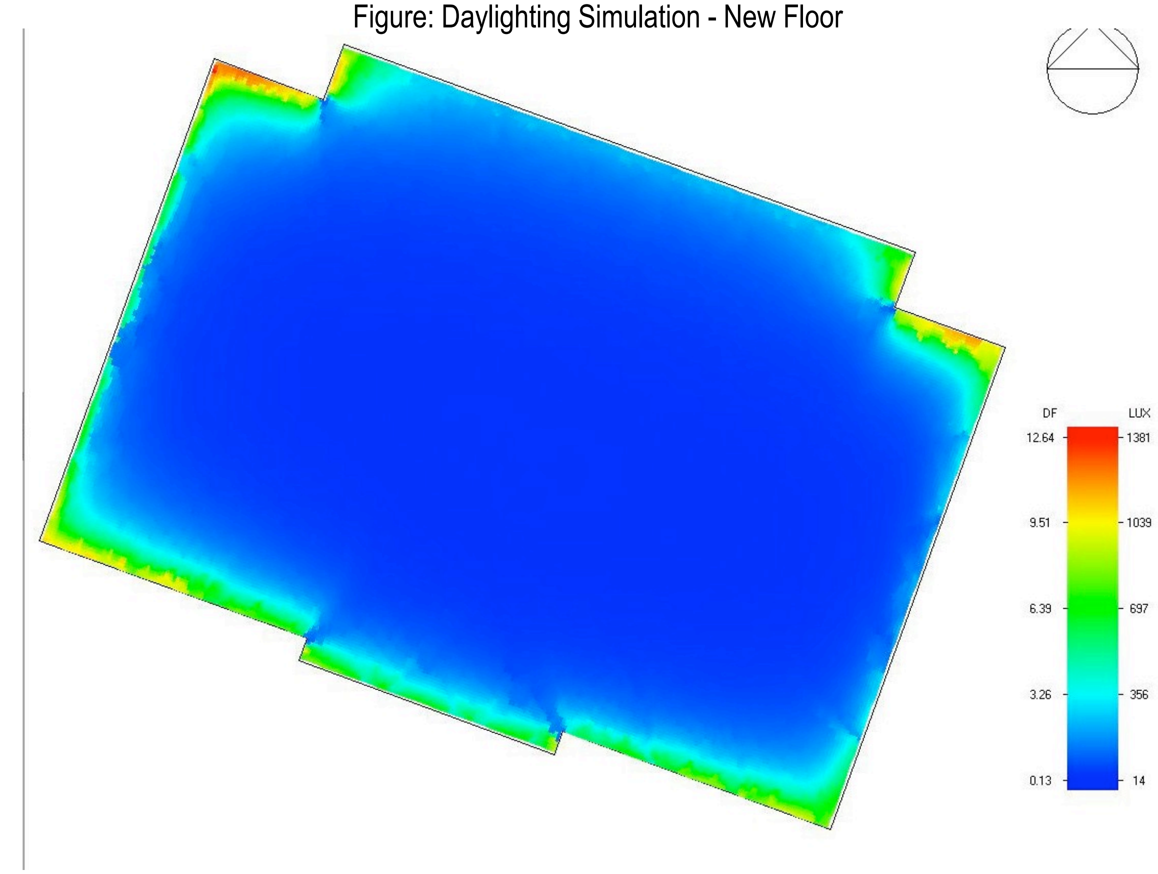


Figure: Daylighting Simulation - Retail 2

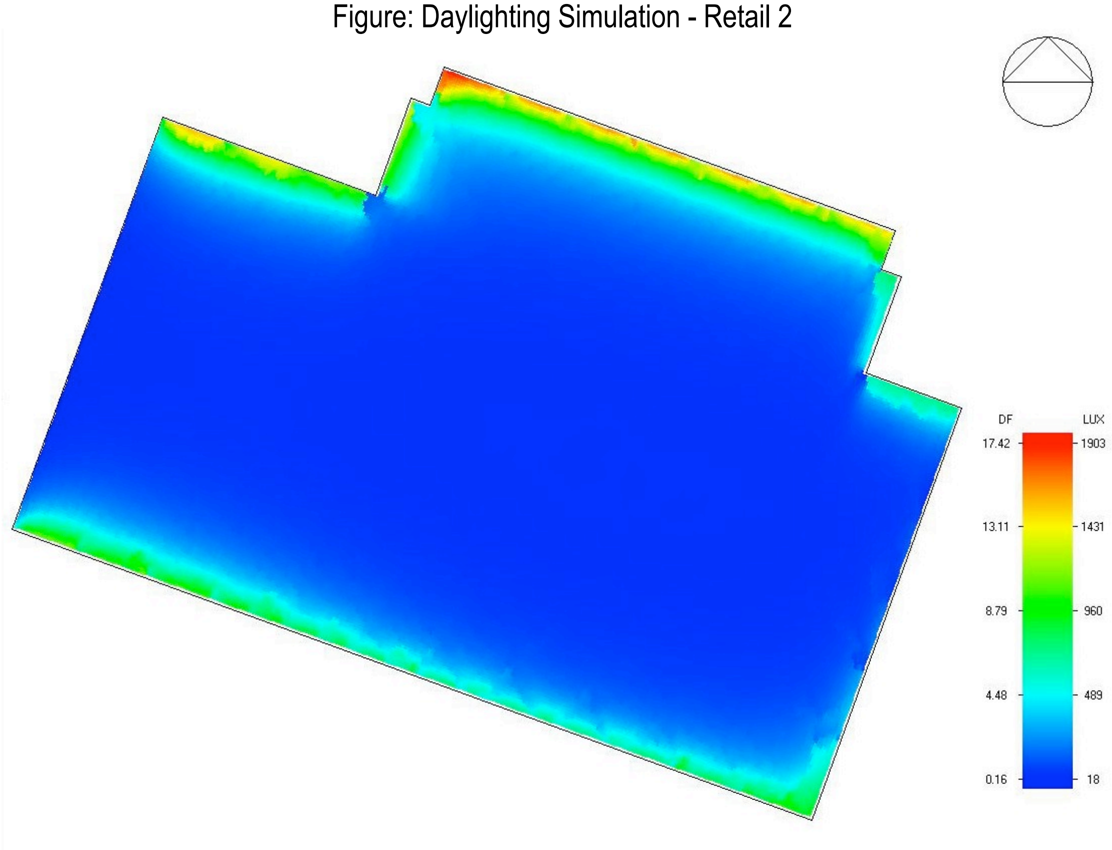
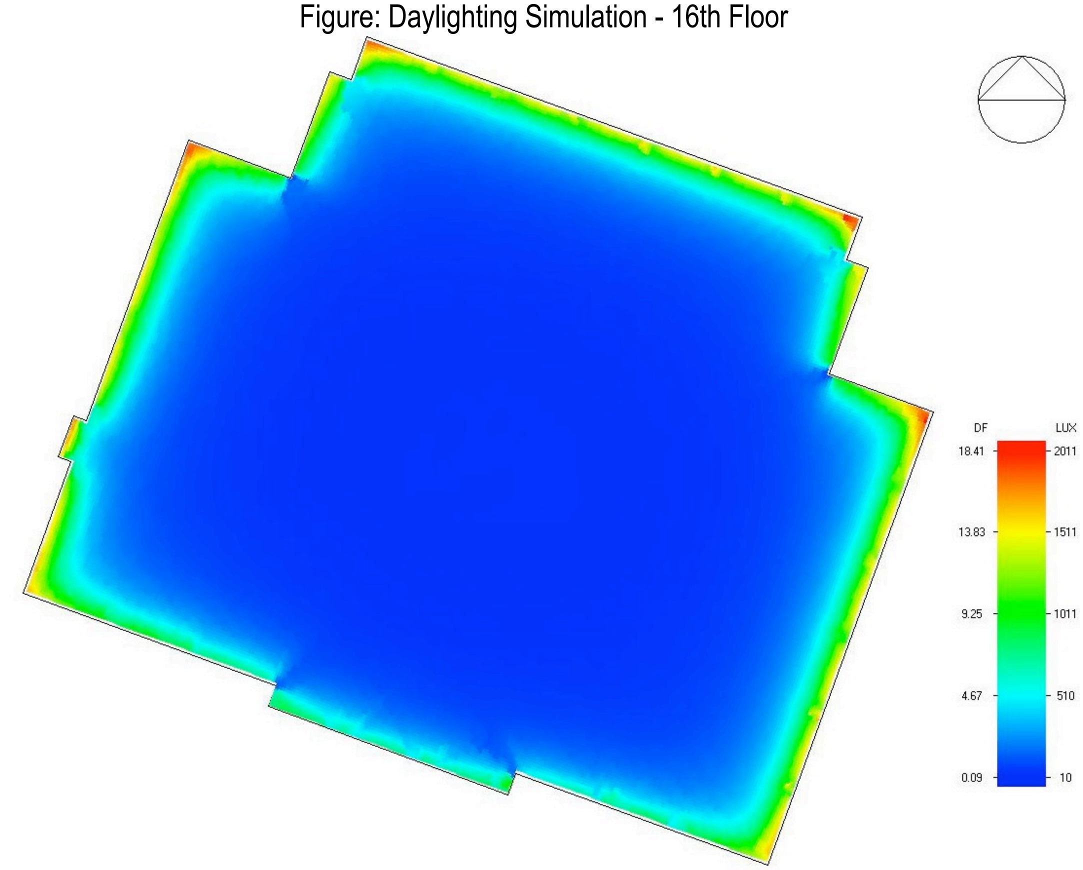
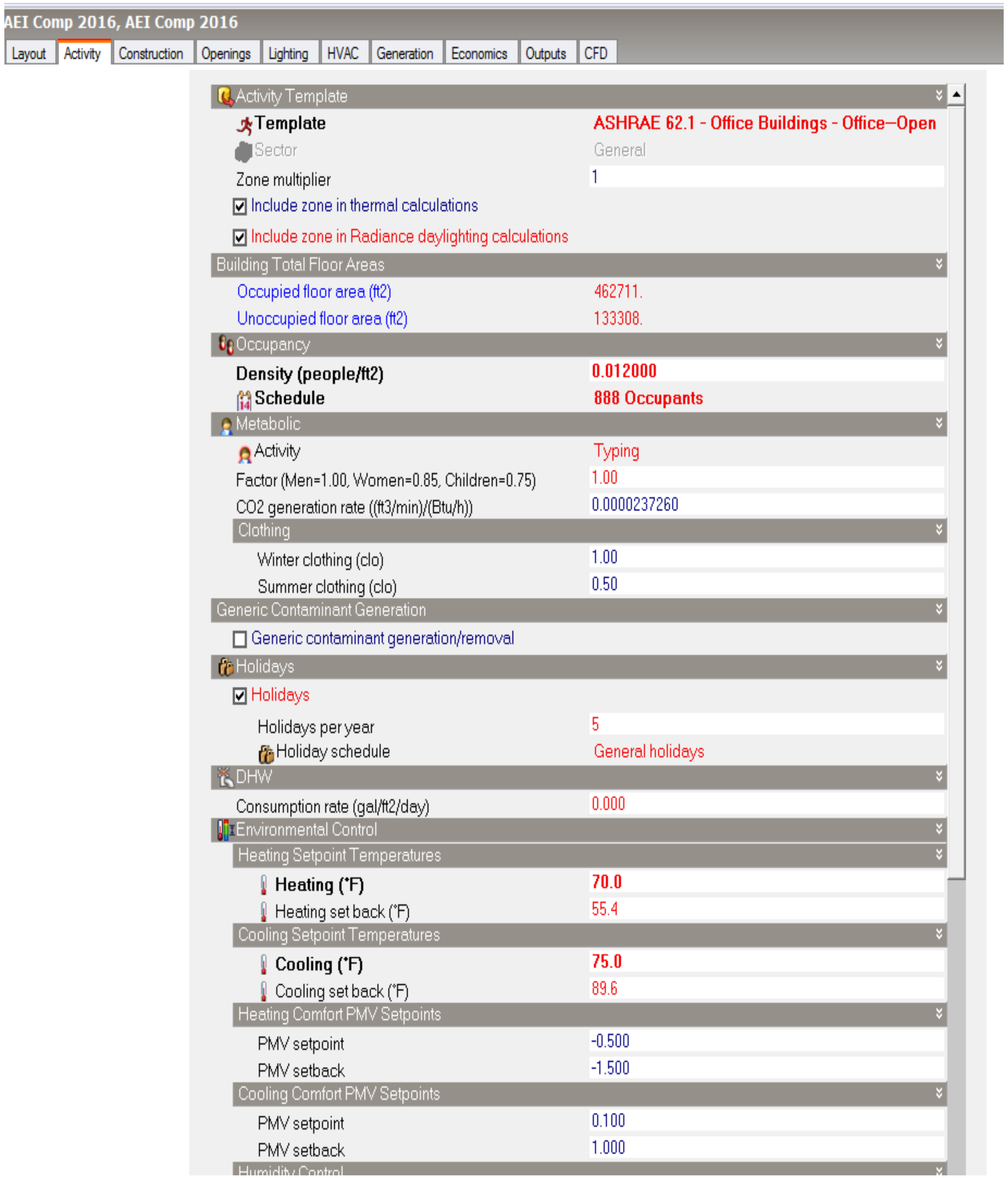
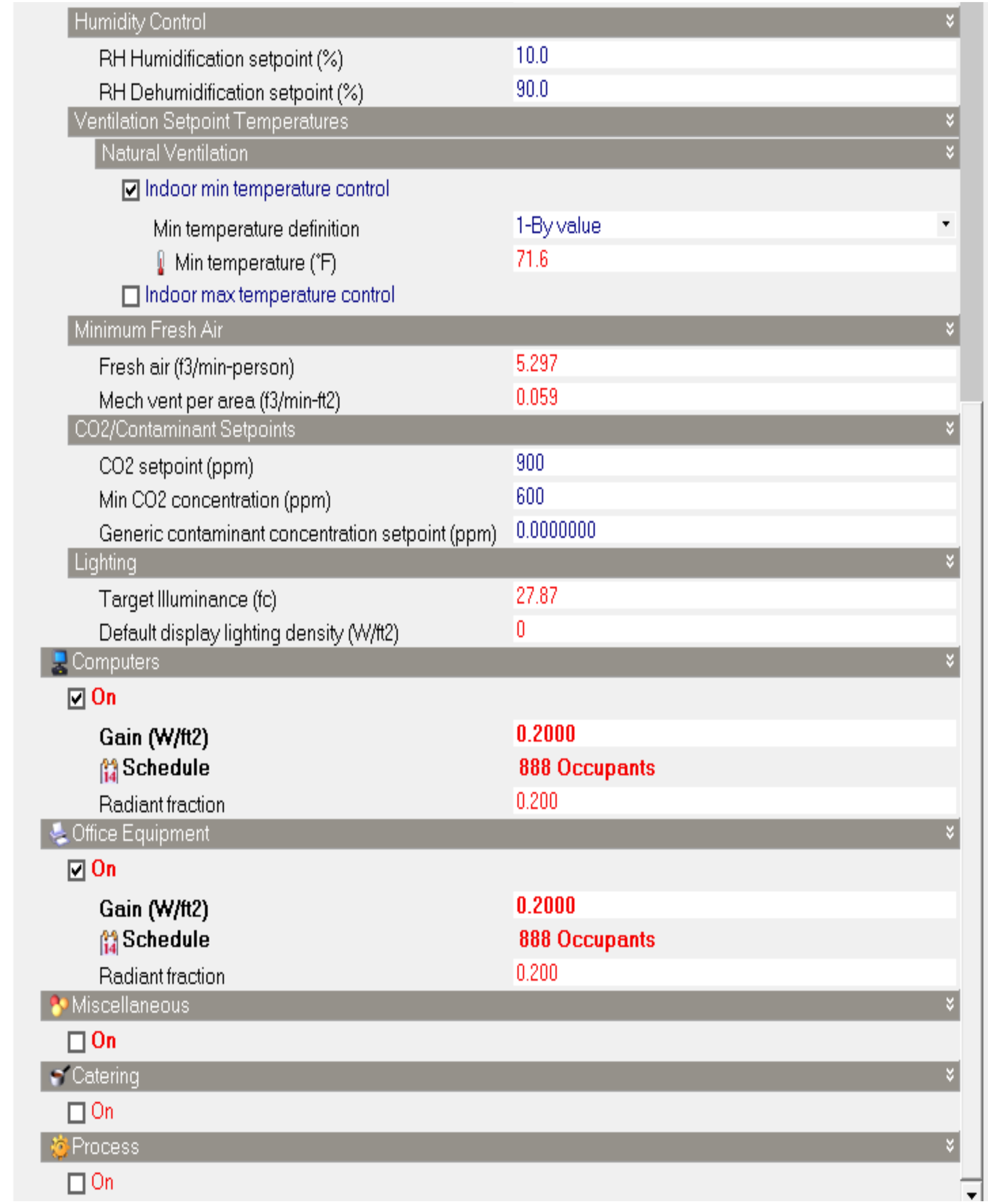


Figure: Daylighting Simulation - 16th Floor

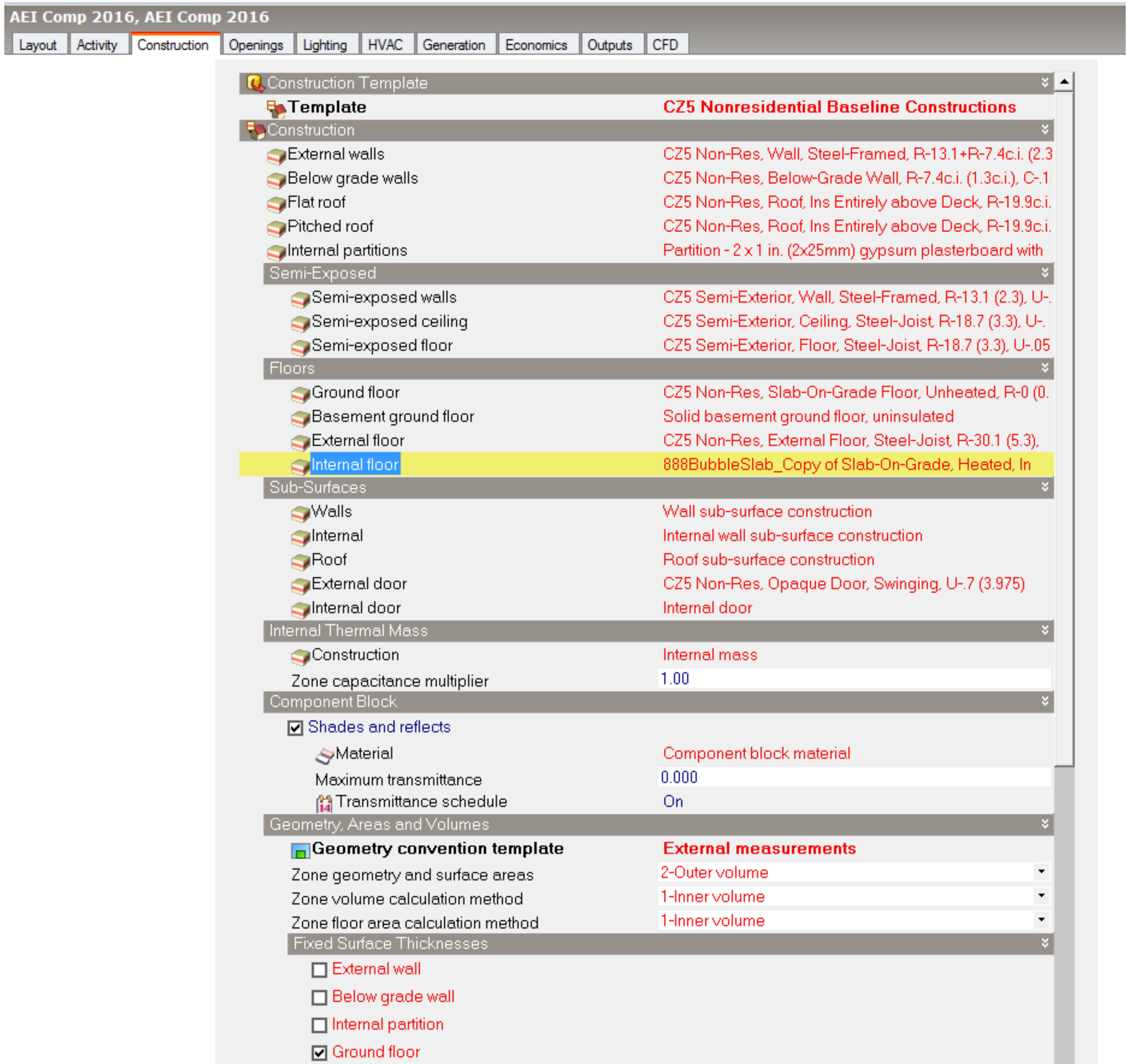


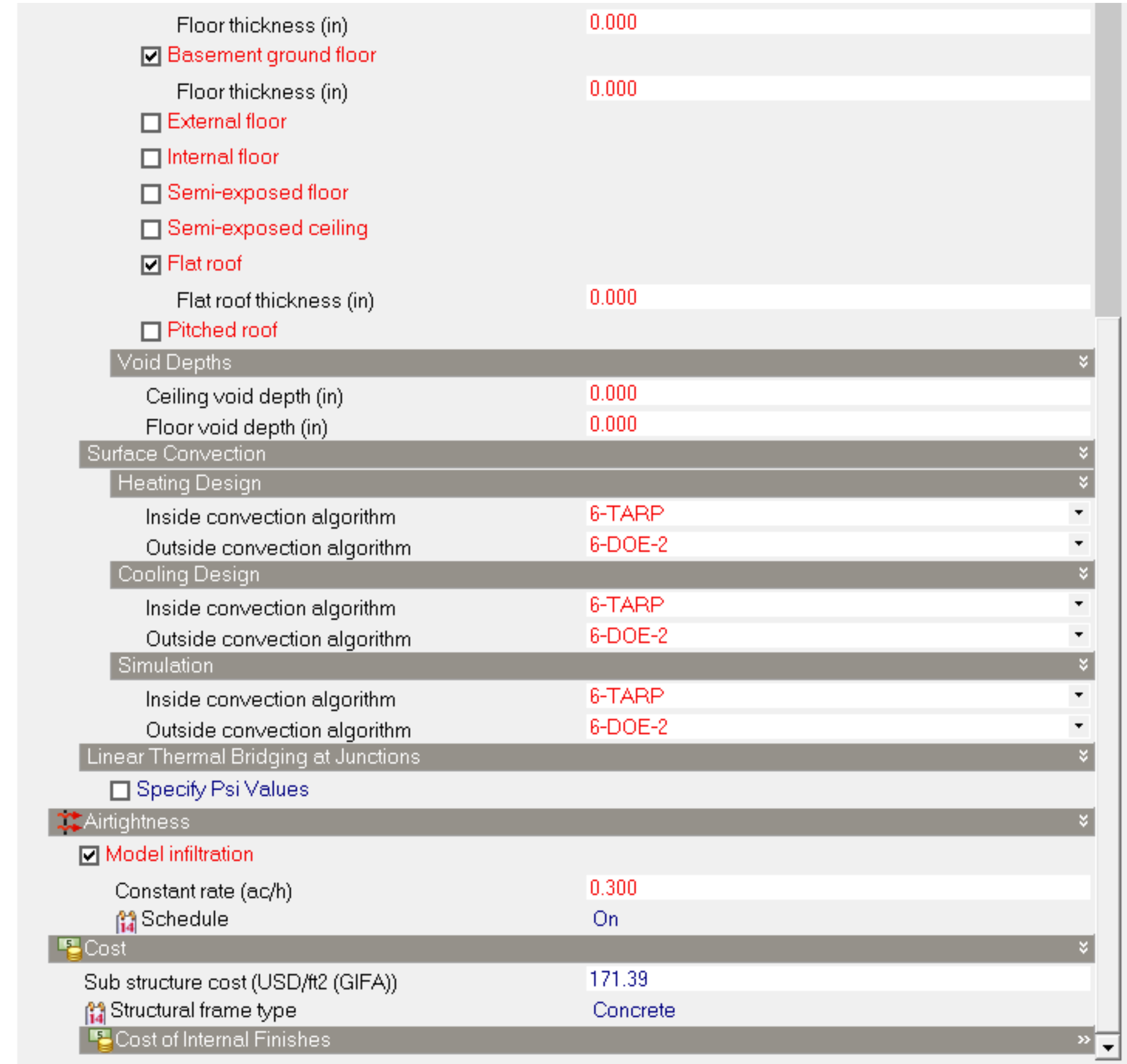
Appendix 13: Design Builder Simulations



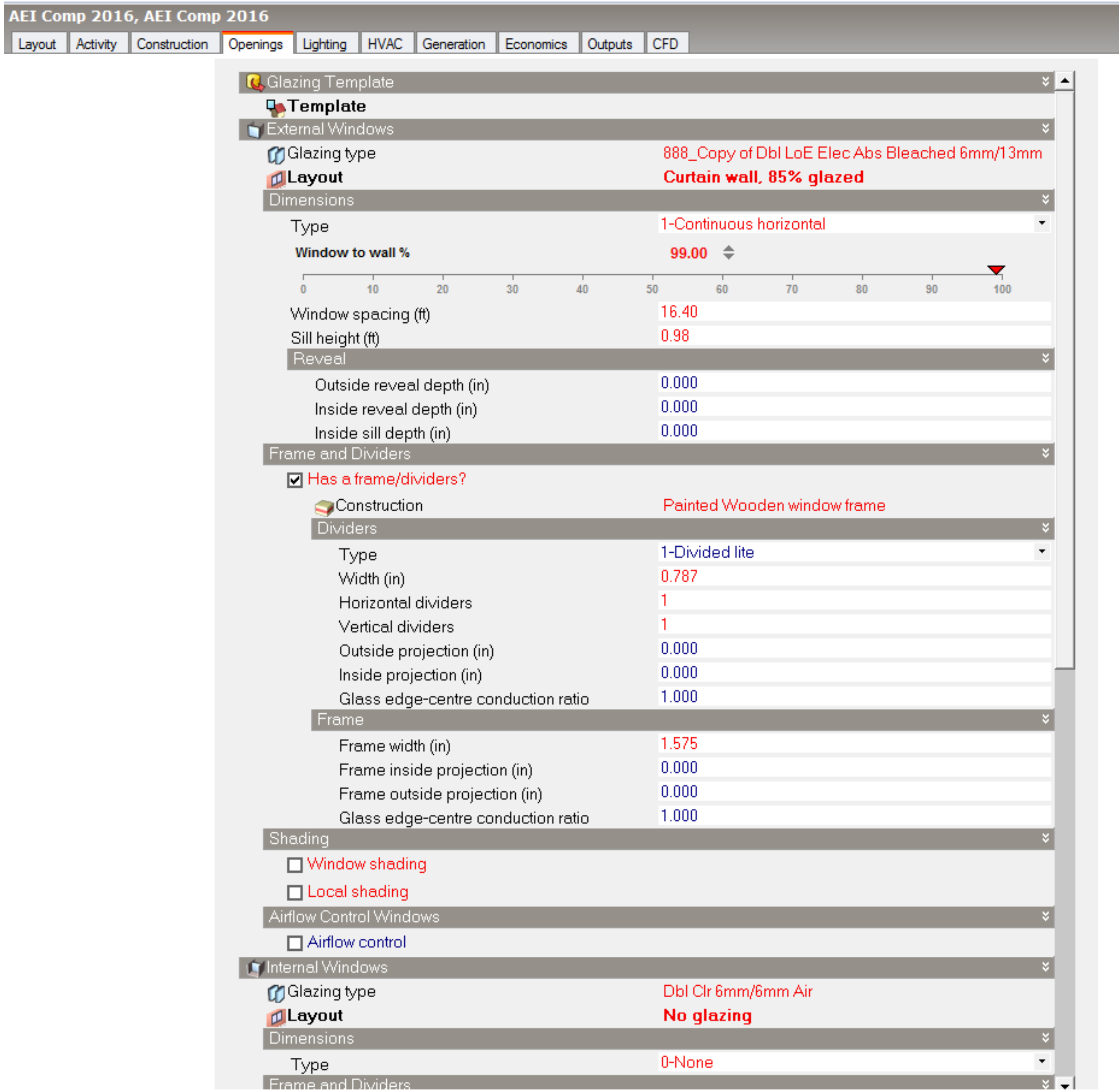


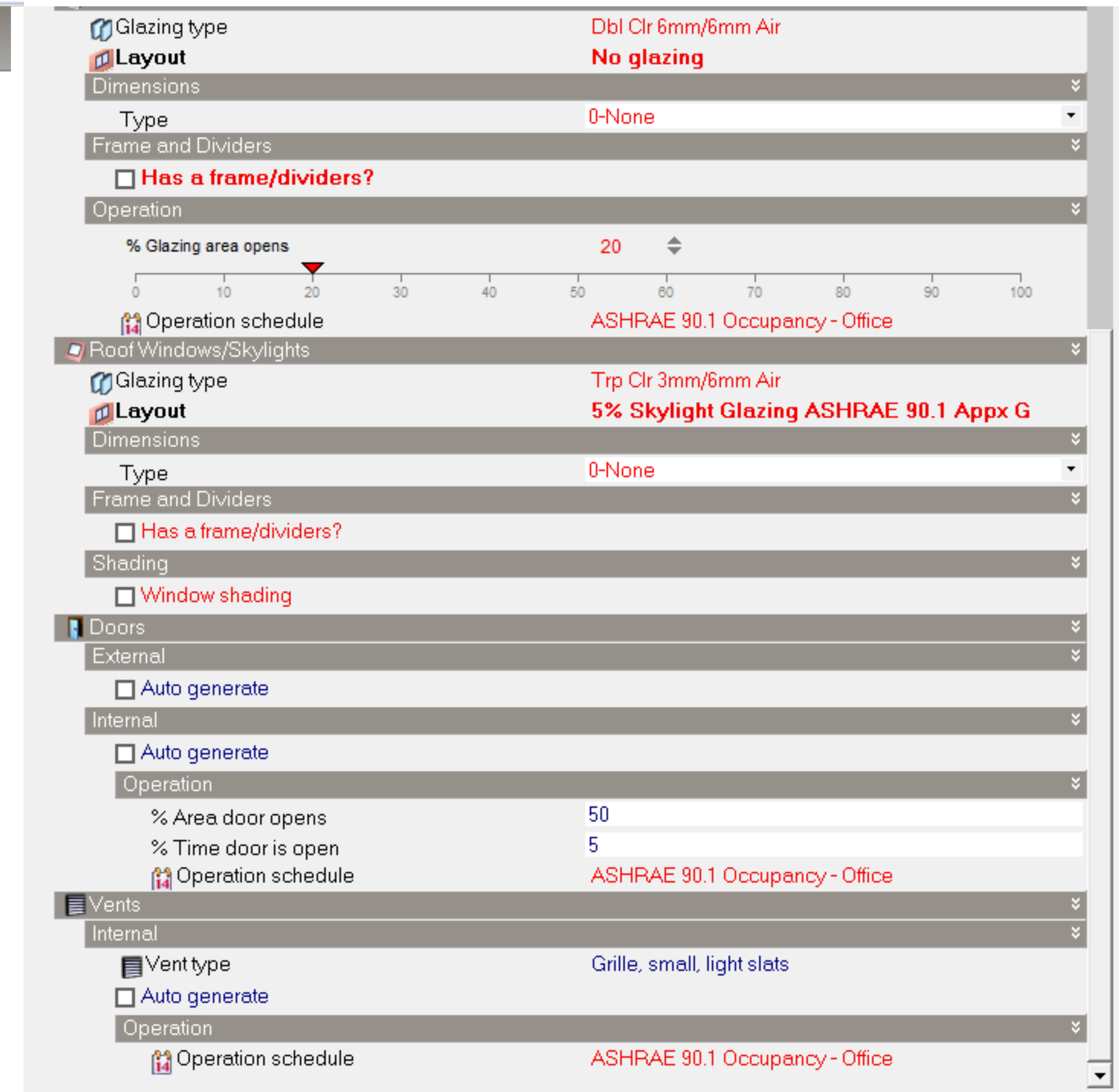
DesignBuilder Settings: Activity Tab



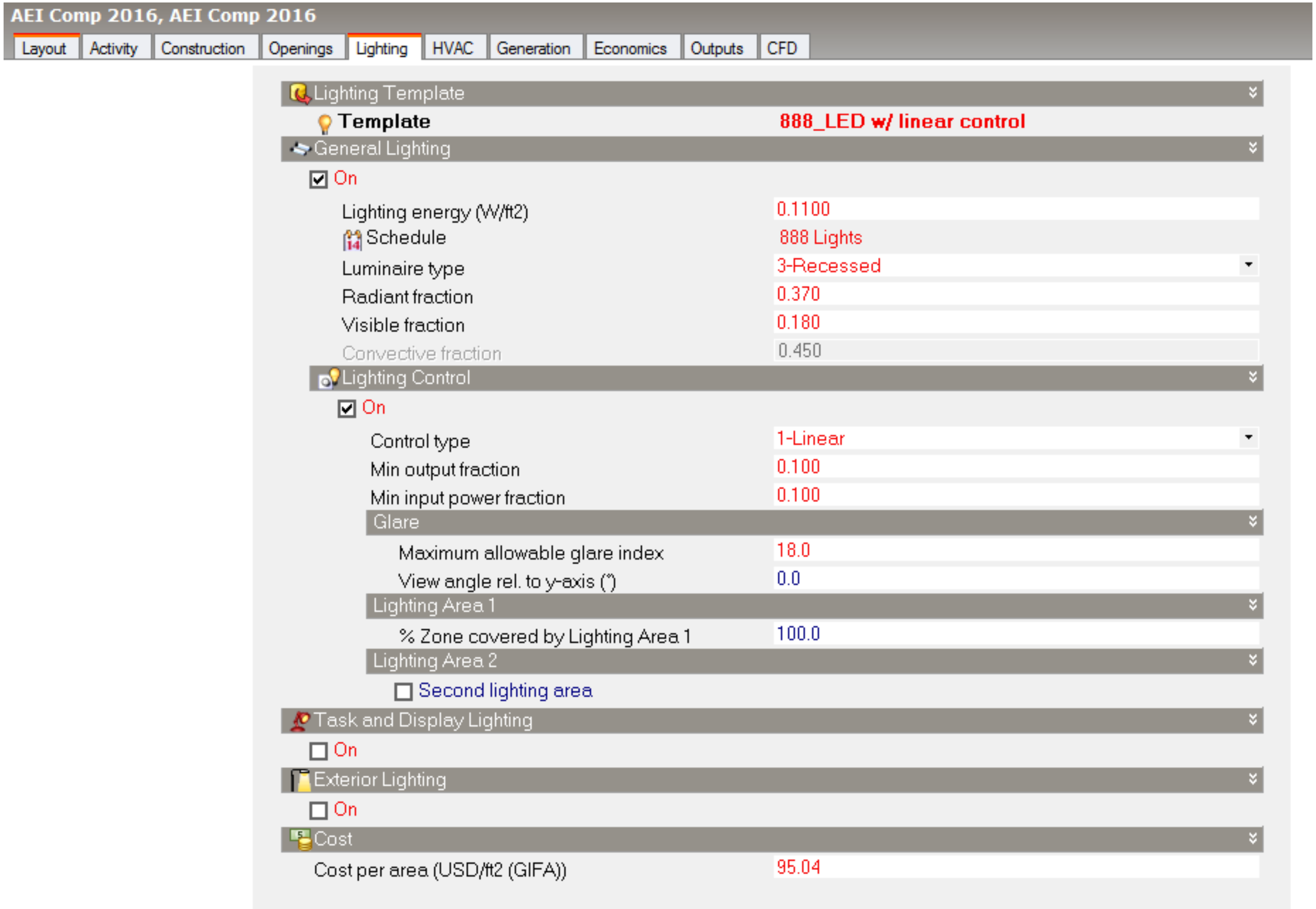


DesignBuilder Settings: Construction Tab

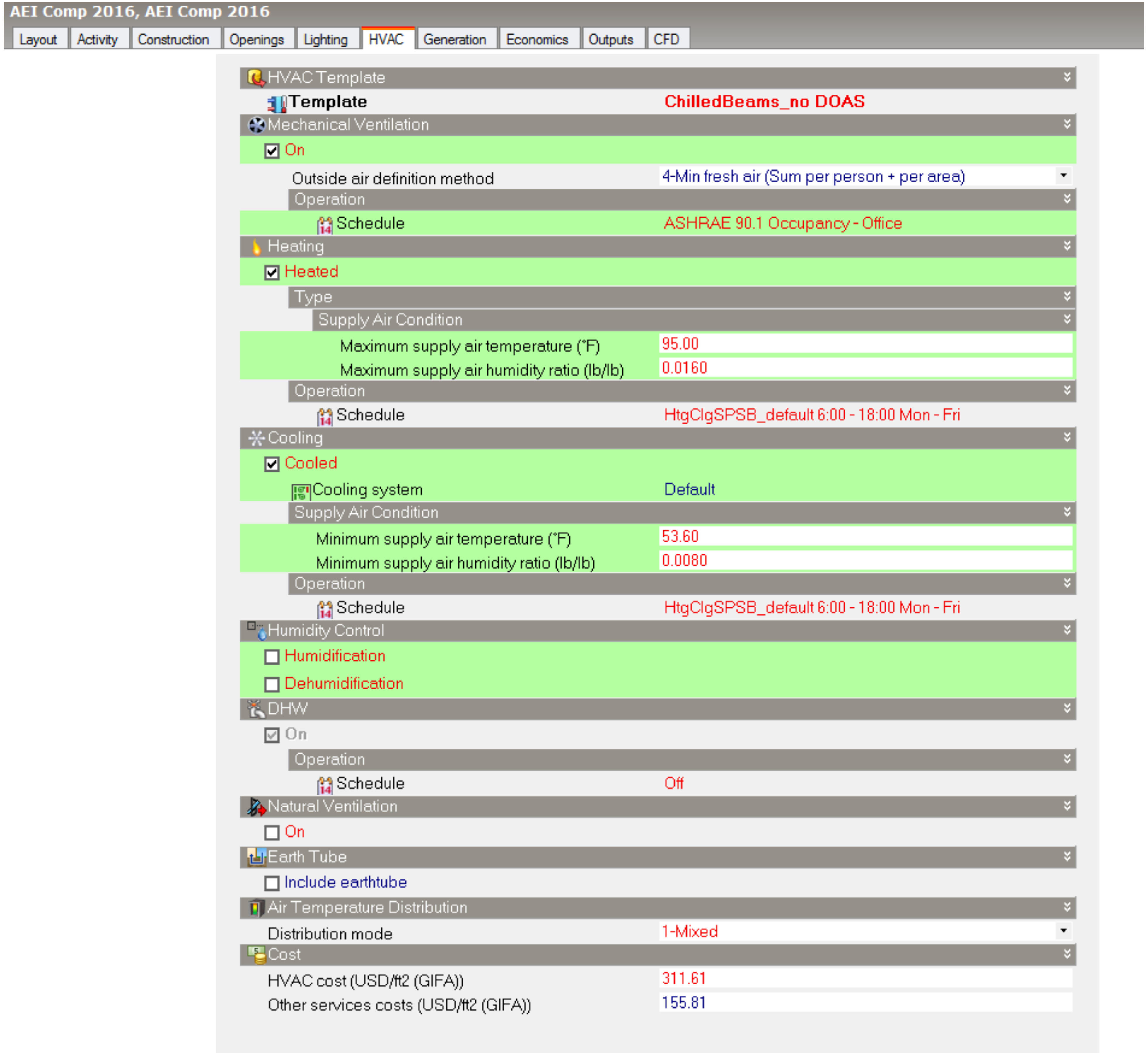




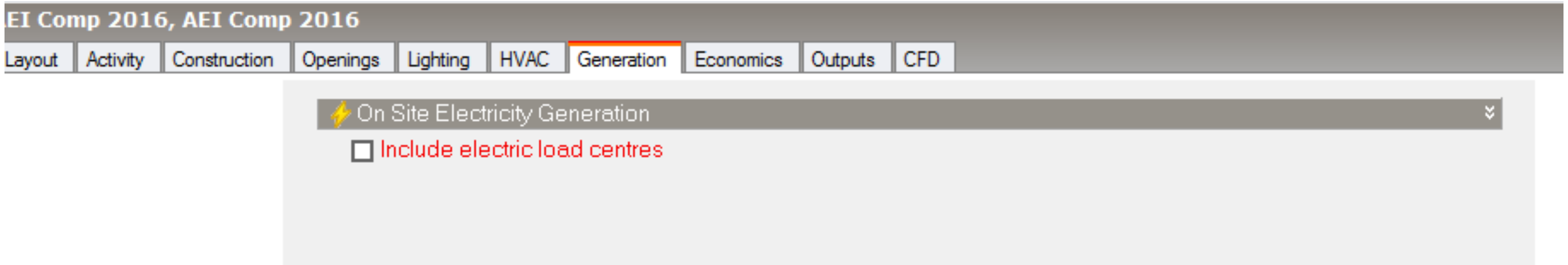
DesignBuilder Settings: Openings Tab



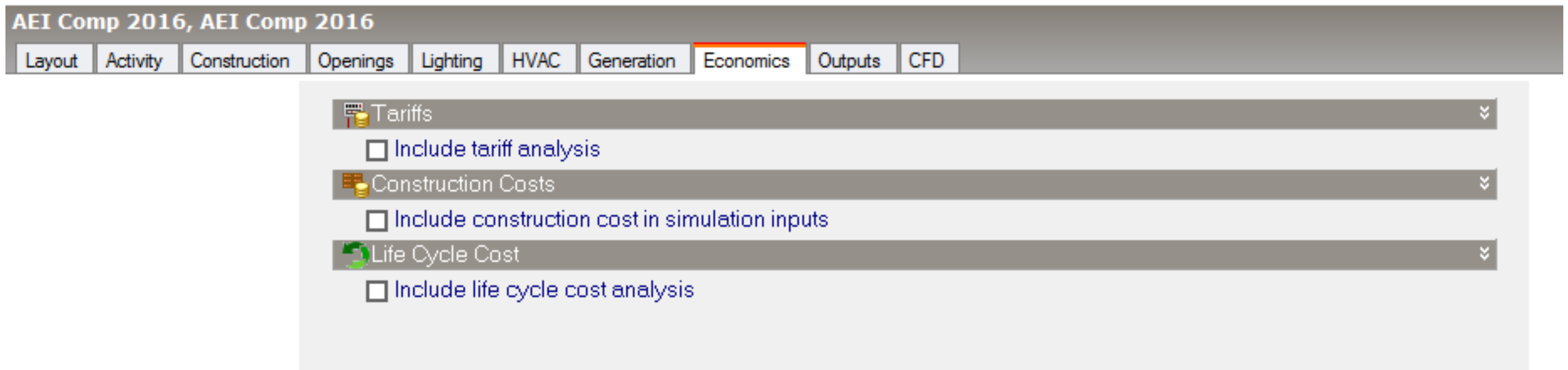
DesignBuilder Settings: Lighting Tab



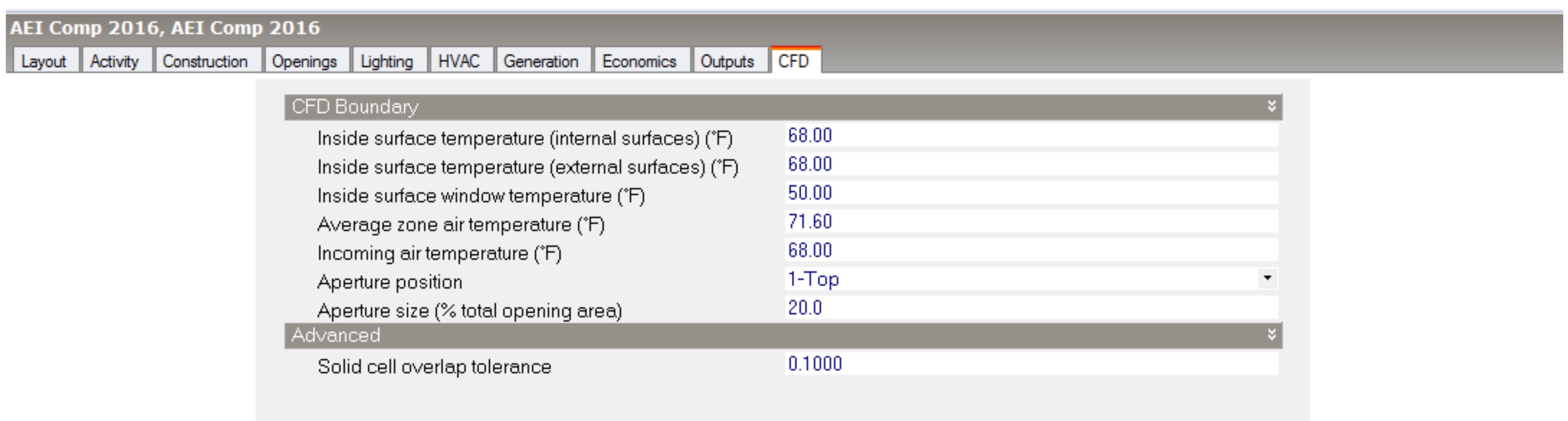
DesignBuilder Settings: HVAC Tab



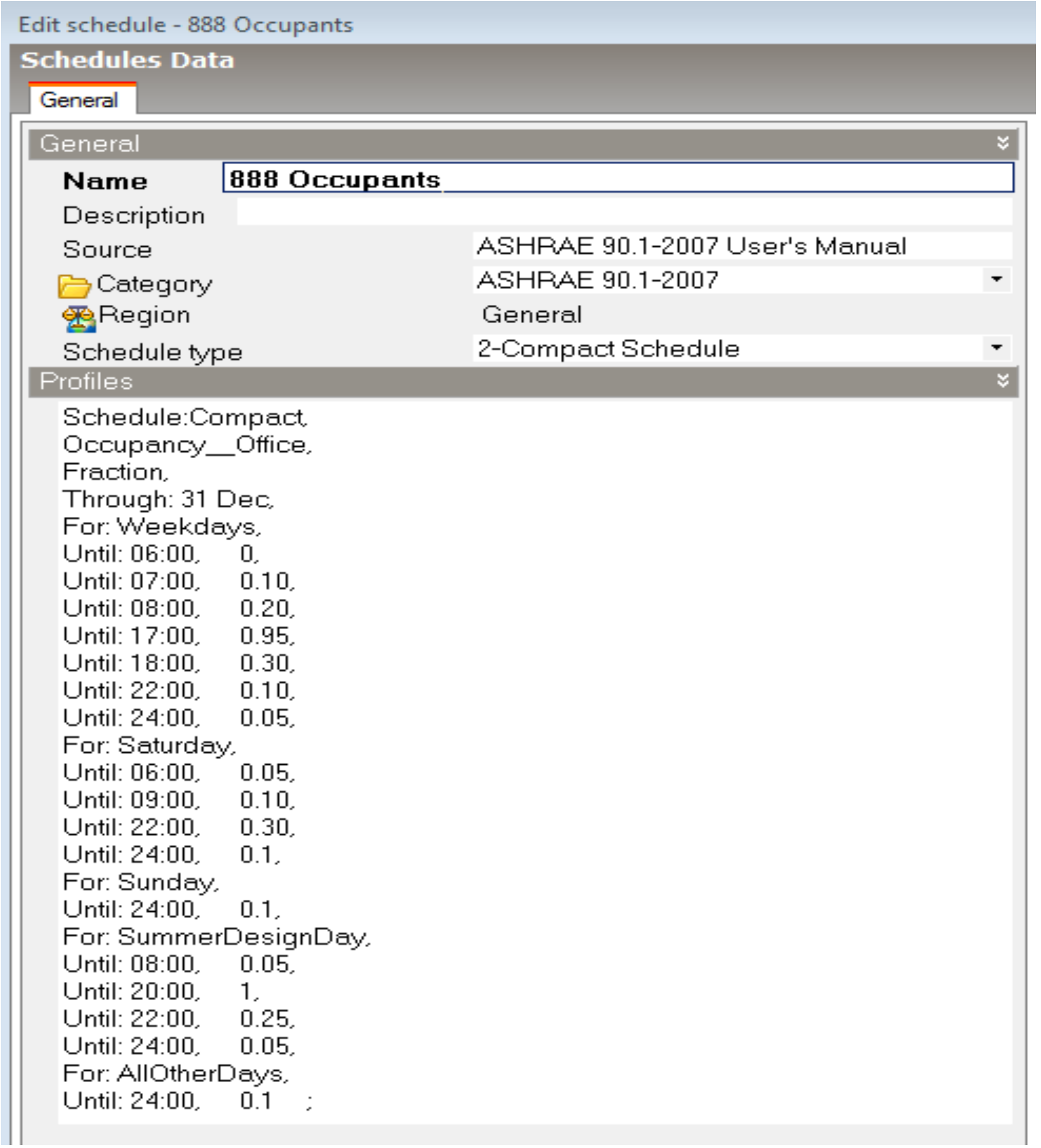
DesignBuilder Settings: Generation Tab



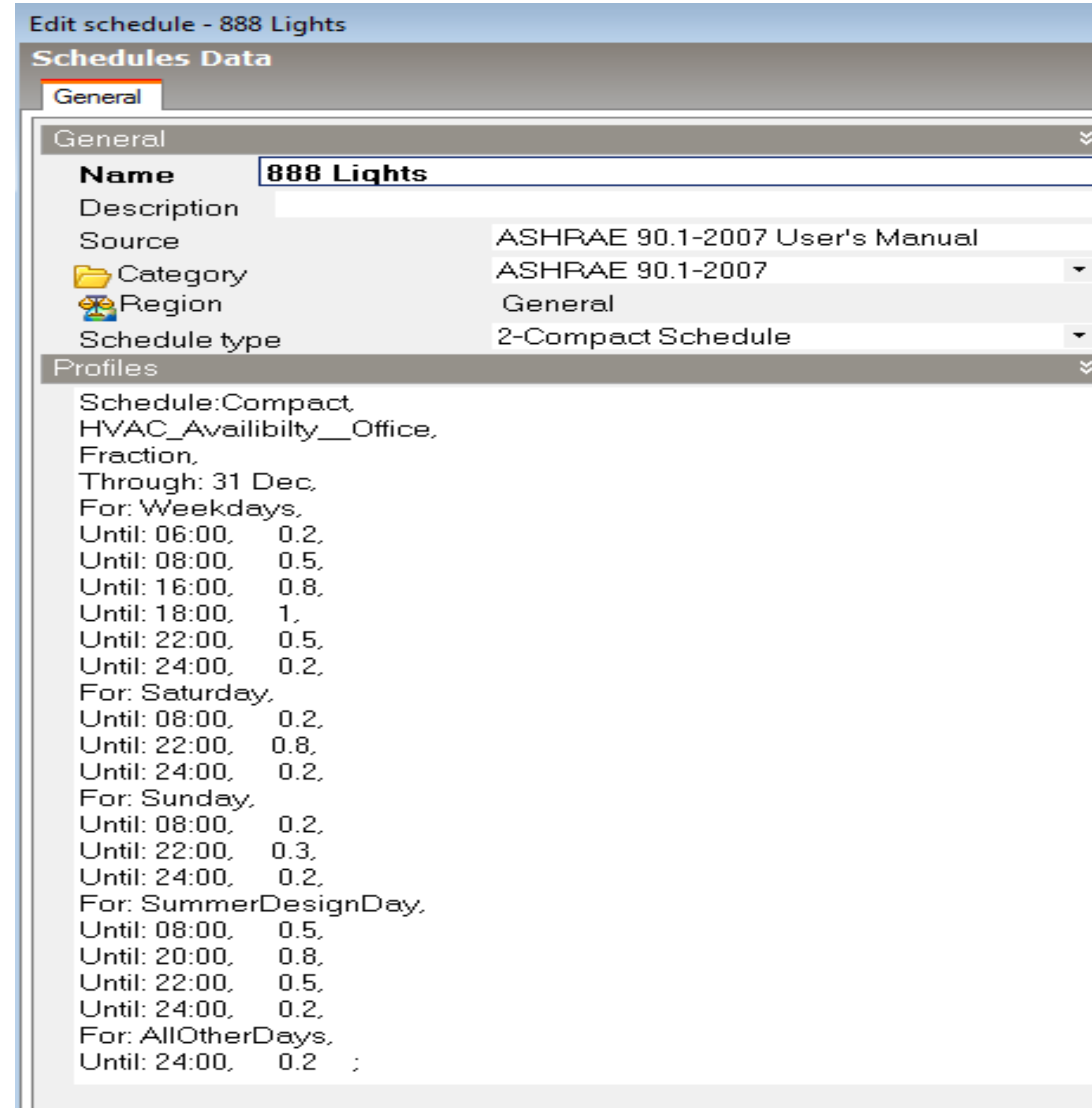
DesignBuilder Settings: Economics Tab



DesignBuilder Settings: Computer Fluid Dynamics (CFD) Tab



DesignBuilder Settings: Lights & Equipment Schedule



DesignBuilder Settings: Building & Occupancy Schedule

APPENDIX 14: Water Consumption and Fixture Selection

Table 1: Fixture Specifications for Baseline and Design

		# of Fixtues	Baseline	Design	Unit
RETAIL	Toilet	15	1.6	1.28	gpf
	Urinal	4	1	0	gpf
	Showerheads	8	2.5	2	gpm
	Bathroom Faucet	16	2.2	1.5	gpm
	Kitchen Faucet	5	2.2	1.5	gpm
OFFICE	Toilet	140	1.6	1.28	gpf
	Urinal	28	1	0	gpf
	Bathroom faucet	84	2.2	1.5	gpm

Table 2: Annual Water Consumption for Different Usage Areas

	Baseline (gallons/year)			Design (gallons/year)		
	Annual Flush Volume	Annual Flow Volume	Total Consumption	Annual Flush Volume	Annual Flow Volume	Total Consumption
Retail	195,275	156,344	351,619	105,120	106,598	211,718
Office	2,299,500	1,267,025	3,566,525	958,125	926,928	1,885,053
		Total=	3,918,144		Total=	2,096,772

Table 3:Flush and Flow Calculations for Fixtures

		person	day	flushes/day	flush/year	flush/year
FLUSH	female	100	365	2	73,000.0	82,125.00
	male	100	365	0.25	9,125.0	
		100	365	1.75	63,875.0	
	female	700	365	3	766,500.0	894,250.00
	male	700	365	0.5	127,750.0	
		700	365	2.5	638,750.0	
		person	day	minutes/day	minutes/year	minutes/year
FLOW	female	100	365	0.66	24,090.0	35,532.75
	male	100	365	0.066	2,409.0	
		100	365	0.248	9,033.8	
	female	700	365	0.33	84,315.0	333,427.50
	male	700	365	0.15	38,325.0	
		700	365	0.825	210,787.5	

STEP 1A - ENTER THE LANDSCAPED AREA (A)

23,738 Area of the designed landscape (square feet)

STEP 1B - ENTER THE AVERAGE MONTHLY REFERENCE EVAPOTRANSPIRATION (ET_o)

6.18 Average monthly reference ET (inches/month) for the site's peak watering month

Obtain from Water Budget Data Finder at www.epa.gov/watersense/nhspecs/wb_data_finder.html

OUTPUT - BASELINE FOR THE SITE

91,444 Monthly baseline (gallons/month) based on the site's peak watering month

OUTPUT - WATER ALLOWANCE FOR THE SITE

64,010 Monthly landscape water allowance (gallons/month) based on the site's peak watering month

Table 1. Landscape Water Requirement

Zone	Hydrozone/Landscape Feature Area (sq. ft.)	Plant Type or Landscape Feature	Landscape Coefficient (K_L)	Irrigation Type
1	140	Trees - Low water requirement	0.2	Drip - Standard
2	2,700	Turfgrass - Low water requirement	0.6	Micro Spray
3	19,154	Groundcover - Low water requirement	0.2	Micro Spray
4	1,744	Shrubs - Low water requirement	0.2	Drip - Standard

STEP 3A - REVIEW THE LWA AND LWR FROM PART 1 AND PART 2

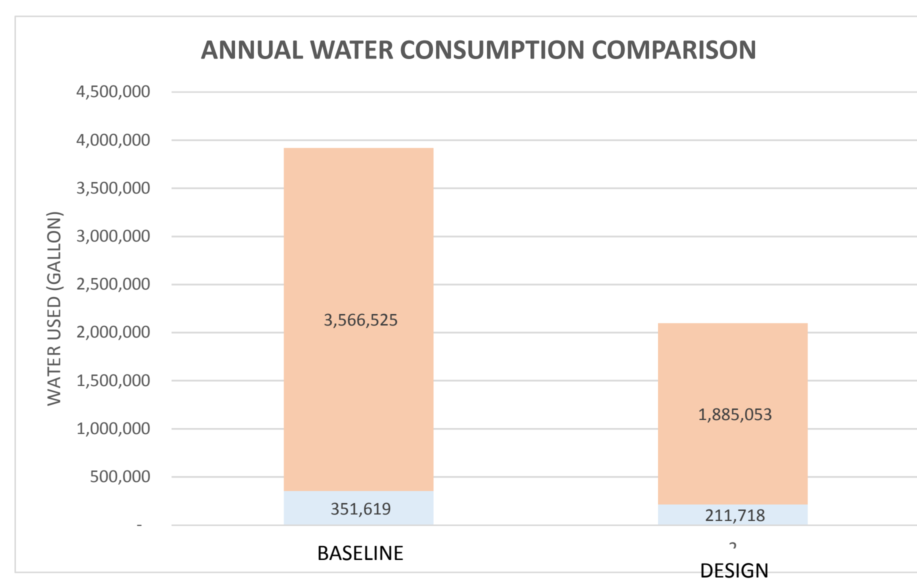
LWA 64,010 (gallons/month) LWR 17,908 (gallons/month)

OUTPUT - DOES THE DESIGNED LANDSCAPE MEET THE WATER BUDGET?

YES If YES, then the water budget criterion is met.

If NO, then the landscape and/or irrigation system needs to be redesigned to use less water.

The designed landscape water requirement is a 80% reduction in water use from the baseline calculated in Part 1.



46% reduction in water consumption by the bathroom and kitchen fixtures is achieved.

APPENDIX 15: Grey water and Rainwater Systems

Input Values	
Catchment area (ft²):	26,208.00
Collection efficiency (%):	95.00
Initial tank volume (gal):	-
Tank size (gal):	65,000.00
Plant water use coeff:	3.00
Irrigated area (ft²):	23,000.00
Monthly indoor demand (gal):	2,575,834.00

	Avg. monthly rainfall (in)	Avg. PET (in)	AC Condensate (gal)
January:	3.35	2.02	0
February:	3.27	2.71	0
March:	4.33	3	0
April:	3.74	5.23	0
May:	3.5	7.48	0
June:	3.66	8.08	0
July:	3.43	7.79	0
August:	3.35	7.78	0
September:	3.43	6.06	0
October:	3.94	4.9	0
November:	3.98	3.06	0
December:	3.78	2.12	0
Total:	**43.76**	**60.23**	**0**

Table: Rainwater and Tank Calculations

MINIMUM REQUIRED TANK SIZE CALCULATIONS:

	Rainwater (Gallons)	Greywater (Gallons)
January:	54,697.41	86,127.23
February:	53,391.20	86,127.23
March:	65,413.87	86,127.23
April:	61,065.16	86,127.23
May:	57,146.54	86,127.23
June:	59,758.96	86,127.23
July:	56,003.61	86,127.23
August:	54,697.41	86,127.23
September:	56,003.61	86,127.23
October:	64,330.68	86,127.23
November:	64,983.78	86,127.23
December:	61,718.27	86,127.23
Max Value	**65,413.87**	**86,127.23**

Minimum Tank Size (Gallons)	65,413.87

* Tank size for rainwater= avg. rainfall x cathment area x harvesting coefficient

Table: Rainwater Tank Product Specifications

SPECIFICATIONS							Processing Skid Dimensions (Inches)		
Model#	Processing Capacity (GPM)	Gallons Per Day*	Inlet PSI	Outlet Filtration (Microns)	Inlet Size (From Sump) Inches	Outlet Size (To Tank) Inches	Length	Width	Height
GW-600	10	7,200	35	10	2	1	72	36	84
GW-1200	20	14,400	35	10	2	1.5	72	36	84
GW-1800	30	21,600	35	10	2	1.5	96	36	96
GW-3000	50	36,000	35	10	2	2	96	36	96

Table: Greywater Filtration Product Specifications

Model	Diameter	Eave Height	Peak Height*	Capacity (Gallons)
WHS-FS/HR 602	6′	7′- 3″	8′ - 9″	1,400
WHS-FS/HR 603	6′	10′ - 9″	12′ - 4″	2,200
WHS-FS/HR 604	6′	14′ - 4″	15′ - 10″	2,900
WHS-FS/HR 801	8′	3′ - 8″	5′ - 10″	1,200
WHS-FS/HR 802	8′	7′ - 3″	9′ - 5″	2,500
WHS-FS/HR 803	8′	10′ - 9″	12′ - 11″	3,900
WHS-FS/HR 901	9′	3′ 8″	6′ 1″	1,500
WHS-FS/HR 902	9′	7′ - 3″	9′ 7″	3,200
WHS-FS/HR 903	9′	10′ - 9″	13′ 2″	4,900

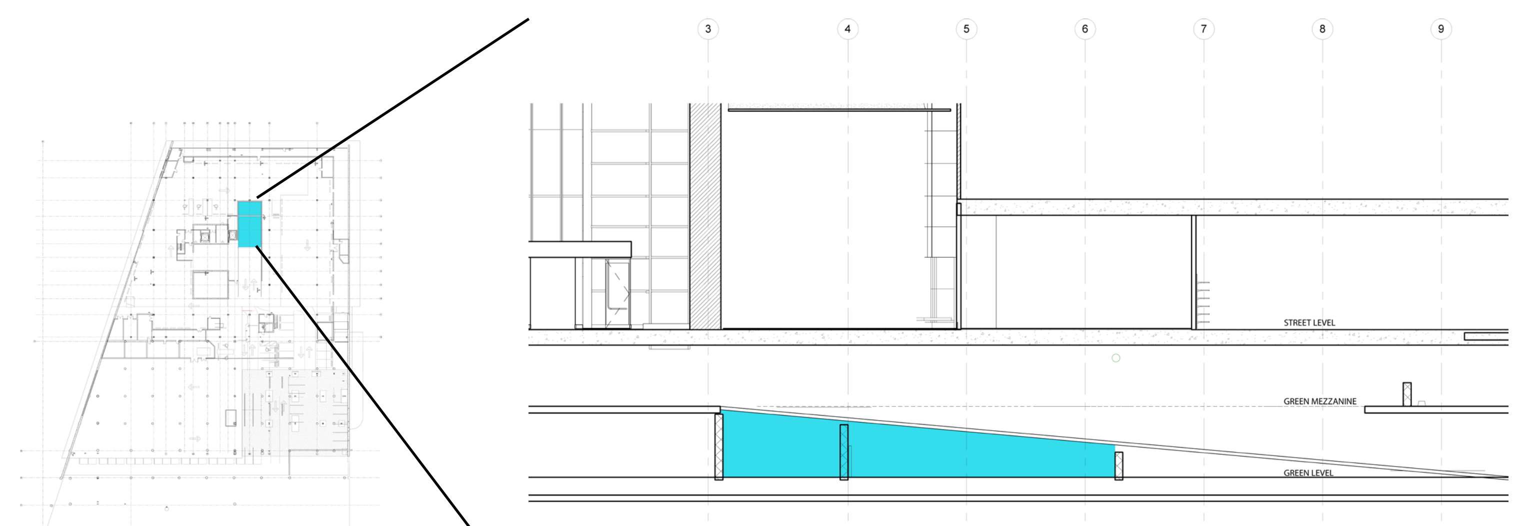


Figure: Tank Location in Green Level

APPENDIX 16: WIND TURBINE AND SOLAR PANEL PERFORMANCES

Table: Monthly Energy Production by the Wind Turbines

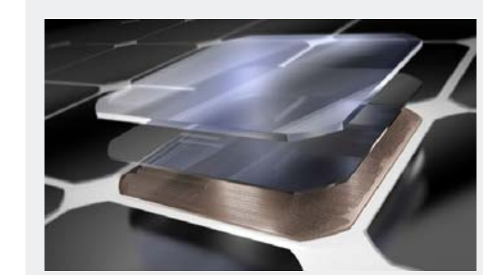
Month	Wind Speed (MPH)	Wind Speed (m/s)	Average Power (watts)	kWh per hour	kWh per day	kWh per month
January	13.6	6.080	1400	1.4	33.6	1008
February	13.5	6.035	1375	1.375	33	990
March	13.5	6.035	1375	1.375	33	990
April	13	5.812	1230	1.23	29.52	885.6
May	11.9	5.320	940	0.94	22.56	676.8
June	11.2	5.007	780	0.78	18.72	561.6
July	11	4.917	750	0.75	18	540
August	10.8	4.828	720	0.72	17.28	518.4
September	11.2	5.007	780	0.78	18.72	561.6
October	11.8	5.275	920	0.92	22.08	662.4
November	12.5	5.588	1100	1.1	26.4	792
December	13.2	5.901	1275	1.275	30.6	918
					Annual Total	9,104.40
				(14) Turbines	Annual Total	127,461.60

Table: Monthly Energy Production by the PV Panels

Month	Average Solar Radiaton (kWh/(m²)	Total Solar Panel Area (m²)	Solar Panel Yield	Performance Ratio	Energy Output (kWh/month)
January	1095	378.16	15%	0.69	42,857.82
February	1460			0.69	57,143.76
March	1642.5			0.75	69,876.88
April	1679			0.75	71,429.70
May	1679			0.75	71,429.70
June	1788.5			0.75	76,088.16
July	1861.5			0.75	79,193.79
August	1861.5			0.75	79,193.79
September	1679			0.75	71,429.70
October	1387			0.75	59,007.14
November	1131.5			0.75	48,137.40
December	1058.5			0.75	45,031.77
				Average	64,234.97

PV Panel Visuals

SPR-E20-327

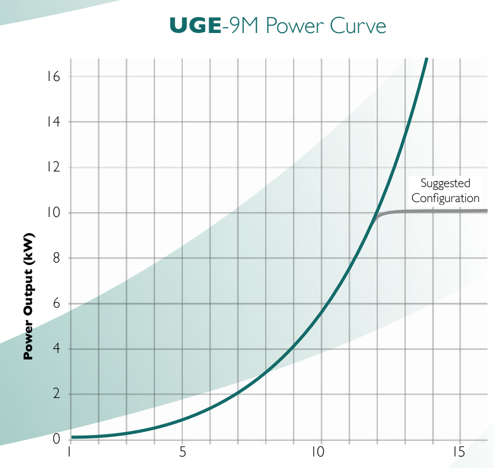


Maxeon® Solar Cells: Fundamentally better.

SPECIFICATIONS

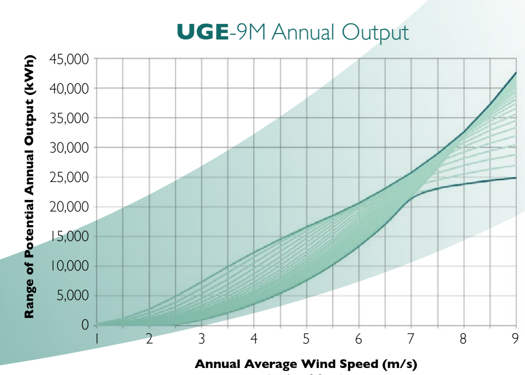
General

- Axis ____ Vertical
- Height ____ 9.6 m (31' 6")
- Width ____ 6.4 m (21')
- Swept Area ____ 61.4 m² (661.5 ft²)
- Weight ____ 4000 kg (8816 lb)
- Blade Materials ____ Carbon Fiber & Fiberglass with Steel reinforcement



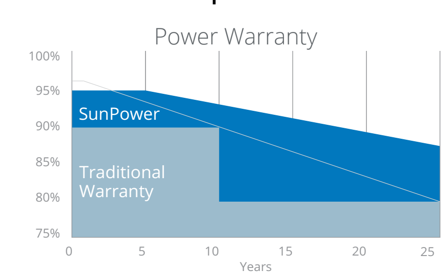
Performance

- Energy Output ____ 14,500 kWh/yr (at 5.5 m/s)
- Cut-In Wind Speed ____ 3.5 m/s (7.8 mph)
- Cut-Out Wind Speed ____ 30 m/s (67 mph)
- Rated RPM ____ 55 RPM
- Survival Wind Speed ____ 50 m/s (110 mph)



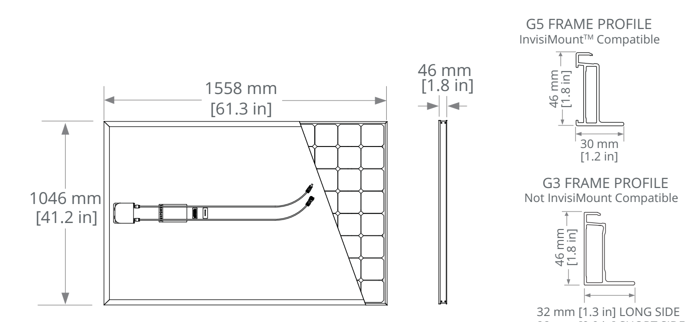
Electric Generation

PV Panel Specifications



More guaranteed power: 95% for first 5 years, -0.4%/yr. to year 25. 7

Electrical Data	SPR-E20-327	SPR-E19-320
Nominal Power (Pnom)[11]	327 W	320 W
Power Tolerance	+5/–0%	+5/–0%
Avg. Panel Efficiency[12]	20.4%	19.9%
Rated Voltage (Vmpp)	54.7 V	54.7 V
Rated Current (Impp)	5.98 A	5.86 A
Open-Circuit Voltage (Voc)	64.9 V	64.8 V
Short-Circuit Current (Isc)	6.46 A	6.24 A
Max. System Voltage	600 V UL & 1000 V IEC	
Maximum Series Fuse	15 A	
Power Temp Coef.	–0.38% / °C	
Voltage Temp Coef.	–176.6 mV / °C	
Current Temp Coef.	3.5 mA / °C	



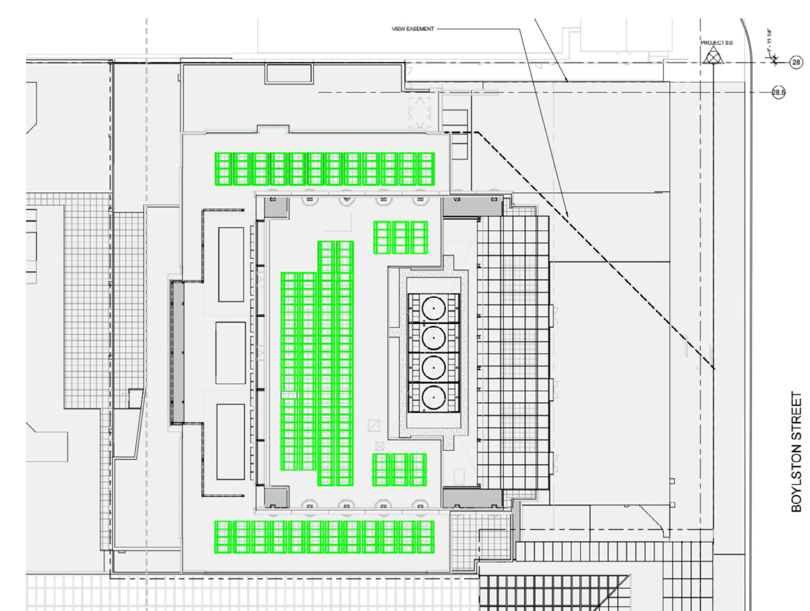


Figure: Rooftop PV Panel Layout

MECHANICAL SUBMITTAL DRAWING SHEETS

FLOOR 6 ACB Mech room location: semi-core Distribution System: ACB

DUCTROP

16-Feb-2016

	Ref #	ITEM	2009 ASHRAE duct code	Lngth or #	Duct Size Dia or Width	Height	BRANCH CFM	CFM	P/100'	Center-Line VEL	AVG VEL	VP	C	Fric dP	dVP	Cumulative	EQUIV DIAM
MECH1_1	A-Q																
	O.A.	duct		17.25	28	26		6,572	0.085	1390	1300	0.120		0.015		0.015	29.5
	O.A.	90, elbow			28	26		6,572	0.085	1390	1300	0.120	0.400	0.048	0.000	0.063	29.5
	O.A.	duct		17	28	26		6,572	0.085	1390	1300	0.120		0.015	0.000	0.077	29.5
	O.A.	90, elbow			28	26		6,572	0.085	1390	1300	0.120	0.400	0.048	0.000	0.126	29.5
	O.A.	duct		30.25	28	26		6,572	0.085	1390	1300	0.120		0.026	-0.018	0.133	29.5
1	Separator	equal, wye			20	20	3,241	3,331	0.105	1280	1200	0.102	0.297	0.030	0.000	0.163	21.9
2		45, elbow	CR3-6		20	20		3,331	0.105	1280	1200	0.102	0.340	0.035	-0.043	0.155	21.9
3		45, wye	SR5-3,b		16	14	1,914	1,416	0.090	970	910	0.059	0.390	0.023	0.000	0.178	16.4
4		45, elbow	CR3-6		16	14		1,416	0.090	970	910	0.059	0.340	0.020	0.000	0.197	16.4
5	ENTER	duct		1	16	14		1,416	0.090	970	910	0.059		0.001	0.000	0.198	16.4
6	A	45, elbow	CR3-6		16	14		1,416	0.090	970	910	0.059	0.035	0.002	0.000	0.200	16.4
7	AB	duct		2	16	14		1,416	0.090	970	910	0.059		0.002	0.000	0.202	16.4
8	B	45, elbow	CR3-6		16	14		1,416	0.090	970	910	0.059	0.034	0.002	0.000	0.204	16.4
9	BC	duct		25	16	14		1,416	0.090	970	910	0.059		0.022	-0.015	0.212	16.4
10	C	45, wye	SR5-3,b		14	12	501	915	0.082	840	780	0.044	0.024	0.001	0.000	0.213	14.2
11	CD	duct		0.5	14	12		915	0.082	840	780	0.044		0.000	0.000	0.213	14.2
12	D	45, elbow	CR3-6		14	12		915	0.082	840	780	0.044	0.030	0.001	0.000	0.215	14.2
13	DE	duct		11.25	14	12		915	0.082	840	780	0.044		0.009	0.000	0.224	14.2
14	E	45, elbow	CR3-6		14	12		915	0.082	840	780	0.044	0.030	0.001	0.000	0.225	14.2
15	EF	duct		2	14	12		915	0.082	840	780	0.044		0.002	0.000	0.227	14.2
16	F	45, elbow	CR3-6		14	12		915	0.082	840	780	0.044	0.031	0.001	0.000	0.228	14.2
17	FG	duct		27	14	12		915	0.082	840	780	0.044		0.022	-0.007	0.243	14.2
18	G	45, wye	SR5-3,b		12	12	193	723	0.077	770	720	0.037	0.023	0.001	0.000	0.244	13.1
19	GH	duct		1	12	12		723	0.077	770	720	0.037		0.001	0.000	0.245	13.1
20	H	45, elbow	CR3-6		12	12		723	0.077	770	720	0.037	0.033	0.001	0.000	0.246	13.1
21	HI	duct		13	12	12		723	0.077	770	720	0.037		0.010	-0.003	0.253	13.1
22	I	tee, straight	SR5-13		12	10	144	578	0.080	740	690	0.034	0.035	0.001	0.000	0.255	12.0
23	IJ	duct		11.67	12	10		578	0.080	740	690	0.034		0.009	0.000	0.264	12.0
24	J	tee, straight	SR5-13		10	9	144	434	0.094	740	690	0.034	0.034	0.001	0.000	0.265	10.4
25	JK	duct		10.58333	10	9		434	0.094	740	690	0.034		0.010	0.000	0.275	10.4
26	K	45, elbow	CR3-6		10	9		434	0.094	740	690	0.034	0.034	0.001	0.000	0.276	10.4
27	KL	duct		2	10	9		434	0.094	740	690	0.034		0.002	0.000	0.278	10.4
28	L	45, elbow	CR3-6		10	9		434	0.094	740	690	0.034	0.033	0.001	0.000	0.279	10.4
29	LM	duct		2	10	9		434	0.094	740	690	0.034		0.002	0.000	0.281	10.4
30	M	90, elbow			10	9		434	0.094	740	690	0.034	0.040	0.001	0.000	0.283	10.4
31	MN	duct, vertical		1.5	10	9		434	0.094	740	690	0.034		0.001	0.000	0.284	10.4
32	N	90, elbow			10	9		434	0.094	740	690	0.034	0.040	0.001	0.000	0.285	10.4
33	NO	duct		1.083333	9	10		434	0.094	740	690	0.034		0.001	-0.015	0.271	10.4
34	O	tee, straight	SR5-13		9	9	145	289	0.059	550	510	0.019	0.034	0.001	0.000	0.272	9.8
35	OP	duct		3.666667	9	9		289	0.059	550	510	0.019		0.002	-0.014	0.260	9.8
36	P	tee, straight	SR5-13		9	9	145	145	0.016	270	260	0.005	0.033	0.000	0.000	0.260	9.8
37	PQ	duct		3.666667	9	9		145	0.016	270	260	0.005		0.001	0.000	0.260	9.8
38	Q	90, elbow			9	9		145	0.016	270	260	0.005	0.035	0.000		0.260	9.8
Total				**183.42**				**3,331**	**0.081**	**1,390**	**1,300**					**0.260**	
MECH1_2	A-N																
	O.A.	duct		17.25	28	26		6,572	0.085	1390	1300	0.120		0.015		0.015	29.5
	O.A.	90, elbow			28	26		6,572	0.085	1390	1300	0.120	0.400	0.048	0.000	0.063	29.5
	O.A.	duct		17	28	26		6,572	0.085	1390	1300	0.120		0.015	0.000	0.077	29.5
	O.A.	90, elbow			28	26		6,572	0.085	1390	1300	0.120	0.400	0.048	0.000	0.126	29.5
1	O.A.	duct		30.25	28	26		6,572	0.085	1390	1300	0.120		0.026	-0.025	0.127	29.5
2	Separator	equal, wye			20	20	3,331	3,241	0.099	1240	1170	0.096	0.297	0.028	0.000	0.155	21.9
3		45, elbow	CR3-6,		20	20		3,241	0.099	1240	1170	0.096	0.340	0.033	-0.016	0.172	21.9
4		45, wye	SR5-3,		16	16	1,351	1,890	0.109	1130	1060	0.080	0.390	0.031	0.000	0.203	17.5
5	ENTER	duct		0.916667	16	16		1,890	0.109	1130	1060	0.080	0.340	0.028	-0.027	0.204	17.5
6	A	45, wye	SR5-3,		16	16	358	1,533	0.075	920	860	0.053	0.024	0.001	0.000	0.205	17.5
7	AB	duct		24.33333	16	16		1,533	0.075	920	860	0.053		0.018	-0.008	0.216	17.5
8	B	45, wye	SR5-3,		12	10	870	663	0.102	850	800	0.045	0.024	0.001	0.000	0.217	12.0
9	BC	duct		16	12	10		663	0.102	850	800	0.045		0.016	0.000	0.233	12.0
10	C	45, elbow	CR3-6,		12	10		663	0.102	850	800	0.045	0.034	0.002	0.000	0.235	12.0
11	CD	duct		2	12	10		663	0.102	850	800	0.045		0.002	0.000	0.237	12.0
12	D	45, elbow	CR3-6,		12	10		663	0.102	850	800	0.045	0.031	0.001	0.000	0.238	12.0
13	DE	duct		3.5	12	10		663	0.102	850	800	0.045		0.004	-0.014	0.228	12.0
14	E	tee, straight	SR5-13,		12	10	112	551	0.074	710	660	0.031	0.034	0.001	0.000	0.229	12.0
15	EF	duct		10.5	12	10		551	0.074	710	660	0.031		0.008	0.004	0.241	12.0
16	F	tee, straight	SR5-13,		10	9	112	439	0.097	750	700	0.035	0.034	0.001	0.000	0.242	10.4
17	FG	duct		10.5	10	9		439	0.097	750	700	0.035		0.010	-0.005	0.247	10.4
18	G	tee, straight	SR5-13,		9	8	112	327	0.097	700	650	0.031	0.034	0.001	0.000	0.248	9.3
19	GH	duct		10.6	9	8		327	0.097	700	650	0.031		0.010	-0.003	0.256	9.3
20	H	tee, straight	SR5-13,		8	7	82	245	0.104	670	630	0.028	0.034	0.001	0.000	0.257	8.2
21	HI	duct		10.58333	8	7		245	0.104	670	630	0.028		0.011	-0.012	0.256	8.2
22	I	tee, straight	SR5-13,		7	7	82	164	0.069	510	480	0.016	0.033	0.001	0.000	0.257	7.7
23	IJ	duct		10.58333	7	7		164	0.069	510	480	0.016		0.007	-0.005	0.259	7.7
24	J	tee, straight	SR5-13,		6	5	82	82	0.065	420	390	0.011	0.033	0.000	0.000	0.259	6.0
25	JK	duct		9.666667	6	5		82	0.065	420	390	0.011		0.006	0.000	0.266	6.0
26	K	45, elbow	CR3-6,		6	5		82	0.065	420	390	0.011	0.034	0.000	0.000	0.266	6.0
27	KL	duct		2	6	5		82	0.065	420	390	0.011		0.001	0.000	0.267	6.0
28	L	45, elbow	CR3-6,		6	5		82	0.065	420	390	0.011	0.033	0.000	0.000	0.268	6.0
29	LM	duct		3.583333	6	5		82	0.065	420	390	0.011		0.002	0.000	0.270	6.0
30	M	90, elbow			6	5		82	0.065	420	390	0.011	0.045	0.000	0.000	0.271	6.0
31	MN	duct, vertical		1.5	6	5		82	0.065	420	390	0.011		0.001		0.272	6.0
Total				**180.7667**				**3,241**	**0.086**	**1,390**	**1,300**					**0.272**	
MECH2_1	A-J																
1		duct		44.58333	30	22		5,992	0.092	1400	1310	0.122		0.041		0.041	28.0
2	Separator	equal, wye			20	20	2,868	3,125	0.093	1200	1120	0.090	0.297	0.027	0.000	0.068	21.9
3		45, elbow	CR3-6		20	20		3,125	0.093	1200	1120	0.090	0.340	0.031	-0.030	0.068	21.9
4		45, wye	SR5-3		16	16	1,489	1,636	0.084	980	920	0.060	0.390	0.023	0.000	0.092	17.5
5	ENTER	duct		5.333333	16	16		1,636	0.084	980	920	0.060		0.004	-0.012	0.085	17.5
6	A	45, wye	SR5-3		14	14	514	1,122	0.081	880	820	0.048	0.024	0.001	0.000	0.086	15.3
7	AB	duct		13.58333	14	14		1,122	0.081	880	820	0.048		0.011	-0.013	0.083	15.3
8	B	45, wye	SR5-3		12	10	536	586	0.082	750	700	0.035	0.022	0.001	0.000	0.084	12.0
9	BC	duct		6.833333	12	10		586	0.082	750	700	0.035		0.006	0.000	0.090	12.0
10	C	45, elbow	CR3-6		12	10		586	0.082	750	700	0.035	0.034	0.001	0.000	0.091	12.0
11	CD	duct		2	12	10		586	0.082	750	700	0.035		0.002	0.000	0.093	12.0
12	D	45, elbow	CR3-6		12	10		586	0.082	750	700	0.035	0.034	0.001	0.000	0.094	12.0
13	DE	duct		14.33333	12	10		586	0.082	750	700	0.035		0.012	-0.007	0.098	12.0
14	E	tee, straight	SR5-13		10	10	148	439	0.074	670	630	0.028	0.034	0.001	0.000	0.099	10.9
15	EF	duct		9.75	10	10		439	0.074	670	630	0.028		0.007	-0.004	0.103	10.9
16	F	45, wye	SR5-3		9	8	148	291	0.078	620	580	0.024	0.023	0.001	0.000	0.103	9.3
17	FG	duct		15.66667	9	8		291	0.078	620	580	0.024		0.012	-0.006	0.109	9.3
18	G	45, wye	SR5-3		7	6	145	145	0.081	530	500	0.018	0.012	0.000	0.000	0.109	7.1
19	GH	duct		10.58333	7	6		145	0.081	530	500	0.018		0.009	0.000	0.118	7.1
20	H	45, elbow	CR3-6		7	6		145	0.081	530	500	0.018	0.034	0.001	0.000	0.118	7.1
21	HI	duct		2	7	6		145	0.081	530	500	0.018		0.002	0.000	0.120	7.1
22	I	45, elbow	CR3-6		7	6		145	0.081	530	500	0.018	0.044	0.001	0.000	0.121	7.1
23	IJ	duct		7.583333	7	6		145	0.081	530	500	0.018		0.006	0.000	0.127	7.1
24	J	90, elbow			7	6		145	0.081	530	500	0.018	0.045	0.001	0.000	0.128	7.1
25	JK	duct		1.5	7	6		145	0.081	530	500	0.018		0.001	0.000	0.129	7.1
26	K	90, elbow			7	6		145	0.081	530	500	0.018	0.043	0.001	0.000	0.130	7.1
27	KL	duct		0.666667	7	6		145	0.081	530	500	0.018		0.001	0.000	0.130	7.1
28	L	tee, straight	SR5-13		7	6		145	0.081	530	500	0.018	0.035	0.001	0.000	0.131	7.1
29	LM	duct		3.833333	7	6		145	0.081	530	500	0.018		0.003	0.000	0.134	7.1
30	M	tee, straight	SR5-13		7	6		145	0.081	530	500	0.018	0.033	0.001	0.000	0.135	7.1
31	MN	duct		4.166667	7	6		145	0.081	530	500	0.018		0.003		0.138	7.1
Total				**142.4167**				**3,125**	**0.082**	**1,400**	**1,310**					**0.138**	
MECH2_2	A-H																
	O.A.	duct		44.58333	30	22		5,992	0.092	1400	1310	0.122		0.041		0.041	28.0
1	Separator	equal, wye			20	20	3,125	2,868	0.080	1100	1030	0.075	0.297	0.022	0.017	0.081	21.9
2		45, elbow	CR3-6		20	18		2,868	0.102	1220	1150	0.093	0.340	0.032	-0.030	0.082	20.7
3		45, wye	SR5-3,b		16	16	1,195	1,672	0.087	1000	940	0.062	0.390	0.024	0.000	0.106	17.5
4		45, elbow	CR3-6		16	16		1,672	0.087	1000	940	0.062	0.340	0.021	0.000	0.127	17.5
5	ENTER	duct		0.583333	16	16		1,672	0.087	1000	940	0.062		0.001	0.000	0.128	17.5
6	A	45, elbow	CR3-6		16	16		1,672	0.087	1000	940	0.062	0.033	0.002	0.000	0.130	17.5
7	AB	duct		2	16	16		1,672	0.087	1000	940	0.062		0.002	0.000	0.132	17.5
8	B	45, elbow	CR3-6		16	16		1,672	0.087	1000	940	0.062	0.032	0.002	0.000	0.134	17.5
9	BC	duct		23.16667	16	16		1,672	0.087	1000	940	0.062		0.020	0.000	0.154	17.5
10	C	45, wye	SR5-3		16	14	208	1,465	0.095	1000	940	0.062	0.023	0.001	0.000	0.155	16.4
11	CD	duct		3.25	16	14		1,465	0.095	1000	940	0.062		0.003	-0.008	0.150	16.4
12	D	45, wye	SR5-3		14	14	280	1,184	0.090	930	870	0.054	0.022	0.001	0.000	0.151	15.3
13	DE	duct		17.75	14	14		1,184	0.090	930	870	0.054		0.016	-0.014	0.153	15.3
14	E	45, wye	SR5-3,b		14	12	315	870	0.075	800	750	0.040	0.020	0.001	0.000	0.154	14.2
15	EF	duct		0.916667	14	12		870	0.075	800	750	0.040		0.001	0.000	0.155	14.2
16	F	45, elbow	CR3-6		14	12		870	0.075	800	750	0.040		0.000	0.000	0.155	14.2
17	FG	duct		7	14	12		870	0.075	800	750	0.040		0.005	-0.006	0.154	14.2
18	G	tee, straight	SR5-13		12	10	290	580	0.080	740	700	0.034	0.036	0.001	0.000	0.155	12.0
19	GH	duct		14	12	10		580	0.080	740	700	0.034		0.011	-0.010	0.156	12.0
20	H	tee, straight	SR5-13		9	8	290	290	0.078	620	580	0.024	0.035	0.001	0.000	0.157	9.3
21	HI	duct		14.16667	9	8		290	0.078	620	580	0.024		0.011	0.000	0.168	9.3
22	I	90, elbow			9	8		290	0.078	620	580	0.024	0.042	0.001	0.000	0.169	9.3
23	IJ	duct,vertical		1.5	9	8		290	0.078	620	580	0.024		0.001		0.170	9.3
Total				**128.9167**				**2,868**	**0.084**	**1,400**	**1,310**					**0.170**	

SUMMARY

		CFM		Duct Length (ft.)	Fitting #	Pressure Drop	
MECH1	6,572	**MECH1_1**	3,331	183.42	23	0.260	
		MECH1_2	3,241	180.77	18	0.272	0.272
MECH2	5,992	**MECH2_1**	3,125	142.42	16	0.138	
		MECH2_2	2,868	128.92	13	0.170	0.170
TOTAL	**12,564**		**12,564**	**635.52**	**70**		

1 Typical Office Floor Primary Air Duct Sizing

Equipment	ASHRAE 90.1 2007 - Base Case (kW)	Proposed Design (kW)
Cooling		
Absorption chillers	1,969.44	1,643.40
Cooling towers	3,516.80	974.91
VAV system fans	47.74	11.94
DOAS	0.00	35.81
Relief/spill fans	23.87	23.87
Chilled water pumps	23.87	23.87
Condensing water pumps	23.87	23.87
Servers	13.42	13.42
Elevator cooling	105.50	105.50
Heating		
VAV system fans	23.87	0.00
Condensing boiler	78.33	78.33
Hot water pumps	9.33	18.65
Miscellaneous heaters	1.86	1.86
Fans (other)		
Kitchen exhaust	11.20	11.20
Toilet exhaust	3.73	3.73
Miscellaneous heaters	3.73	3.73
Garage ventilation	52.75	52.75
Plumbing		
Domestic hot water booster	11.20	11.20
Water cooler	0.50	0.50
Elevator	9.70	9.70
Lighting		
Interior lighting	505.37	58.94
Exterior lighting	3.50	2.10
Garage lighting	48.12	11.55
Plug loads	147.34	122.80
Energy Sources		
Cogeneration - auxiliaries	0.00	14.92
Cogeneration - dry cooler	0.00	7.46
Wind turbines	0.00	-14.55
Solar panels	0.00	-7.10
Total	**6,635**	**3,244**
% Energy Use Reduction	**51.10%**	

2 Total Power Consumption

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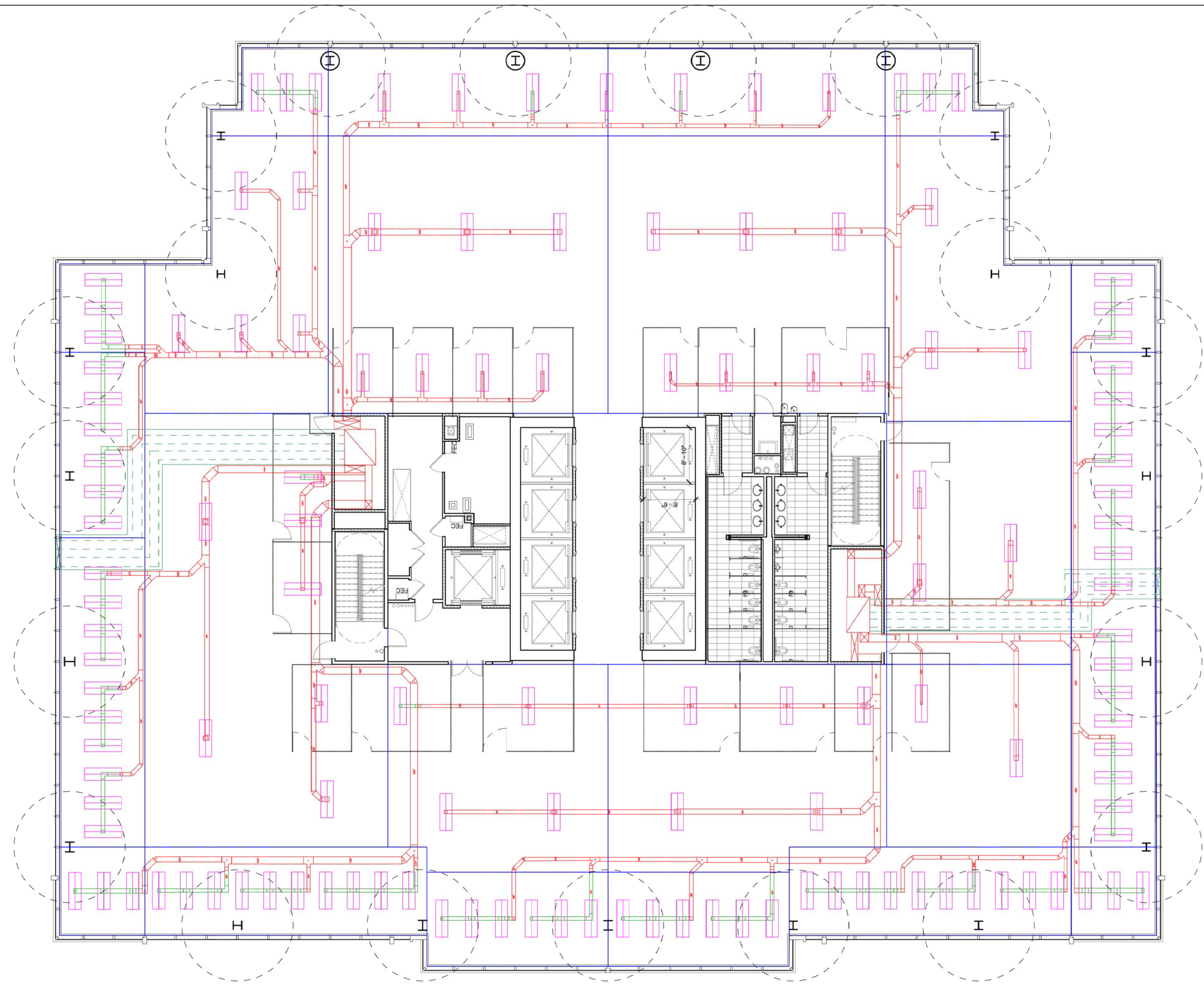
Additional HVAC Design Tables

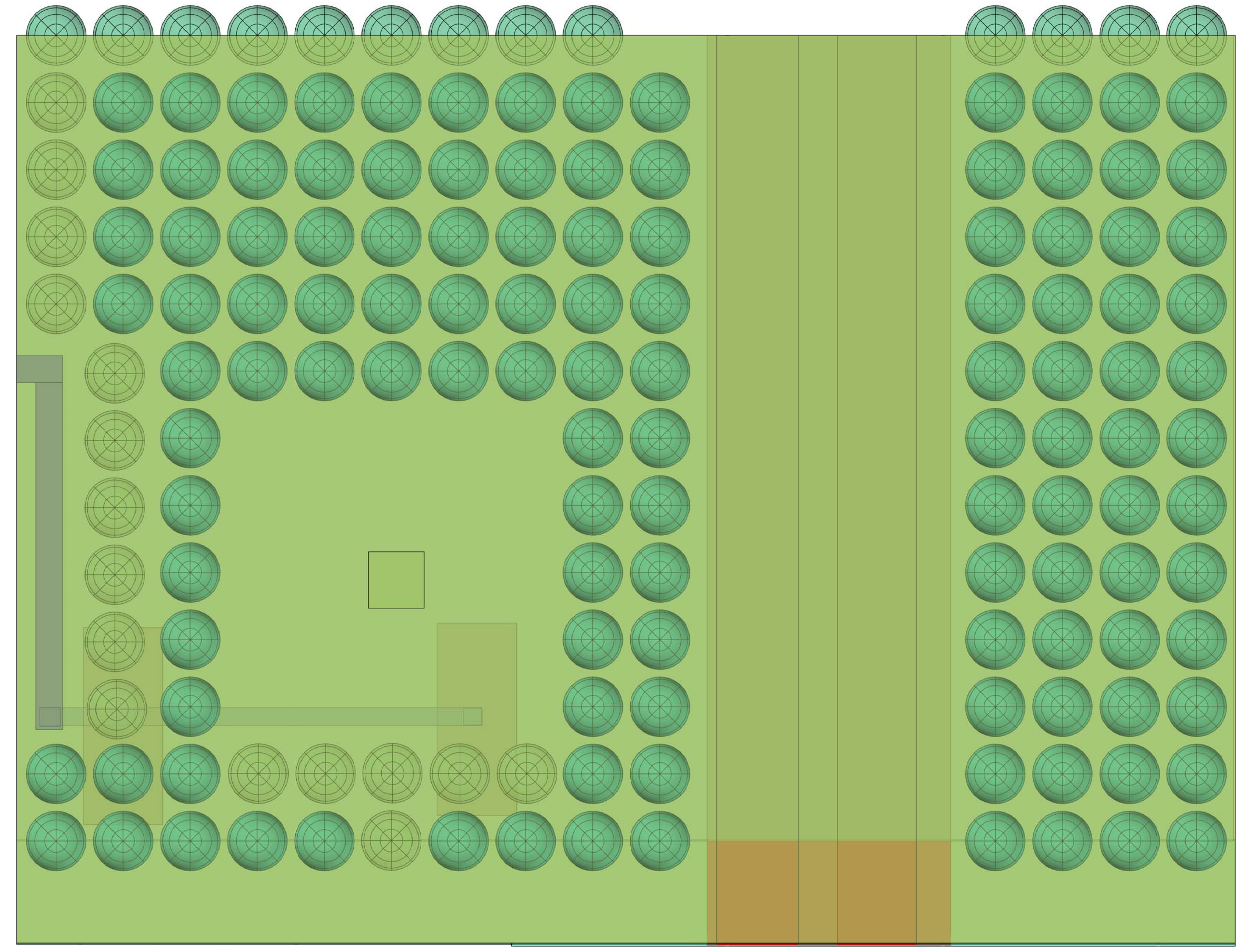
TEAM 05

DATE

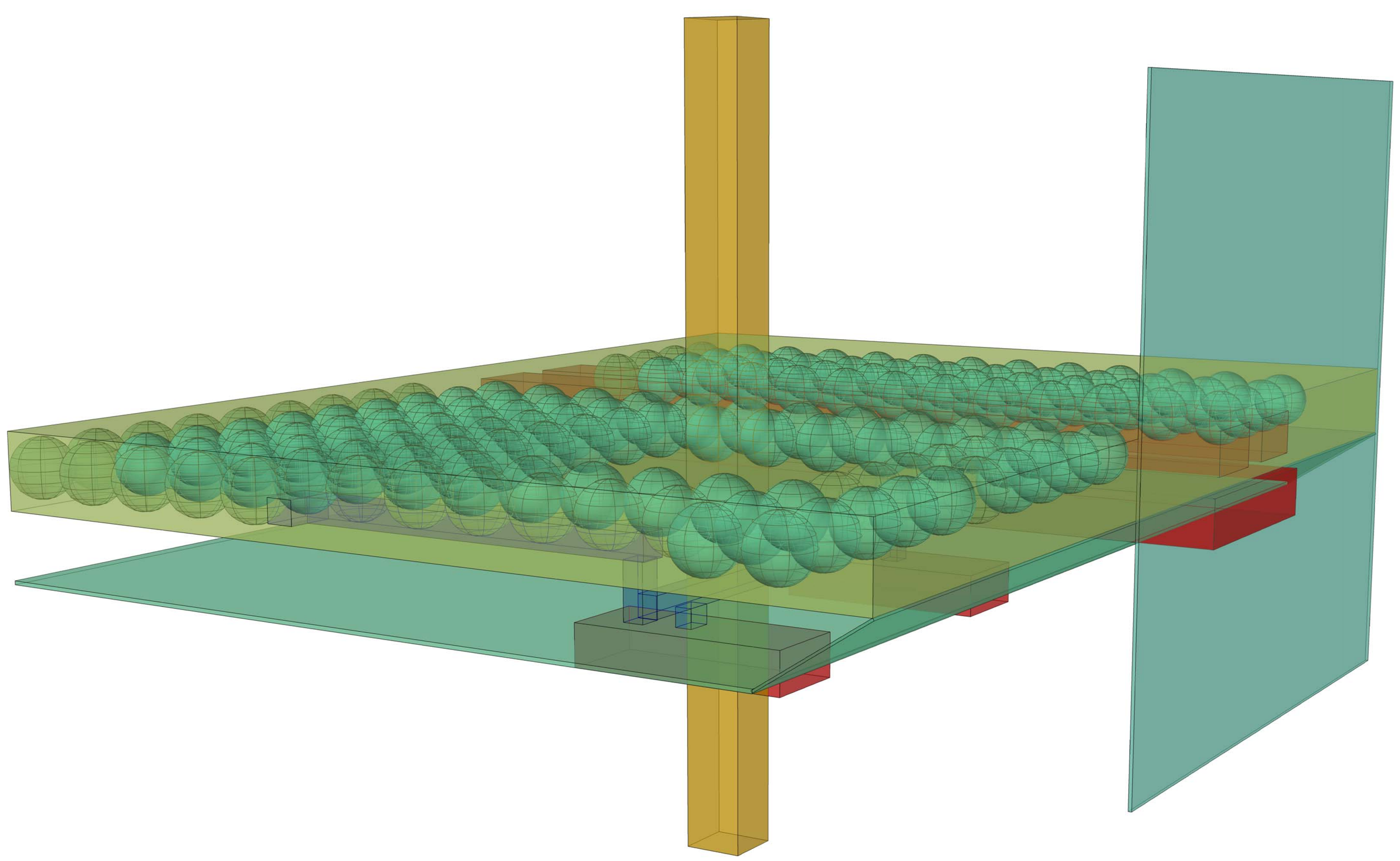
D01



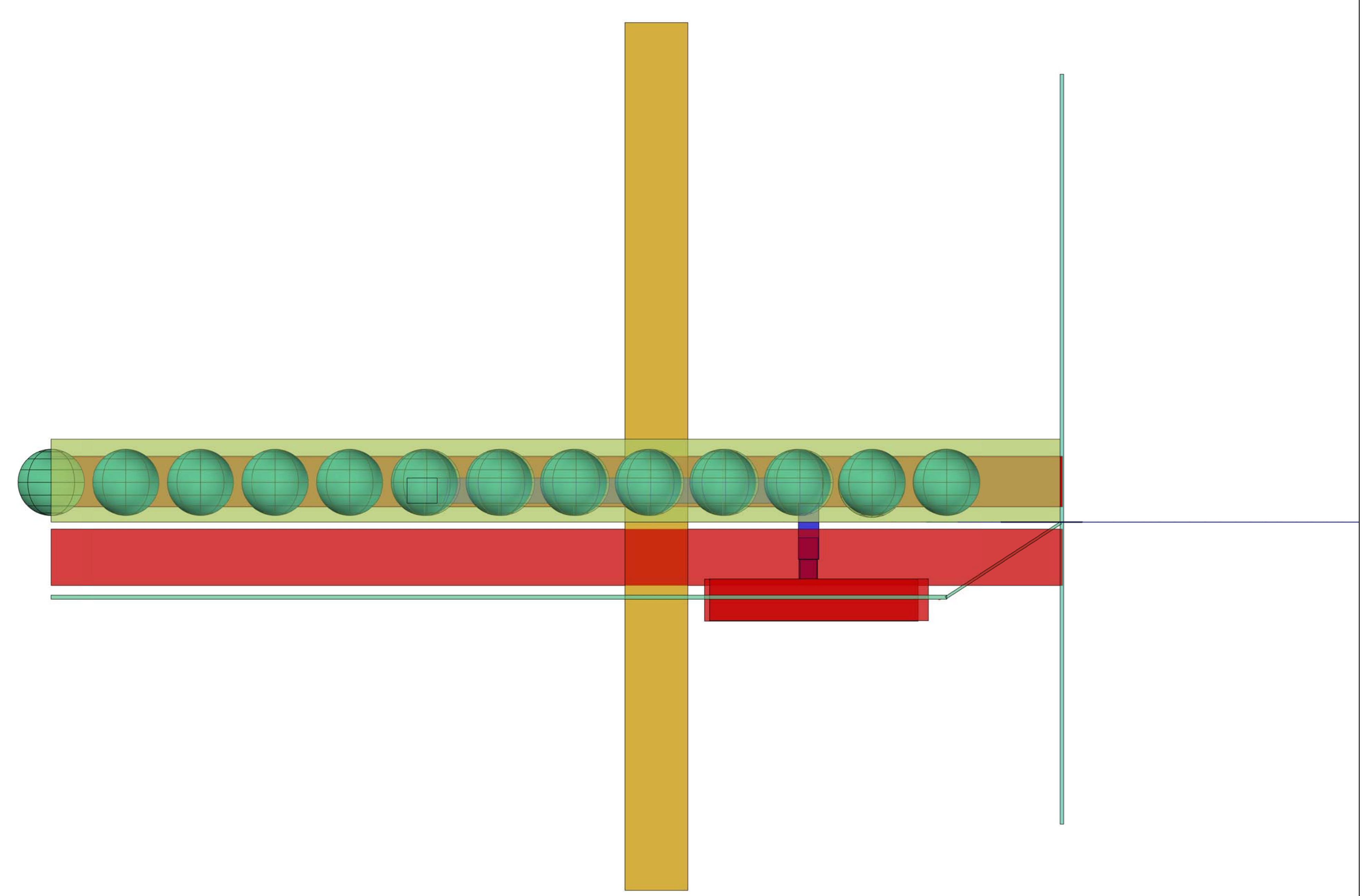
1 Active Chilled Beam Layout of a Typical Office Floor



2 3D of the Integration between Mechanical Ducts and the Bubbledeck
Plan View



3 3D of the Integration between Mechanical Ducts and the Bubbledeck
Axonometric View



4 3D of the Integration between Mechanical Ducts and the Bubbledeck
Section View

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Active Chilled Beam Diagram

TEAM 05

02.17.16

D02

1

Level 1 Duct Layout Out

First Floor

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Duct Layout Level 1

TEAM 05

3/15/2016

D02.1

2 Level 2 Duct Layout Out

First Floor

888 Boylston Street

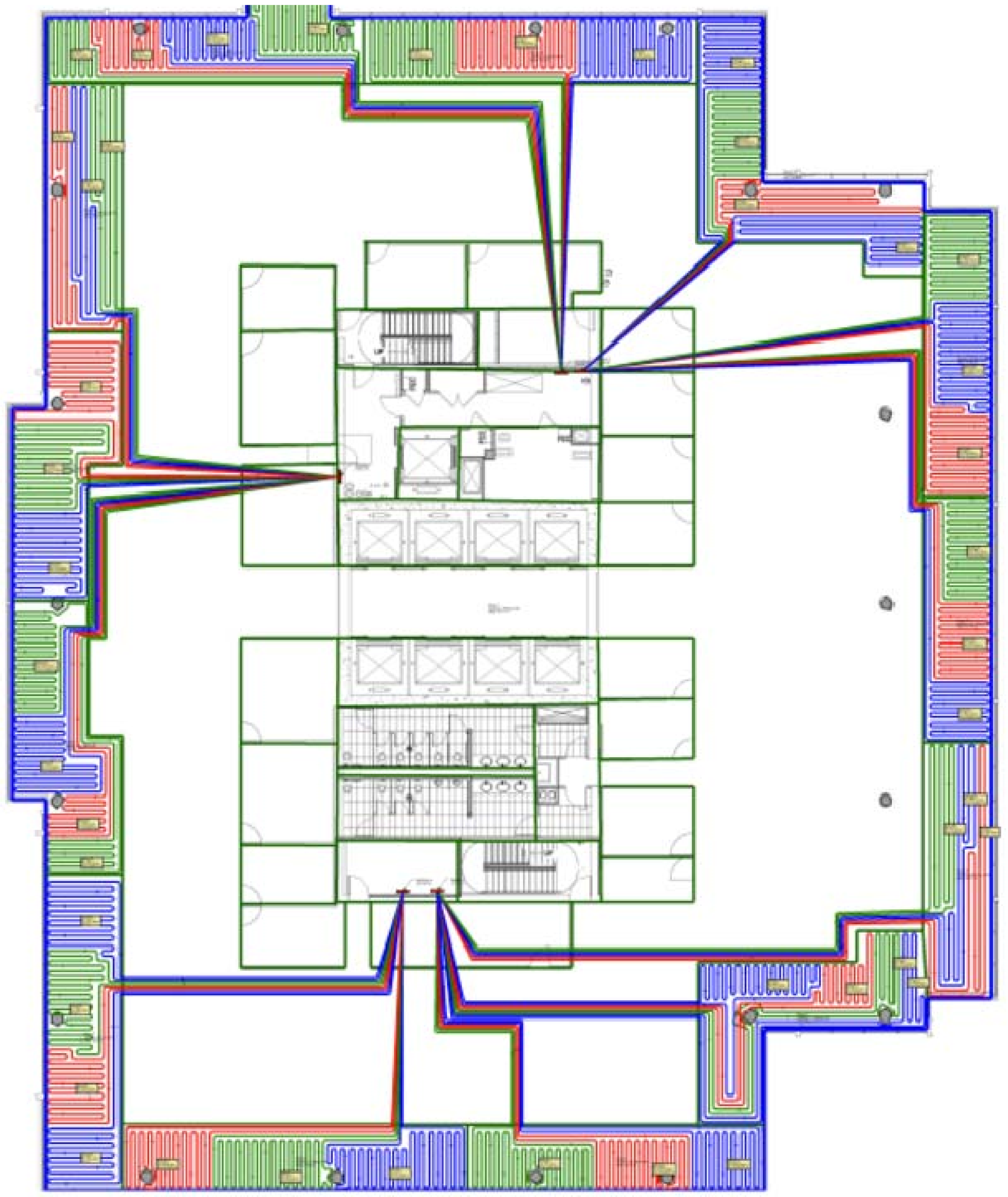
Architectural Engineering Institute

Duct Layout Level 2

TEAM 05

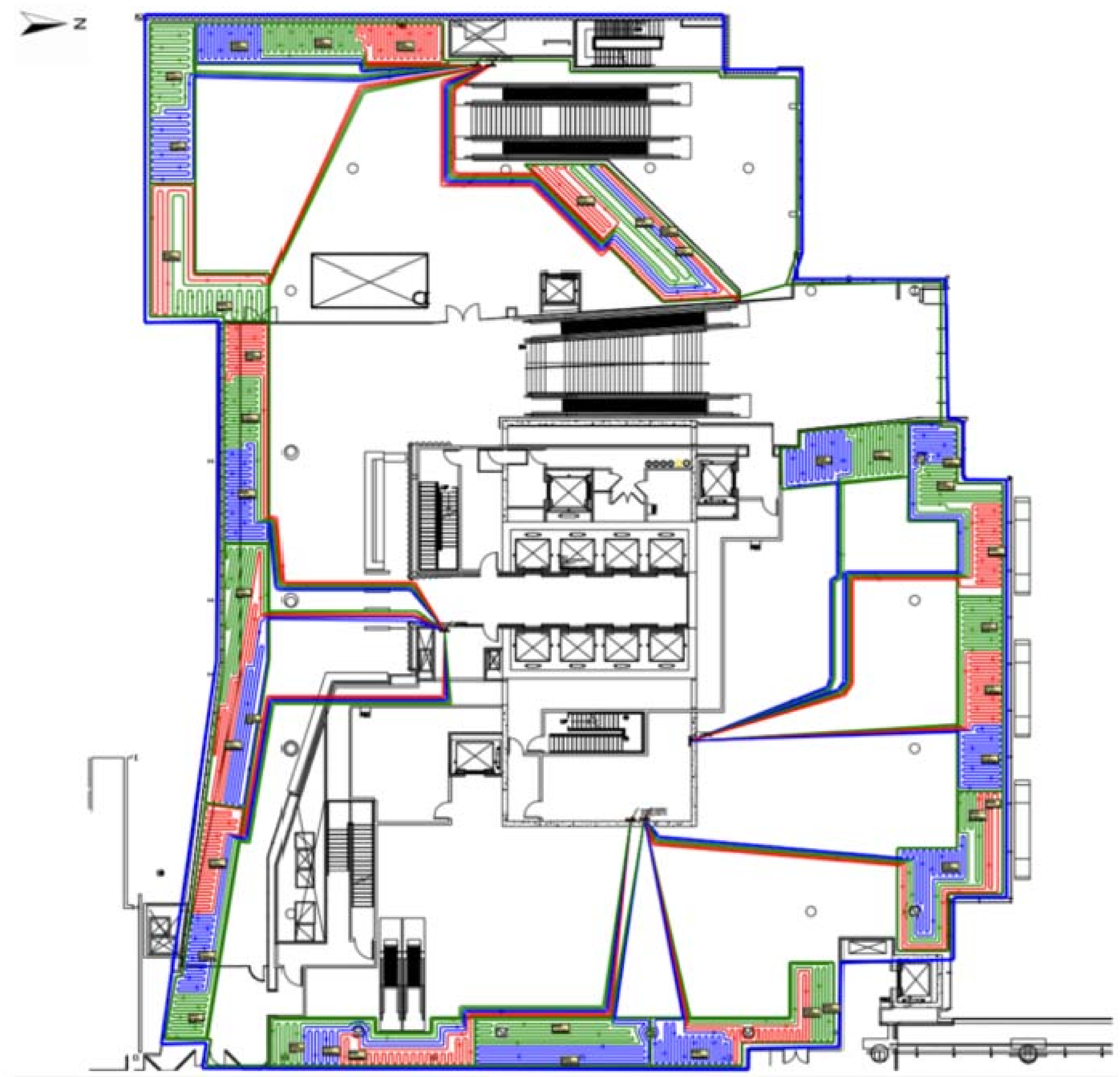
3/15/2016

D02.2



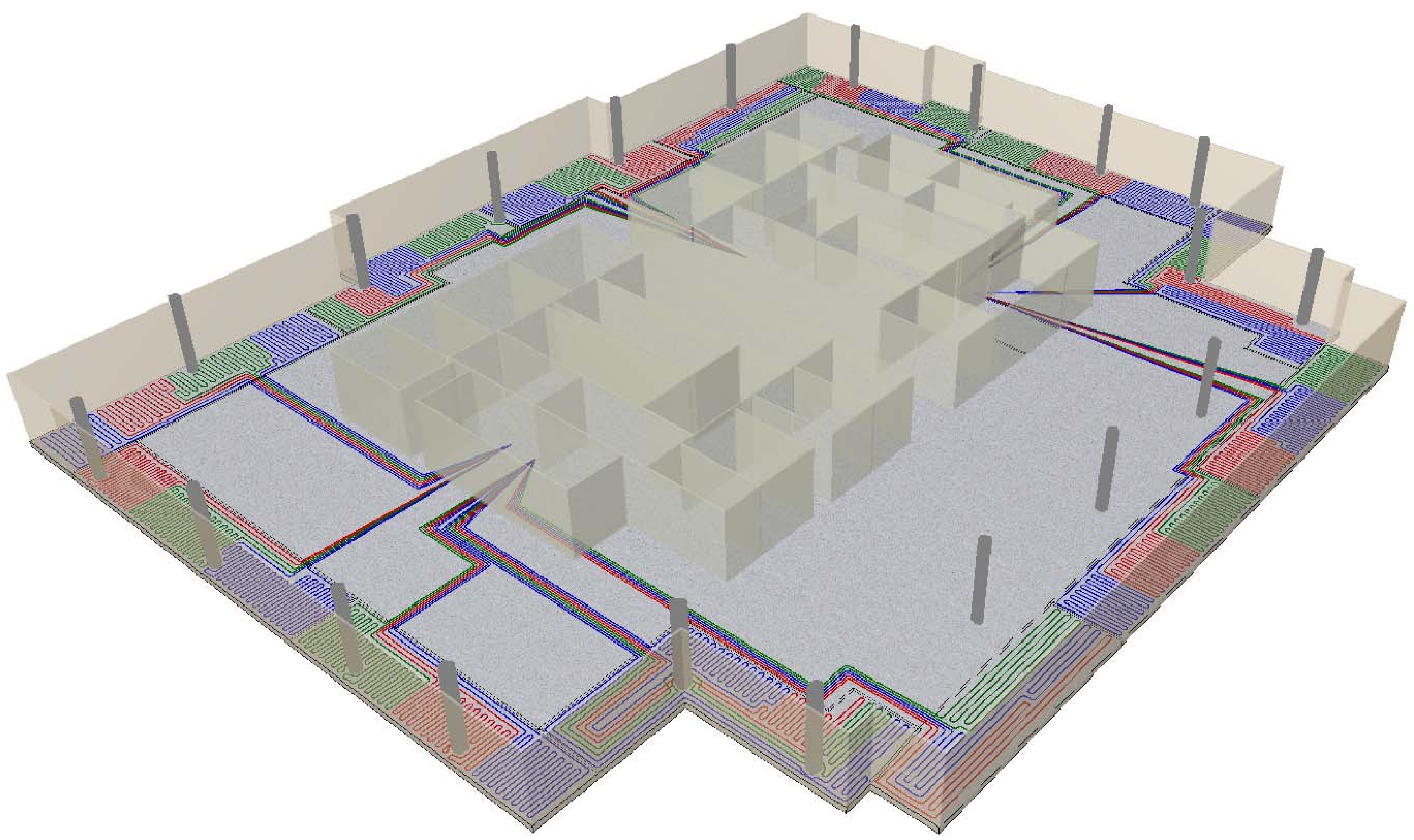
1 Radiant heating system layout - floor plan

A typical office floor



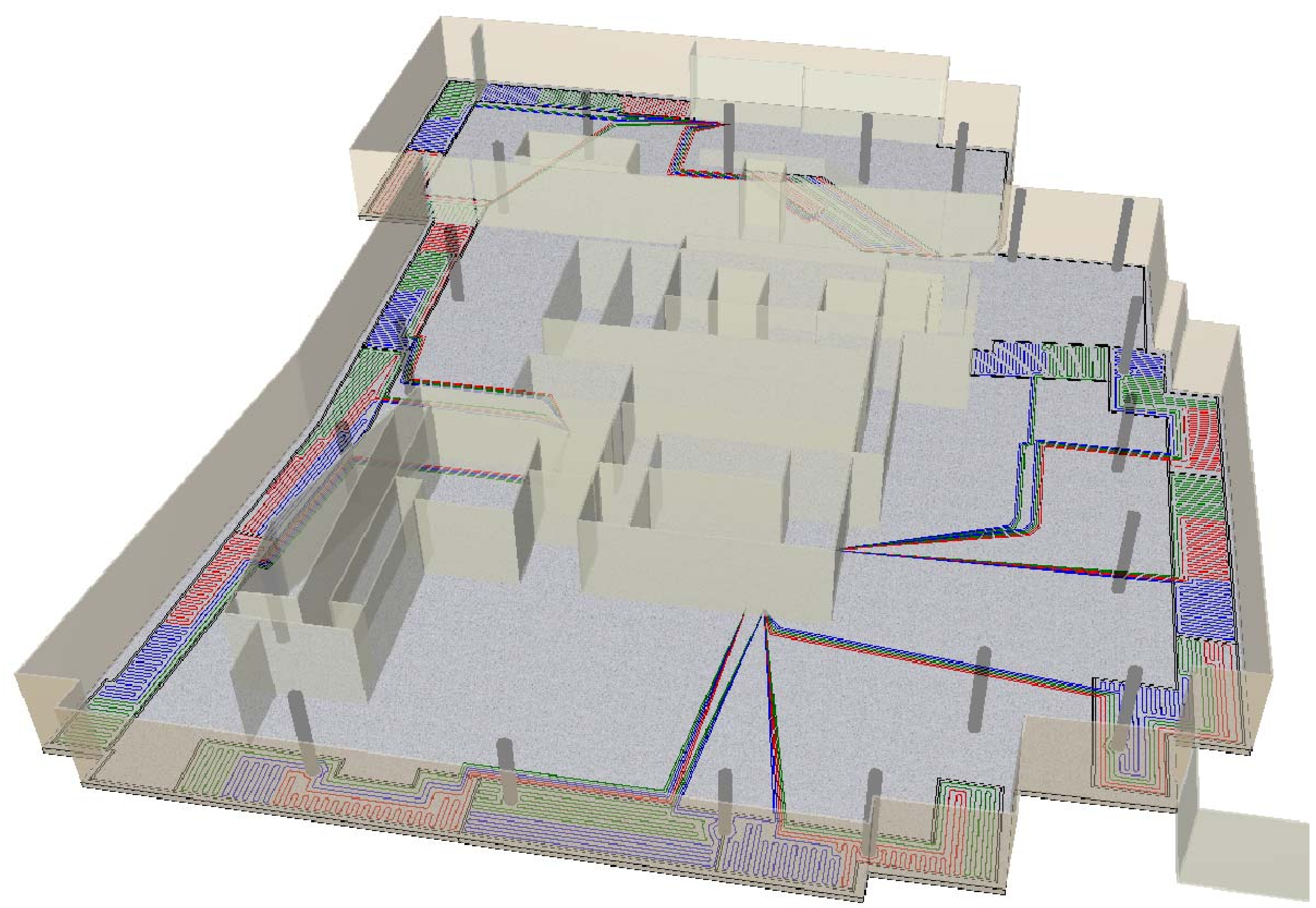
2 Radiant heating system layout - floor plan

Second floor



3 Radiant heating system layout - Axonometric

A typical office floor



4 Radiant heating system layout - Axonometric

Second floor

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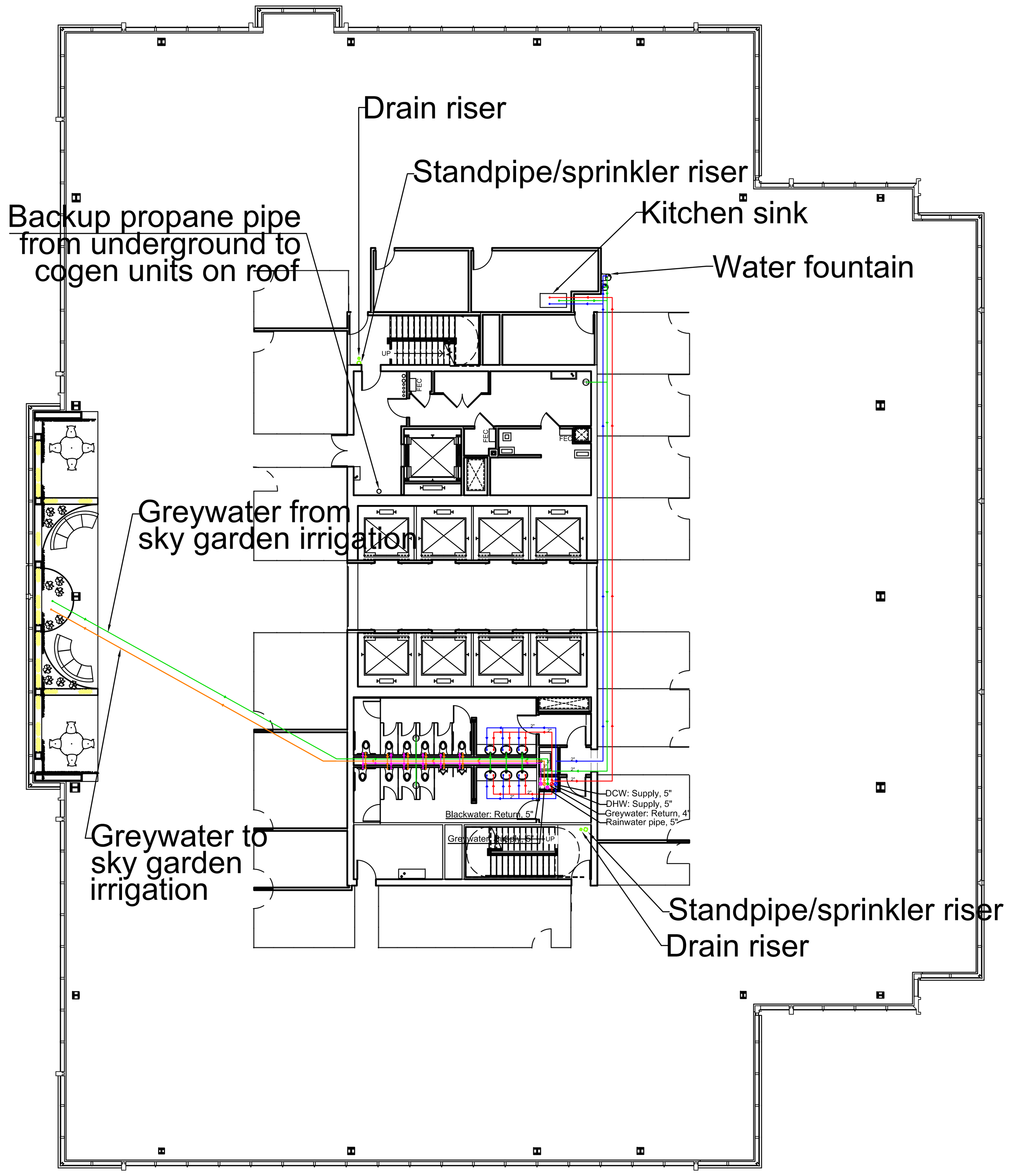
Radiant Heat Floor Layout

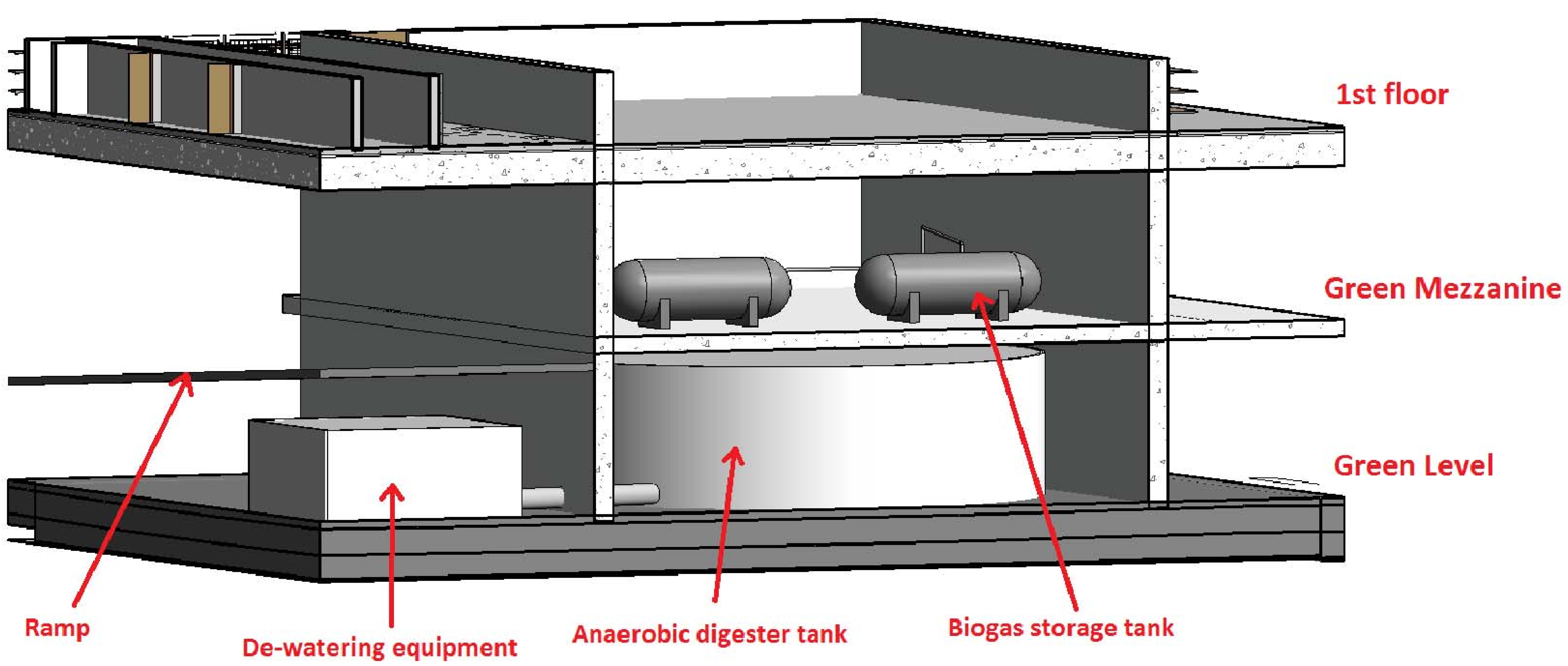
TEAM 05

02.17.16

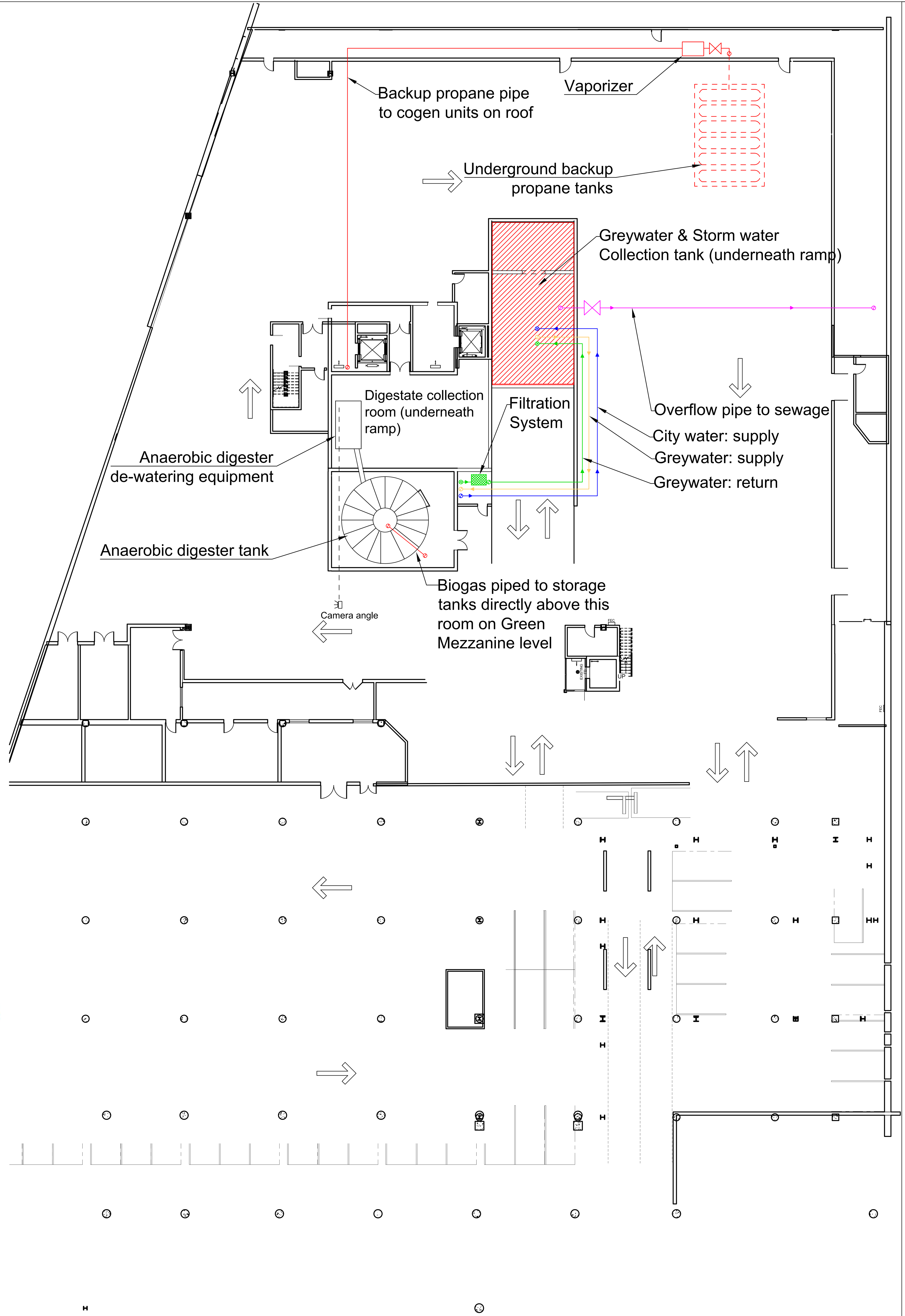
D03



1 Plumbing layout
Typical office floor



2 3D model of the anaerobic digester
Green Level and Green Mezzanine



3 Plumbing layout, Anaerobic digester, and propane storage tank
Green Level

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Plumbing system, Anaerobic Digester, Propane storage tank

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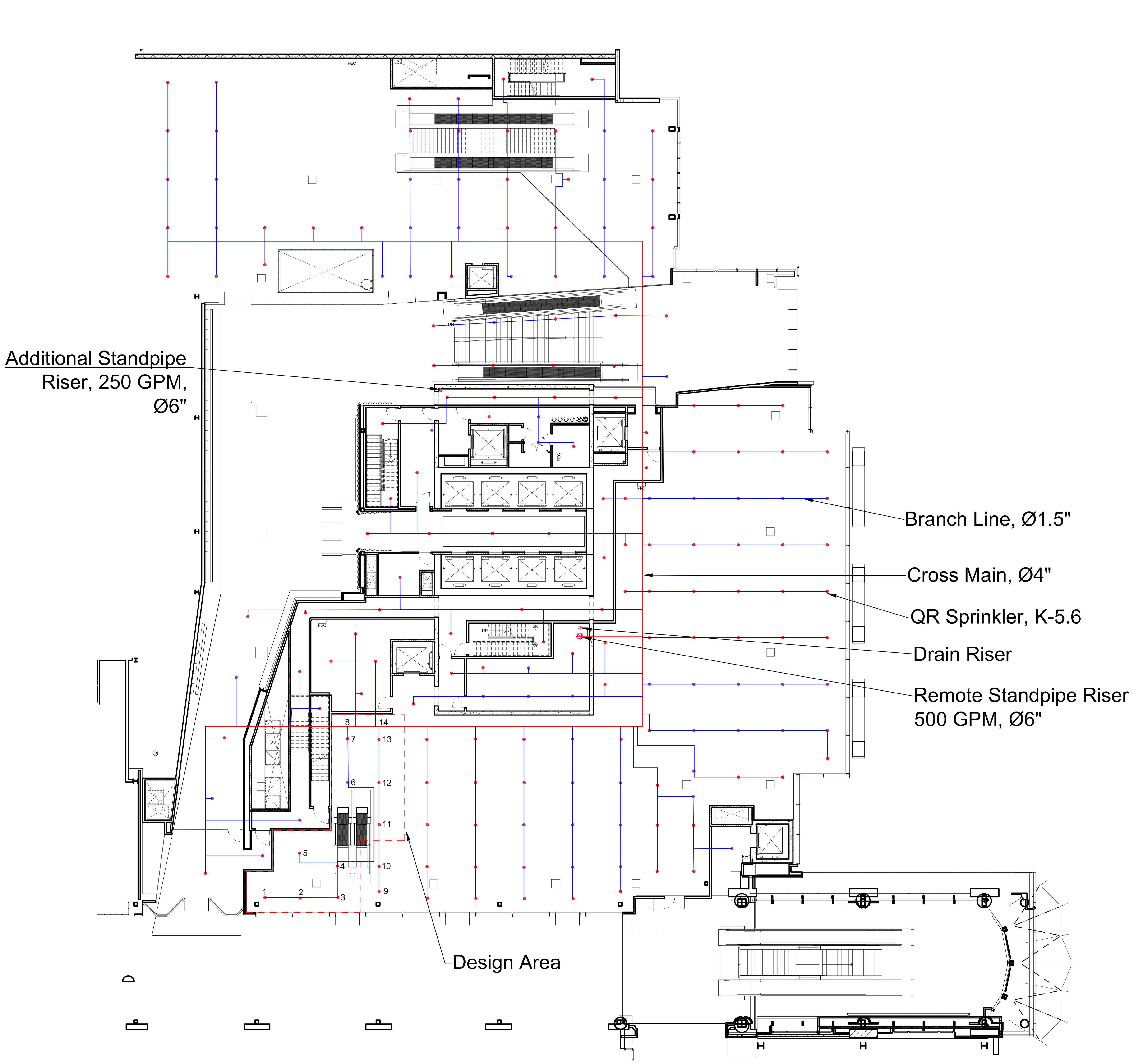
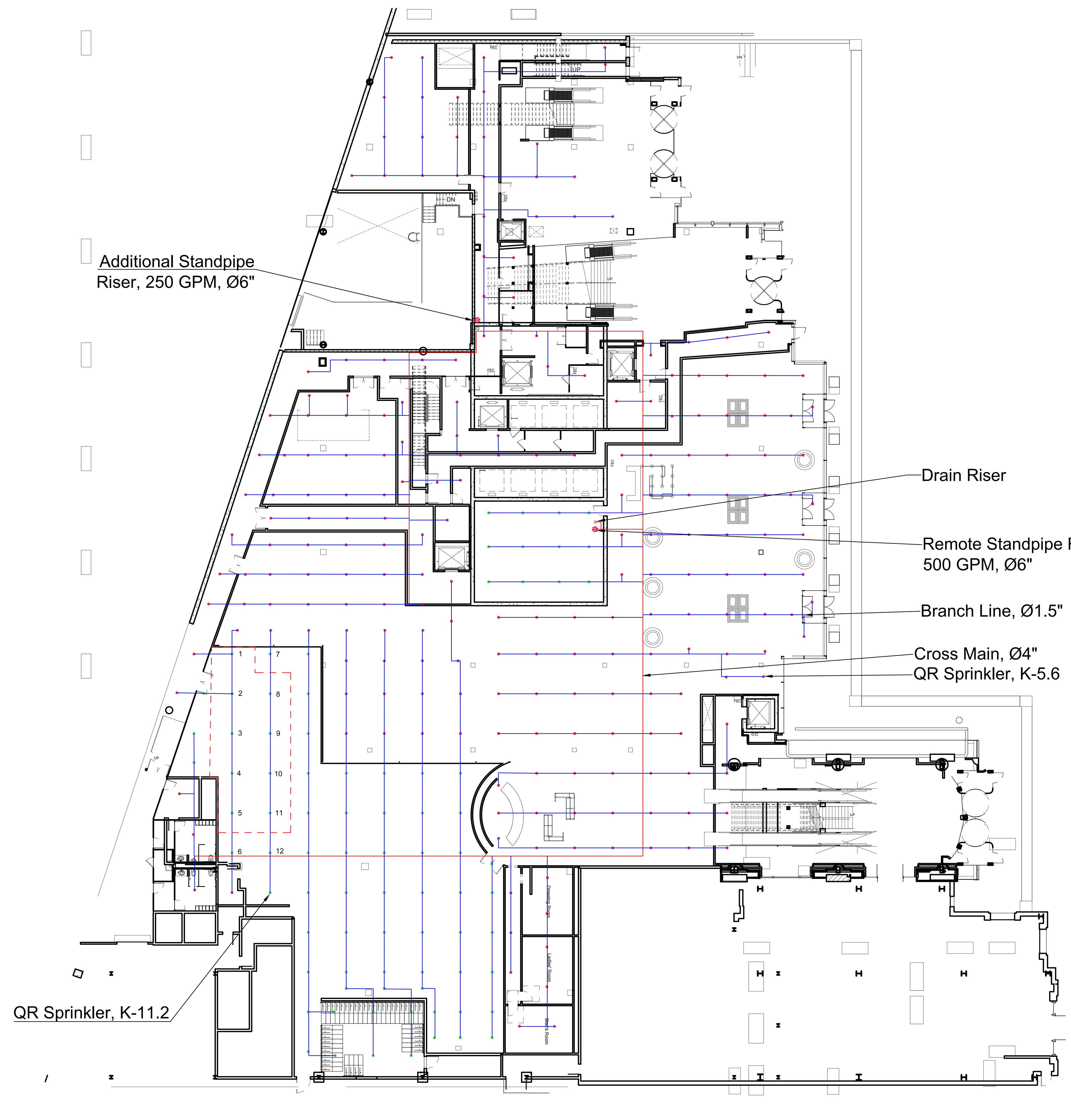
D04



1 Sprinkler layout for 2nd floor

Second floor



2 Sprinkler layout for 1st floor

First floor

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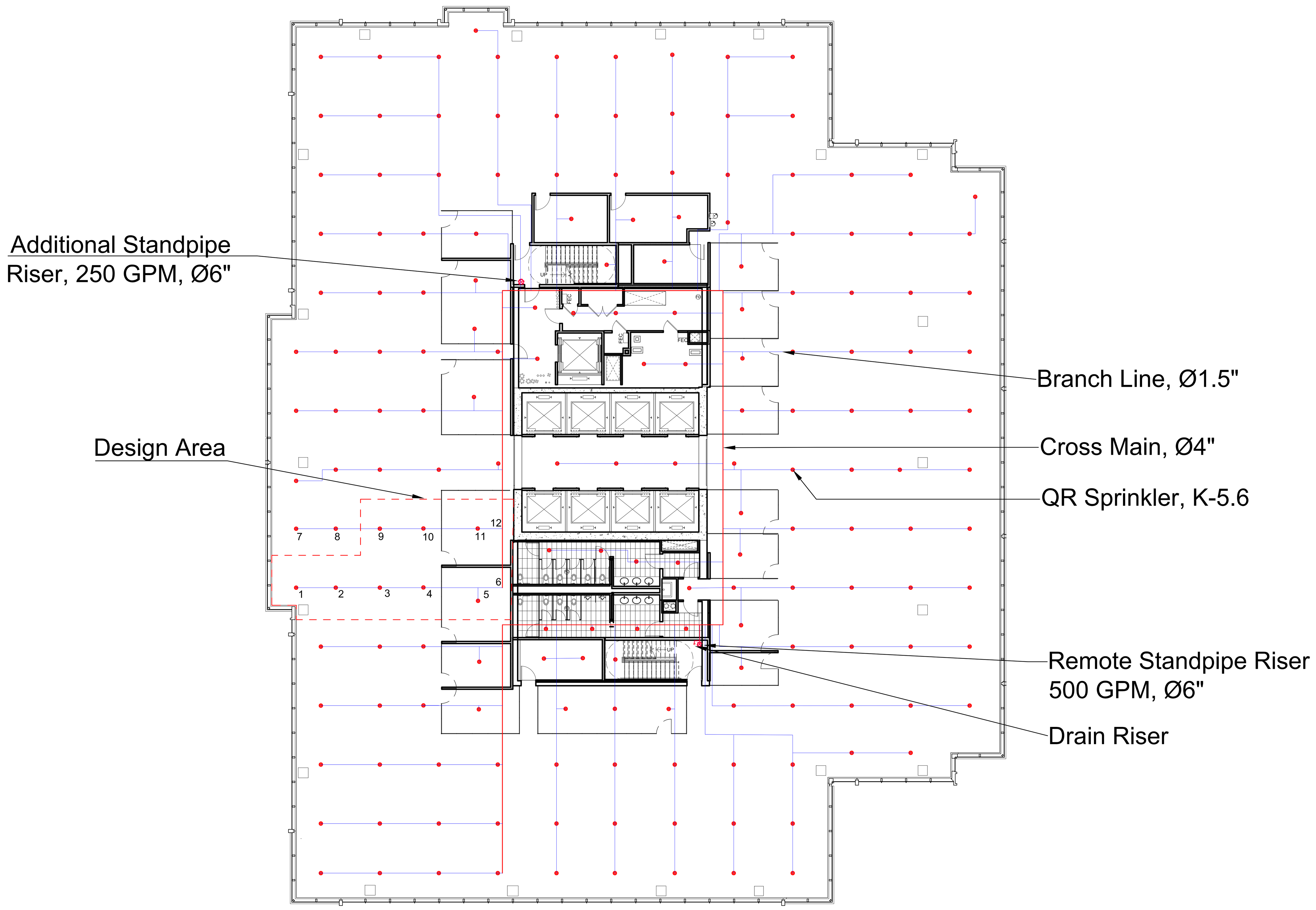
Sprinkler Layout

TEAM 05

DATE

D05



1 Sprinkler layout

Typical office floor

2 Sprinkler layout

Third floor

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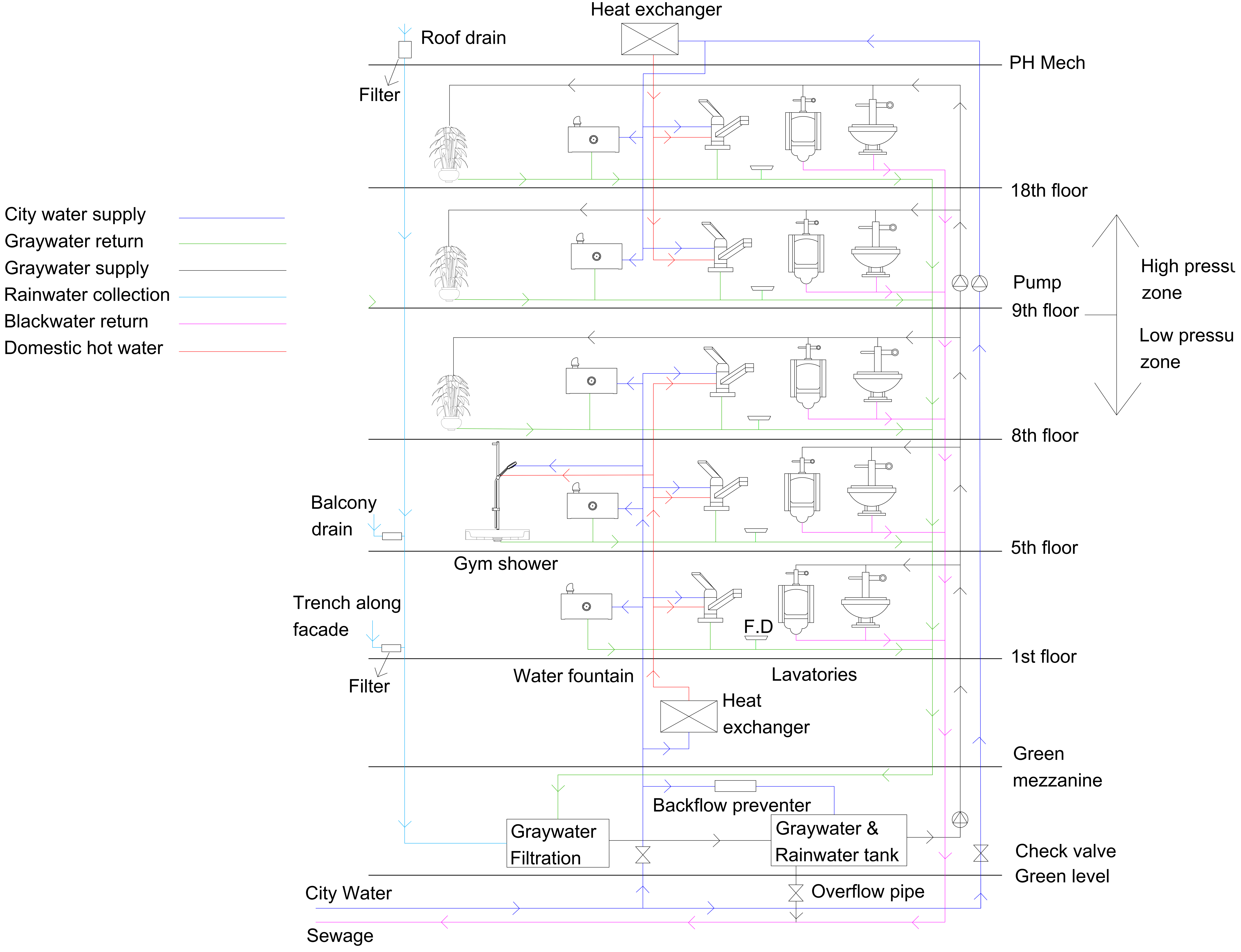
Sprinkler Layout

TEAM 05

DATE

D05.1



1 Vertical diagram of plumbing system

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Plumbing System

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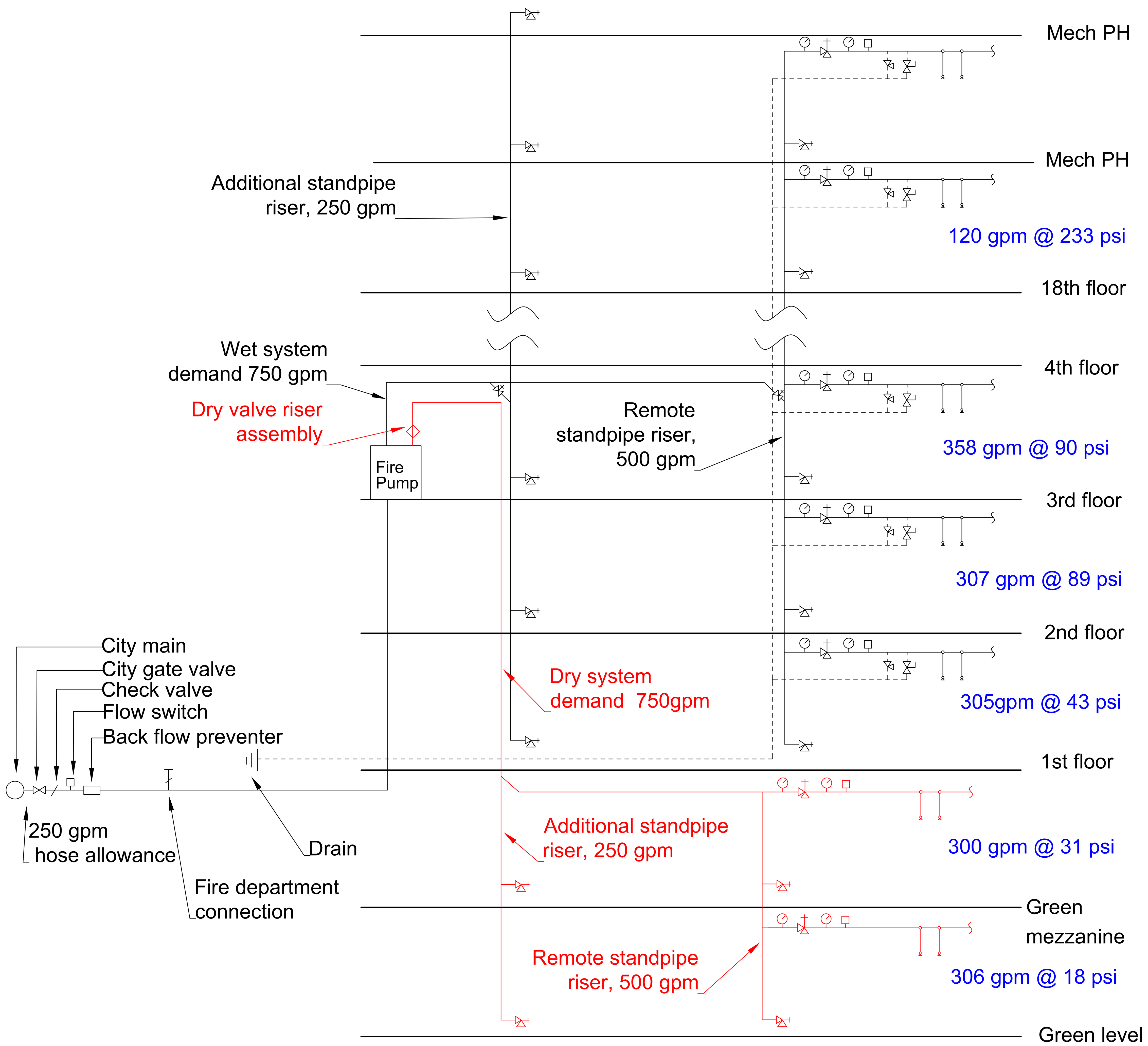
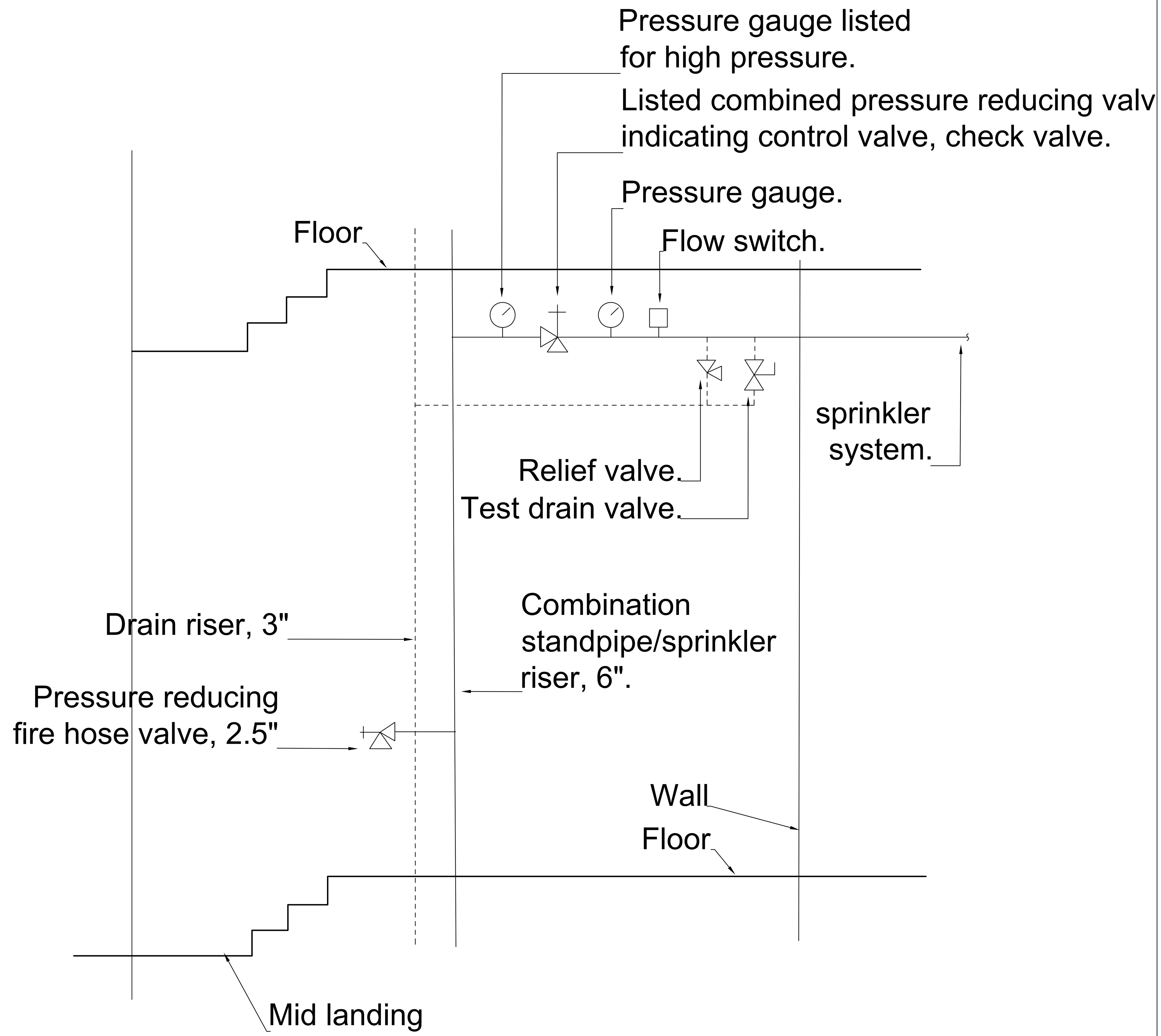
D06



1 Vertical diagram of standpipe riser and associated trims/valves



2 Piping arrangement for combined sprinkler/standpipe system

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Standpipe System

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D07