888 Boylston Street Interdisciplinary Team

Project Description

This project tasked students with addressing the design, integration, construction, and cost issues of a 17-story building in Boston, Massachusetts in terms of a high performance building. Students were to create a sustainable integrated design between structural, mechanical, and electrical engineering disciplines with a minimum energy reduction required to meet 50% of the baseline obtained via ASHRAE 90.1-2007 all while ensuring public safety. The proposed design must take into consideration the impact on adjoining businesses, structures, and public ways, yet be designed in a way to ensure a high level of resiliency and the ability to maintain a "fast restart" in the case of a natural, or man-made disaster.

The Building

The following information outlines the design goals and engineering systems for the multi-use 888 Boylston Street project in Boston, Massachusetts. 888 Boylston Street rises from a two-story below-ground parking structure to a three-story retail space capped by a 14-story office space. 888 Boylston Street is set to serve as an icon of intelligent, sustainable design for the City of Boston.

Building Summary

Location: Boston Massachusetts (Back Bay Neighborhood)
Area: 425,000 ft^2
Stories: 17
Retail: 1-3
Office: 4-17
Mechanical Penthouse: Roof

Owner Project Requirements

Students were provided with a thorough description of owner project requirements. To create a successful submittal, the final submission was carefully modeled around the following requirements:

1. *Sustainable design and construction*
2. *Provide resiliency with respect to local environmental considerations*
3. *Consider integration and impact ion adjoining structures and public ways*
4. *Building Integration Submittal*
5. *Structural Systems Submittal*
6. *Mechanical Systems Submittal*
7. *Electrical Systems Submittal*

Creating an Icon of the Sustainable Design Ideology

Multidiscipline Participation

Structural System Overview

Overview:
- Drilled Shaft Deep Foundation System
- Composite Steel Beam Superstructure
- Reinforced Concrete Shear Wall Core
- Seventy Foot Tall Storefront Column Truss
- Level 04 Cantilever Truss System

Savings:
- Building Height Reduction: 1' Floor to Floor, 12' Overall

Total Savings: $1,500,000 in upfront costs

Mechanical System Overview

Overview:
- Hybrid Heat Rejection Loop
- Phase Change Materials (PCM) with Stack Effect Ventilation System
- Chilled Beam Cooling System
- In-slab Radiant Heating System
- Heat Recovery Chillers

Savings:
- Water Reduction: 345,000 gallons per year
- Energy Reduction: 4,300,000 kWh per year

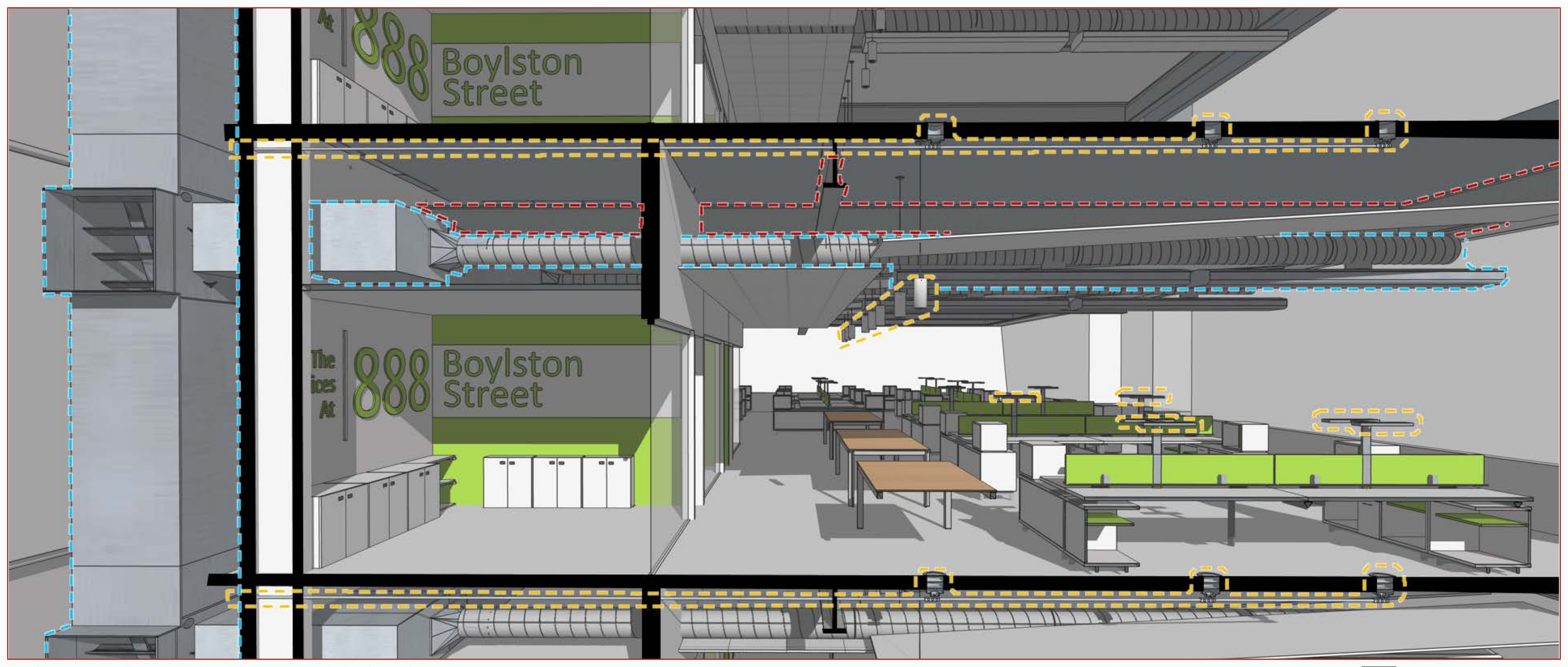
Total Savings: $601,000 per year

Electrical System Overview

Overview:
- Multiple Renewable Energy Generation Technologies
  +Photovoltaic Generation: 265,000 kWh per year
  +Wind Turbine Generation: 250,000 kWh per year
- Tier-IV Mission-Critical System with 2N Redundancy
- Significant Use of Class II Low Voltage (48 V) Lighting System
  +Greatly reduces need for conduit and certified electricians
  +Savings of $250,000 in initial construction costs

Savings:
- Renewable Energy Generation: 515,000 kWh per year
- Energy Usage Reduction: 1,398,041 kWh per year

Total Electrical Savings: $268,000 per year

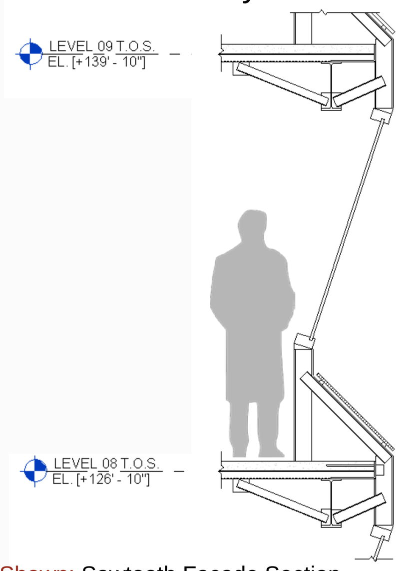


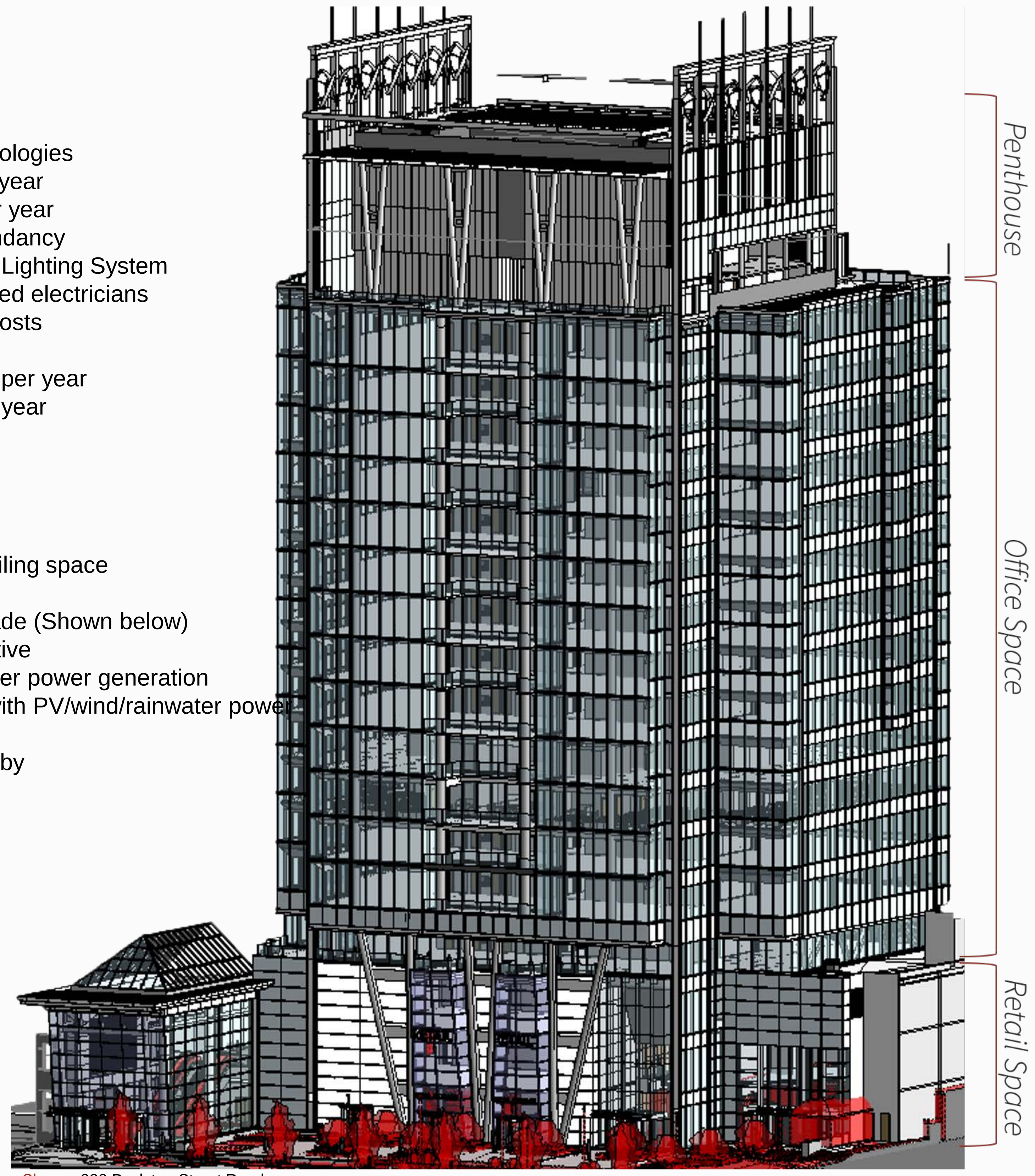
Shown: 888 Boylston Street Integrated Engineering Systems

Structural Systems | Mechanical Systems | Electrical Systems

Integrated Design Overview

Overview:
- Multidiscipline system coordination within ceiling space
- "Sky Garden" addition to northern façade
- "Sawtooth Façade" addition to southern façade (Shown below)
- Public Sustainability Knowledge (PSK) Initiative
  +Micro-turbine within public view for rainwater power generation
  +Green LED light features interconnected with PV/wind/rainwater power generation
  +Solar/wind array statistics displayed in lobby


Shown: Sawtooth Façade Section



Shown: 888 Boylston Street Render

Industry Collaboration

23 Industry Mentors + 34 Evaluators

Estimated value of time spent on professional input - $250,000
- The value of professional input was calculated on Day One, which made students take this investment in their work very seriously.

Industry Mentors – Teams were paired with a full set of professionals to provide guidance regularly throughout the two-semester program. The volunteer mentors were:
- 17 PEs, SEs & EIs (Structural, Mechanical, Electrical)
- 5 Architects
- Acoustical Consultant

Evaluators – another set of professionals who volunteered their time to critique formal presentations at touchpoints throughout the two-semester course.
- 31 Pes, SEs & EIs
- Graded presentations according to competition rubric
- Follow-up Q&A to compel participants to defend and improve design

Additionally, the design teams sought insight from construction contractors, estimators, deep foundation specialists, and construction engineering faculty, to discuss construction sequencing, equipment clearances, methods, and cost.

Knowledge and Skills Gained

The student participants gained real-world skills as a result of this collaborative effort. Using an actual building design project provided an opportunity to consider synthesis and integration outside of theoretical parameters and to form an interdisciplinary approach. Students became better prepared to enter the profession with the skills an engineer must develop and possess.

Structural Teams
- Effective gravity system layout strategies considering constructability and cost
- Analysis parameters and design guidelines specific to tall buildings (2010 PEER Tall Buildings Institute Guidelines)
- Modularity for formwork design
- Deep foundation system selection with consideration of vibration and settlement concerns for neighboring foundations
- Further software experience: RAM Structural System, RISA 3D (analysis)

Mechanical and Acoustical Teams
- Primary HVAC system selection and design
- Incorporation of both standard and innovative design
- Value engineering for system selection
- Further software experience: Trace 700 for space loads and energy consumption, Ground Loop Design 2014 (by Gaia Geothermal)
- Application of acoustic design fundamentals

Electrical and Lighting Teams
- Power distribution design
- Daylighting and electric lighting design
- Understanding of DC energized ceiling grid functioning
- Practical implementation of alternative power production
- Further software experience: Autodesk 3ds Max, AGi32, SketchUp, Rhino/Grasshopper/Ladybug+Honeybee, SKM Powertools (for short circuit calculations), NREL System Advisory Model (SAM) (for photovoltaic production)

Public Health, Safety and Welfare

The design of 888 Boylston Street protects the health, safety, and welfare of the public through code compliance, emergency system design, hurricane-resistant structural design, and indoor air quality for the mechanical system design. Codes and guidelines are listed in the table below.

Safety
- Structural design teams met the 100-year MRI wind speed for lateral system design. A hurricane impact-resistant curtainwall system was also researched and specified. Safety was a primary concern throughout the design of all structural components, including the I-90 braced-frame cantilever truss and column transfer girders.
- Mechanical designs provide fire protection with automatic sprinklers, fire pumps, smoke control, and pressurization of spaces per IBC 2009 and NFPA requirements.
- The electrical emergency systems provide lighting and standby power during emergencies.
- Designs also include security systems, fire alarms, overcurrent protection, and lightning protection for the building.

Health and Welfare
- Designed for occupant health, productivity, and comfort through mechanical, acoustical, daylighting, and structural floor vibration design.
- Indoor air quality standards were met for the mechanical system design with proper ventilation and exhaust movement, filter selection, and humidity control for occupant health and to prevent proliferation of airborne pathogens.
- Daylighting promotes occupant well-being, while decreasing energy use, which in turn decreases the negative health effects due to energy production.
- The office and retail levels meet AISC Design Guide 11 vibration limits for the office and retail areas minimizing occupant distractions.

PROJECT ISSUED	COORDINATION PLAN	CODE ANALYSIS	SCHEMATIC DESIGN	NCEES Engineering Award Entry 2015/16 Connecting Professional Practice and Education	DESIGN DEVELOPMENT #1	DESIGN DEVELOPMENT #2	CONSTRUCTION DOCUMENT #1	CONSTRUCTION DOCUMENT #2
July 2015	September 2015	September 2015	October 2015		December 2015	January 2016	March 2016	May 2016

888 Boylston Street – Interdisciplinary Team

Abstract

Three separate multidisciplinary teams of six or seven graduate students each were challenged to design a proposed 17-story mixed-use high-rise building located in Boston, Massachusetts. The structure will have 14 stories of offices above three levels of retail, and two levels of sub-grade parking. The teams were to meet guidelines which include energy efficiency 50% better than ASHRAE 90.1 energy use baseline, structural design for resiliency against hurricane wind speeds with a 100-year mean recurrence interval (MRI), the ability to provide 48 hours of runtime for critical office tenants in the case of a power outage, and synthesis and safety for the surrounding environment and people. In an effort to further improve building performance, students adopted several design practices defined in ASHRAE 189.1 (Design of High Performance Buildings), resulting in a LEED Platinum building.

The students, preparing to be electrical, structural, mechanical, lighting and acoustical engineers, worked to create their own interdisciplinary team designs for the complex structure. The primary objective was the development and integration of innovative and original design solutions with a multidisciplinary approach. Further objectives were robust collaboration with over 50 industry professionals that mentored and evaluated the work and the opportunity to gain real-world technical skills, experience and knowledge through this collaborative project. These criteria, along with specific goals of the company, led to designs that demonstrate sustainability, resilience to environmental threats, safety, and synthesis with the surrounding built environment.

In order to ensure public safety, the structural teams designed the lateral system to withstand the 100-year MRI for hurricane wind speeds. The mechanical and electrical teams coordinated to develop the fire protection systems. The electrical teams also designed emergency systems to provide safety and standby power. Public health and welfare was partially addressed by designing for occupant health, productivity, and comfort through indoor air quality control, noise and vibration control, and daylighting. Additionally, the design must connect to the adjacent shopping mall and convention center, and the structure must be designed for a 60-ft long cantilever over the I-90 Massachusetts turnpike without traffic interruptions during construction.

Over the course of two semesters, more than 50 licensed professional engineers and architects from industry, licensed professors from the university and other allied professionals mentored the students in the myriad aspects of the project. These volunteers were matched with student teams to review progress and direct students' understanding of the design process, and to serve as mentors aiding in practical design and system selection. These professionals met with students on a weekly basis outside of class-time. Industry mentors were also tasked to review the building design, narratives, construction documents, and oral presentations of their assigned team. Of the 20 students involved with the project, 13 have taken and passed the Fundamentals of Engineering (FE) exam the remaining 7 have planned to take it by this summer. Further, each will be completing an ABET EAC accredited degree, will work under licensed engineers, and plan to pursue licensure for themselves.

888 Boylston Street – Interdisciplinary Team

Project Description

Three design teams produced complete, integrated designs for a 625,000 sq. ft., 17-story mixed use office building at 888 Boylston Street, in Boston, Massachusetts. The building will have two levels of below grade parking, three levels of high end retail, a 14-story office tower, and a street-level public plaza. Design teams addressed issues relating to building-wide integration of structural, mechanical, and electrical systems as they relate to the three stated project challenges:

1. Prioritize sustainable design and construction,
2. Provide resiliency with respect to local environmental considerations, and
3. Consider integration with and impact on adjoining structures and public ways.

Each team, guided by mentorship from professional engineers, architects and other professionals, used an integrated approach to engineering system decisions during preliminary research, schematic design, and design development phases. 3D Autodesk Revit models were utilized for coordination of equipment layouts, ceiling plenum spaces, equipment clearances, and equipment weights. Throughout the building, engineering designs enhanced occupant health and comfort through daylighting, acoustics, mechanical ventilation, indoor air quality, and meeting structural vibration criteria. Isolated and redundant HVAC, power, and telecommunications systems were all designed so that power is never lost, even in the event of an extended power failure. From the plaza to the executive rooftop suite, the engineering designs enhanced the high-end appeal of the building while adding further functionality to the architectural design.

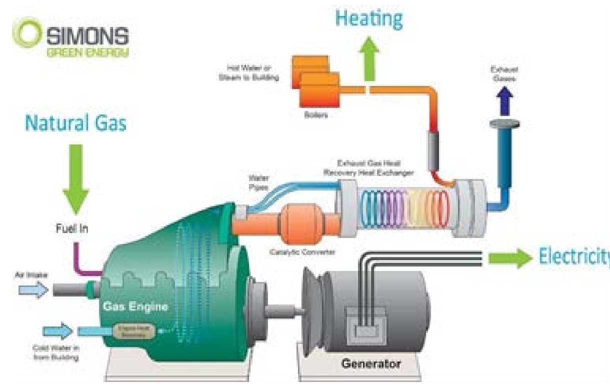
Highlights from design integration include exceeding the ASHRAE 90.1 50% baseline energy reduction and using cogeneration with heat reclaimed from the natural gas-fueled modular micro-turbines located on the 10th level mechanical suite. Drilled shaft "energy piles" were proposed for the deep foundation, and geothermal piping was incorporated into the drilled shaft rebar cages. Such a design will elicit the benefits of a geothermal system without the construction cost associated with drilling additional boreholes. Energy efficiency was further improved by using photovoltaic systems integrated with DC grids on the office levels.

Sustainability

To maximize sustainability, teams devised various integrated ideas. Strategies outlined included on-site power generation, optimized façade design, and a commitment to sustainable construction materials.

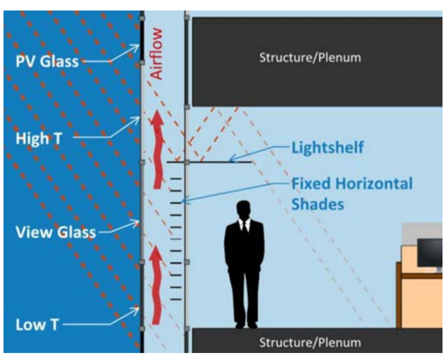
Renewable on-site power generation was achieved in one design through a system of roof-mounted solar panels and photovoltaic glass integrated into the building's south facade. Additionally, hydrogen fuel cells were utilized as the means of emergency on-site power generation. These provide clean, efficient power and generate usable waste heat which will supplement building heating. Design of these two systems required coordination primarily between mechanical and electrical disciplines, though structural was also consulted in order to ensure proper considerations were given for added dead loads and required fire ratings.

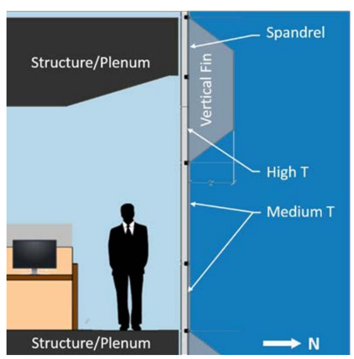
For one team, the primary mechanical system incorporated system redundancy with modular centrifugal chillers and condensing boilers. The primary systems were configured for variable flow to increase efficiency at part loads. A variable air volume (VAV) air distribution system was used for office and retail levels with building system controls. A natural ventilation and fan system was utilized for the garage levels with occupancy and CO2 sensors. Sustainability was achieved through cogeneration with heat reclaimed from the micro-turbines. This will contribute 84% of building heating demand and 100% of domestic water demand. The geothermal energy pile design provided an additional 9% of heating demand while working as a heat sink and also reduced condensing demand by 8% while working as a heat sink. Additionally, a rainwater collection system was designed that will supply 97% of the building's gray water demand. Computer Room Air Conditioner (CRAC) units were selected to cool the building's Tier III data center. Acoustical studies better informed the mechanical system selection.

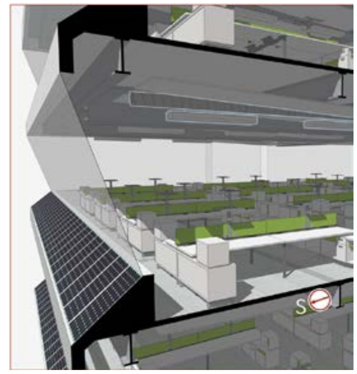


Façade design was a crucial aspect of this project. The teams spent considerable effort designing optimized façade systems that would preserve the building's original architectural design intent, improve thermal insulation, and maximize daylight penetration while reducing discomfort glare throughout the office floors. To achieve these goals, unique façade treatments were designed.

Since the north side is the face to capture optimum sky light for interior lighting (no direct sun), one team worked early on to maximize the floor-to-ceiling height adjacent to the façade to create a light well that will maximize daylighting The building will be oriented approximately 20 degrees west of north, so to reduce the effects of direct sunlight striking the north façade during late afternoon hours throughout the summer, a system of fixed vertical fins was designed to block direct sunlight from penetrating through the light well. On the building's south side, a double-skin façade was implemented to minimize solar heat gain while maintaining floor-to-ceiling glazing (an architectural design objective). The mechanical team utilized the cavity as an exhaust duct for the ventilation system. The use of tempered air within the façade reduced the building's mechanical load throughout the year. Additionally, a fixed horizontal shade system was designed integral to the double-skin to block 100% of direct sunlight from penetrating the façade to the building's interior throughout the entire cooling season, further minimizing solar heat gain. During the winter, this fixed shading system allows low-angle sunlight to penetrate and increase solar heat gain to supplement the building's heating system. Design of these façades required significant integration throughout the entire design process between all design disciplines including structural, mechanical, electrical, and architectural.







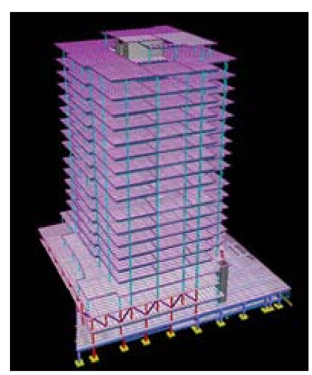
One team proposed a major architectural change from the original plan in designing a “saw-tooth” façade on the southern face of the building. By sloping the south curtain wall inward on each office floor, the building itself acts as an inherent shade from the sun while simultaneously providing a two-foot ledge where photovoltaic panels are placed. This southern ledge provides an excellent location for the photovoltaic panels as it allows for the optimal orientation of panels towards the sun and increases the total solar energy production on 888 Boylston Street by a massive 134%.

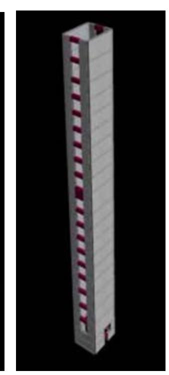
One of the simplest ways to design sustainably is to commit to utilizing sustainable construction materials wherever possible. Utilizing locally-sourced, recycled-content construction materials is an excellent means to help achieve this. An example of this consideration was a structural design team's attempt to maximize steel framing throughout the project, since steel, which contains a high percentage of recycled content, can be locally sourced from Boston steel mills.

Resiliency

Focusing on resiliency as a primary goal resulted in designs that can withstand and take advantage of normal environmental conditions, respond to and recover quickly from extreme weather or natural disasters, and support emergency response in the interest of maximizing occupant safety and supporting public welfare. This was shown in the design by the expanded shear wall system that provided mechanical rooms extra protection for mission critical tenants.

A key structural challenge involved providing a two- story braced frame system with a 60’ cantilever over the I-90 Massachusetts turnpike. The architectural layout also presented challenges for obtaining an effective gravity layout due to an irregular column grid, column-free corners for the office levels, the need for transfer girders, and the slanted façade columns. One team designed the gravity system layout spanning Level 2 through to the roof to consist of steel beams and composite concrete deck with steel W14 columns. For the garage levels, a 5 ksi concrete beam and slab system with 8 ksi concrete columns were proposed. The lateral system design consisted of 8 ksi coupled concrete core walls to satisfy the 100 year MRI wind speed for Boston.





Integration and Synthesis

There were several structural concerns related to the existing site. First, a small two story below-ground parking structure currently stands on the site and will be incorporated into new facility. While the majority of this parking structure will be demolished to make way for the new building, portions will remain, including the retaining walls, mat foundation, and several smaller mechanical rooms. Additionally, the southwest side of the site is constrained below-grade diagonally by the Interstate 90 Turnpike. The turnpike and accompanying fan room will force the building to be built around it in a way to avoid damages and closures on the turnpike.

Collaboration of Faculty, Students, and Licensed Professional Engineers

Through a series of in-person meetings, phone conferences and emails between the students and their mentors from engineering, architectural, acoustical and construction professions, design issues and challenges were brainstormed and solutions were developed. Faculty scheduled time so that the design teams could present progress points throughout the process and invited licensed professionals in the surrounding area to evaluate these progress points in order to provide feedback and suggestions for the design teams.

Over the two semesters the student teams worked with their mentors, they went through documentation and presentation of a Coordination Plan, Project Research, Schematic Design (SD) with an SD progress report, two Design Development (DD) submissions, both with progress reports, and two Construction Document (CD) submissions, both with progress reports. All of these submissions and presentations were evaluated with significant feedback from the evaluation professionals.

So that the students could have a clear understanding of the significance of input from industry mentors and evaluators, they did a calculation the first day of class. They were able to estimate the monetary value of volunteers' time. Using an average standard hourly rate, they determined professionals' contributions to this two-semester class was valued at approximately $250,000!

Structural

For the structural designs, students were able to delve into critical detailing areas with PE structural mentor input. These detail areas include the curtainwall connection to composite slab overhangs, plate embed connections for steel gravity framing at concrete core corner locations and plate girder detailing for a major column transfer. Other notable examples of structural design details mentors helped students to consider included the cantilevered beam system over the I-90 tunnel, a permanent sheet-piling system for the parking garage, and the expanded shear wall system. These collaboration sessions helped to identify engineering best practices for design and documentation. Mentor insight also aided the structural students in better predicting mechanical and electrical equipment loads early in the design phase. The experience was beneficial for the structural students to further learn about the multitude of safety, serviceability, cost, and construction considerations in structural design.

Mechanical

For the mechanical and acoustical design, students were mentored by PE mechanical engineers with high-rise design experience and an acoustical consultant. Much of the discussion with PE mentors involved primary and secondary system selection and design while considering both standard and innovative systems. Mechanical team members also reached out to sales professionals to gather a better understanding of the systems used and to select equipment that would perform within the parameters of the design. Documents were reviewed for clarity by the mechanical mentors, the acoustician, and the architects and engineers from other disciplines.

Lighting and Electrical

For the lighting and electrical design, some of the collaboration with PE electrical engineers focused on creating accurate riser diagrams and system connections. Lighting layouts, micro-turbines, and raised floor considerations were also discussed in addition to other design considerations not commonly covered in engineering curriculum. Electrical teams had weekly meetings and email conversations with mentors to gain expertise and advice in order to design normal and backup power systems that utilize fuel cells and a photovoltaics as renewable power sources. The professionals provided guidance and understanding of equipment selection, interaction, and operation under emergency scenarios.

Protection of Public Health, Safety and Welfare

The design of 888 Boylston protects the health, safety, and welfare of the public through code compliance, emergency system design, hurricane-resistant structural design, and indoor air quality for the mechanical system design. Codes and guidelines are listed in the table below.

Table. Codes, Standards, Guidelines, and References

Category	Applicable codes, standards, guidelines, and references
Governing Building Code	• International Building Code 2009 • Massachusetts Building Code, 8th Edition
Structural	• ASCE 7-10 Minimum Design Loads for Buildings and Other Structures • Structural material design codes (AISC, ACI) • PEER Tall Buildings Institute Guidelines • Drilled shaft design literature
Mechanical	• International Mechanical, Plumbing, Fire Code • ASHRAE standards including: Standard 55 - Thermal Environmental Conditions for Human Occupancy, Standard 62.1 - Ventilation for Acceptable Indoor Air Quality, Standard 90.1 - Energy Standard for Buildings Except Low-Rise Residential Buildings, Standard 189.1 - Standard for the Design of High-Performance Green Buildings • Waste heat reclaim, energy pile, and rainwater reclaim design literature
Acoustical	• Boston Air Pollution Control Commission: Regulations for the Control of Noise in the City of Boston • ANSI/ASA S12.2-2008: Criteria for Evaluating Room Noise • ASTM E1374-02: Standard Guide for Open Office Acoustics • ASHRAE Handbooks
Electrical	• ASHRAE 189.1 • NFPA 70 (National Electrical Code) • NFPA 101 (Emergency and Standby Power Systems) • NFPA 110 (Life Safety) • NFPA 780 (Lightning Protection) • IEC (2009) E.2.6 IECC (2012)
Lighting	• ASHRAE 90.1 (2007) • IES Lighting Handbook

For public safety, each structural design team met the 100-year MRI wind speed for lateral system design. A hurricane impact-resistant curtainwall system was also researched and specified. Safety was a primary concern throughout the design of all structural components, including the I-90 braced-frame cantilever truss and column transfer girders.

A specialized development which will serve to enhance aesthetics while providing multiple aspects of protection were the concrete planters on the plaza. Students designed these to act as bollards to prevent vehicles from driving or accidentally entering pedestrian areas. Not only do the concrete planters protect pedestrian safety, they also increase the blast standoff distance from the building for any vehicle-transported bomb threats.

Public safety is also achieved through the electrical and mechanical system designs. The mechanical designs provide fire protection with automatic sprinklers, fire pumps, smoke control, and pressurization of spaces per IBC 2009 and NFPA requirements. The electrical emergency systems protect lives by providing lighting during emergency and provide legally-required standby power. Designs also include security systems, fire alarms, overcurrent protection, and lightning protection for the building.

Public health and welfare was further addressed by designing for occupant health, productivity, and comfort through mechanical, acoustical, daylighting, and structural floor vibration design. Indoor air quality standards were met for the mechanical system design with proper ventilation and exhaust movement, filter selection, and humidity control in order to support occupant health and prevent proliferation of airborne pathogens. Daylighting in the office spaces also promotes occupant well-being, while decreasing energy use, which in turn decreases the negative health effects due to energy production. Designs minimize occupant distractions, and increase well-being through acoustics and structural vibration control. The office and retail levels meet AISC Design Guide 11 vibration limits for the office and retail areas. Additionally, many design decisions were made to reflect the elegant downtown ambience for building tenants and the community.

Multidiscipline and/or Allied Profession Participation

For this engineering capstone project, three student design teams, consisting of six or seven mechanical, structural and electrical option students each, had support and constructive feedback from professional engineers, professional architects, an acoustical consultant and faculty advisors in architectural engineering. Each team was given a full set of professionals: an architect, several engineers (structural, mechanical, and electrical) and an acoustical consultant. There were 23 non-faculty mentors in all – 16 PEs or SEs, one EI, five professional architects and an acoustical consultant.

Additionally, the design teams sought insight from construction contractors, estimators, deep foundation specialists, and construction engineering faculty, to discuss construction sequencing, equipment clearances, methods, and cost. Professional engineering mentors shared their experiences and insights on technical design, detailing, and interdisciplinary coordination.

After each design milestone, teams prepared a presentation and narrative showcasing the progress of the entire building design within each discipline. Another set of professionals participated as evaluators, providing feedback on presentation and document submissions. This group included 31 PEs, SEs and EIs, and three others, for a total of 34. They graded the presentations and narratives according to competition rubric. Follow-up questions and comments were then discussed with the professionals. This allowed students the opportunity to defend and improve their design. The presentation and discussion process was similar to one that would be found in a professional setting.

Knowledge or Skills Gained

The student participants gained real-world skills as a result of this collaborative effort. First, using an actual building design project provided an opportunity to consider synthesis and integration outside of theoretical parameters. It gave the students the opportunity, not only to form their own interdisciplinary approach, but to witness and learn from people who have made their life's work on this very basis. By having industry mentors, the students became better prepared to enter the profession with a clear understanding of the skills an engineer must develop and possess.

Further, professionals gave feedback at periodic phase presentations, which challenged the students to accept criticism, learn from it, and continue to fine-tune their projects for a wholly realistic design. Finally, this close relationship illuminated the different opportunities and specializations available to pursue as a career, and created potential connections for future employment or collaboration when the students have transitioned into professional engineers, themselves. The significant guidance and evaluation of over 50 experienced professionals raised the bar by having the expectation of real, workable solutions to inherent problems in design. The value of professional input was made clear from day one, which made students take this investment in their work very seriously.

Table. Knowledge and Skills Gained by Group

By Group	Areas of Development
Multidisciplinary Teams	• Interactive collaboration across disciplines • Recognizing the impact each decision has on the rest of the team • Meeting deadlines as a collaborative effort • Honing the ability to research solutions to questions and problems addressed by mentors, faculty, and evaluators • Integration of the entire design process from Schematic Design through to Construction Documents • Further understanding of professional practice in engineering
Structural Teams	• Effective gravity system layout strategies considering constructability and cost • Analysis parameters and design guidelines specific to tall buildings (2010 PEER Tall Buildings Institute Guidelines) • Modularity for formwork design • Deep foundation system selection with consideration of vibration and settlement concerns for neighboring foundations • Further software experience: RAM Structural System, RISA 3D (analysis)
Mechanical and Acoustical Teams	• Primary HVAC system selection and design • Incorporation of both standard and innovative design • Value engineering for system selection • Further software experience: Trace 700 for space loads and energy consumption, Ground Loop Design 2014 (by Gaia Geothermal) • Application of acoustic design fundamentals
Electrical and Lighting Teams	• Power distribution design • Daylighting and electric lighting design • Understanding of DC energized ceiling grid functioning • Practical implementation of alternative power production • Further software experience: Autodesk 3ds Max, AGi32, SketchUp, Rhino/Grasshopper/Ladybug+Honeybee, SKM Powertools (for short circuit calculations), NREL System Advisory Model (SAM) (for photovoltaic production)