Final BIM Thesis Report

AE 482/897G
Fall 11-Spring 12

H.P.R
INTEGRATED DESIGN

The Pennsylvania State University Ice Arena

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Executive Summary

The Penn State Ice Arena is the focus of the Integrated Project Delivery/ Building Information Modeling (IPD/BIM) Senior Thesis. This report will serve as a proposal for HPR Integrated Design's alternative design strategies to achieve more efficient building systems within each discipline. The goals of these strategies are to deliver a facility that will have the highest quality for the budget allotted, reduce building's energy usage and cost, create a fast tracked schedule, and develop a LEED Gold certified hockey arena.

HPR Integrated Design has developed three packages that first saved costs, and then enhanced the building features. These packages will give the owner options to enhance the quality of their ice hockey arena. HPR has studied the feasibility study up through the preliminary design, as well case other case studies, while using value engineering to develop these packages. Listed here are the design packages created.

- Savings Package – Raising of the Event Level
- Prominence Package – Main Arena Roof System Design
- Function Package – Façade Redesign

HPR has utilized the following method for developing each of the design packages.

1. Find an Opportunity
2. Identify our Goals
3. Create a Strategy
4. Define our Process
5. Finalize the Results

Savings Package:

The current design shows a floor-to-floor height between the event level and main concourse level of 20 foot 9 inches. With this height level, there is 10-foot plenum space. The driving force behind raising the event level is to reduce the amount of bedrock needing to be excavated from the site. In doing so, the plenum space will be reduced. HPR believes that by raising the event level approximately three feet, excavation costs will be reduced, and the plenum space that is otherwise wasted will be optimized. Savings from the reduction of excavation will then be reallocated to the main arena roof system design to give the Penn State University a facility of greater value for the same construction cost.

Prominence Package:

When HPR received the drawings for the Penn State Ice Arena, the main arena roof system's design had not been completed. HPR's designers will coordinate and design a roof for the main arena that is iconic and that will support the overhead lighting and duct systems.

Function Package:

With the design of the new roof system, the façade will have to be redesigned in order to coordinate in the efforts to design an iconic facility. As the façade is redesigned, materials will be selected and configured to maximize daylighting, reduce energy loads, and reduce construction and energy costs.

The raising of the event level and the main arena roof systems are closely connected. As the volume of the main arena is increased by a new roof profile, it is then reduced with the raising of the event level up. On a financial side, money saved in excavation by raising the event level can then be reallocated to the more prominent arena roof structural and MEP systems. This will provide the University with a higher quality product for a competitive cost to the current design.

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Penn State Ice Arena Overview

The Penn State Ice Hockey Arena project started in September of 2010 with an $88 million private donation to the school to establish a Division 1-A NCAA Men's and Women's collegiate hockey program at the Pennsylvania State University. Later, an additional donation of $1 million was made if the effort to creating the new arena. The project picked up momentum almost immediately with the pressure of the large donation and with the expectation of construction starting in Spring of 2012 followed by the planned opening of the facility for the 2013-2014 men's and women's ice hockey season.

Since hockey's reemergence on campus in 1971, the Penn State Nittany Lion Icers have annually competed and succeeded at the highest levels of play winning multiple championships. The Penn State University is in the process of transforming its highly successful Men's Hockey club team into a Division 1- NCAA hockey program. A key component to this process is the evaluation of the program's existing facilities and the assessment of new facilities and resources that may be required. Based on this understanding, the university started the process with completing feasibility studies to determine these required additional facilities and resources. Feasibility studies had already been conducted in 1999 for the possibility of a future arena and were again conducted by multiple design firms in 2011. Refining these studies from a decade earlier, the architectural firm of Crawford Architects, was selected to design the new arena.

The Penn State Ice Hockey Arena is a state-of-the-art 220,000 square foot area facility containing 2 sheets of ice, a competition ice sheet and smaller community area ice sheet. The new facility has a seating capacity of over 6,300 seats with the main arena containing 6,000 seats split between a lower bowl and mezzanine level. The arena includes 12 luxury suites with the possibility of future expansion to 24 suites.

The new ice hockey facility site was selected to be located on the corner of University Drive and Curtain Road on Penn State University northeast extents of campus. The new Penn State Ice Arena will bolster the already prominent Pennsylvania State University athletic facilities sector of campus, which is located in close proximity to the new arena. The Bryce Jordan Center, the university's main event arena including the home of the men and women's basketball programs sits directly across University Drive. The arena is located beside the university's football practice facility, Holuba Hall and only a short walk to the University's main athletic facility, Beaver Stadium, home of the nationally recognized NCAA Division 1 football program.

The selected site boasts majestic views of both nature and architectural excellence with views of the area's famous Mount Nittany peak to its southwest. The new Penn State Ice Arena replaced existing parking lots and the university's lacrosse club men's and women's turf field that will be replaced prior to construction of the new arena.

The Penn State Ice Hockey Arena

Pennsylvania State University

University Park, PA

Home of the Penn State Nittany Lions NCAA Division 1A
Men's and Women's Ice Hockey Programs

Actual Project Team:

Architect:	Crawford Architects, LLC	Kansas City, MO
Structural:	Thornton Tomasetti	Kansas City, MO
M/E/P Engineer:	Moore Engineers, P.C.	Camel, IN
Civil Engineer:	Sweetland Engineering	State College, PA
Landscape Architect:	Lager Raabe Skafte Landscape Arch.	Philadelphia, PA
General Contractor:	Mortenson Construction	Minneapolis, MN

Building Statistics:

Owner:	The Pennsylvania State University
Location:	University Park, PA
Size:	220,000 Sq. Ft.
Type:	Multi-purpose Arena
Cost:	$73,000,000
Project Delivery:	Design-Bid-Build with CM at Risk
Project Duration:	February 10, 2012 – September 5, 2013

There is a footprint constraint for this site; a main campus utility artery runs parallel with the west side of the site depicted in Figure 1 as a yellow line.

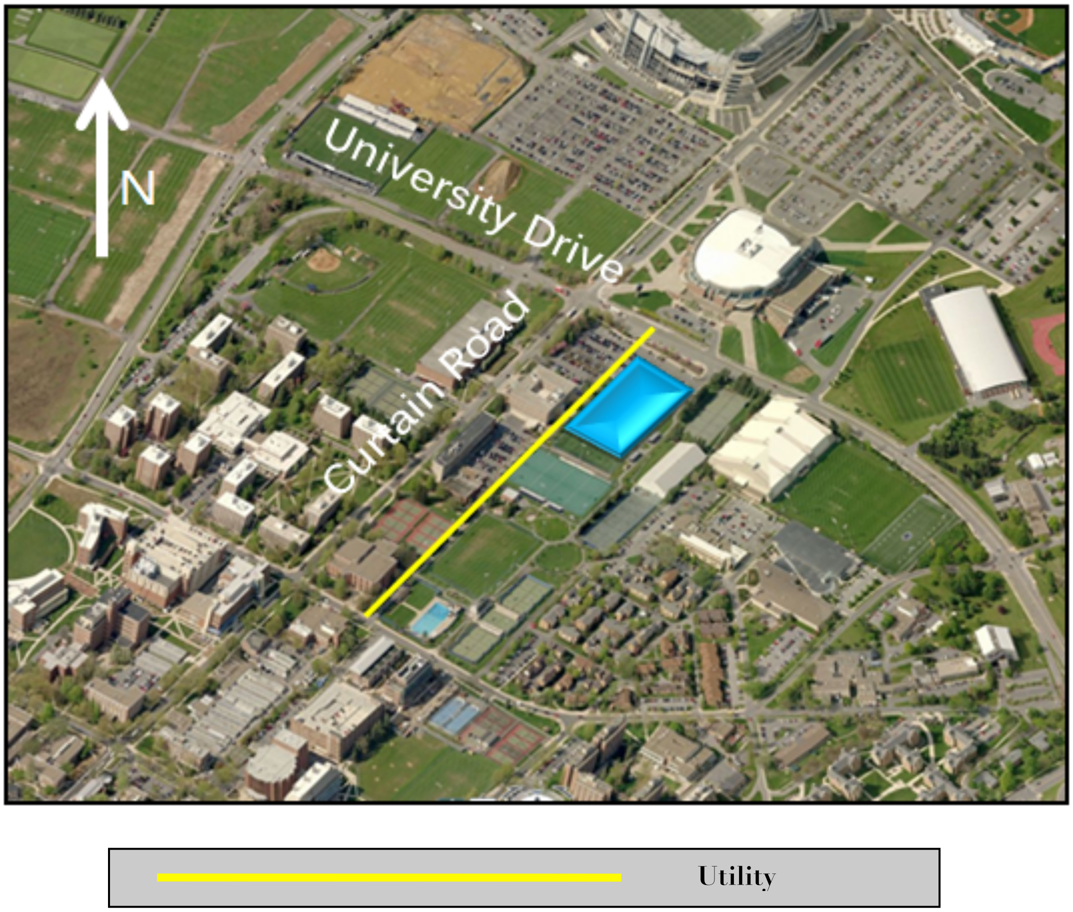


Figure 1: Site & Surroundings

Each floor is occupiable, with the event level hosting the ice sheets, office spaces, locker rooms, and training rooms. The main concourse level, where the main and student entrances are located, has restaurant services, concession stands, and the Mt. Nittany room. There are 14 suites and 2 loge boxes for the Penn State President and donors. The main competition arena will be able to hold 6,000 spectators, while the auxiliary arena will hold 300 spectators.

Existing Architecture

The existing architectural style of the Penn State Ice uses many of the common building materials found on campus. It is mostly brick with a large glass eastern façade. The current design calls for a slightly pitched metal deck roof. Many features of the building are geared towards enhancing the audience's experiences, the large vomitories, panoramic vistas, and optimize viewing angles among many others.

Both sheets of ice are on the event level (shown in Figure 2) along with building administration offices, visitor locker rooms, team locker rooms and team support areas. The main arena ice sheet plays host to the men and women varsity hockey program. The second sheet, the community rink, has been branded the "workhorse" of the facility and will service local patrons and leagues. The entrance for the community rink side of the facility is located on the southeastern side of the building. The electrical, mechanical, and ice plant rooms are all located on the western corner of the event level.

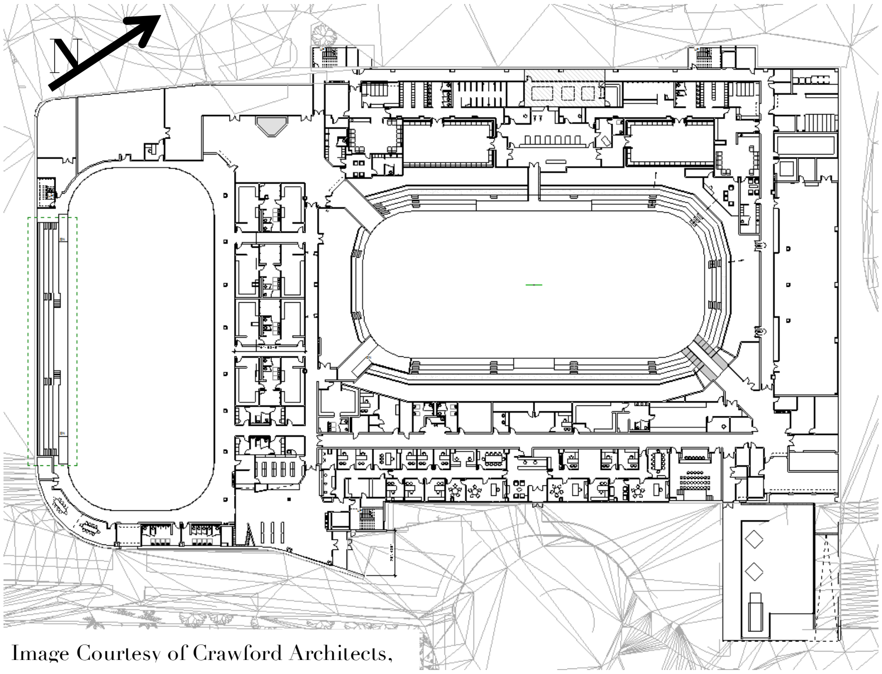


Image Courtesy of Crawford Architects,

Figure 2: Event Level Floor Plan

The main concourse level, shown in Figure 3, will be the level in which the majority of patrons will occupy during a game. It holds all of the main vomitories to enter the arena bowl as well as restrooms and concessions. The main building entrance is located on the northern corner of the building; patrons of the building are greeted by a 2 story atrium which opens up to three options for traveling around the building, the main concourse which wraps the main bowl, a grand stair case to the club level and a large vomitory into the arena bowl. The main student entrance is located on the west façade.

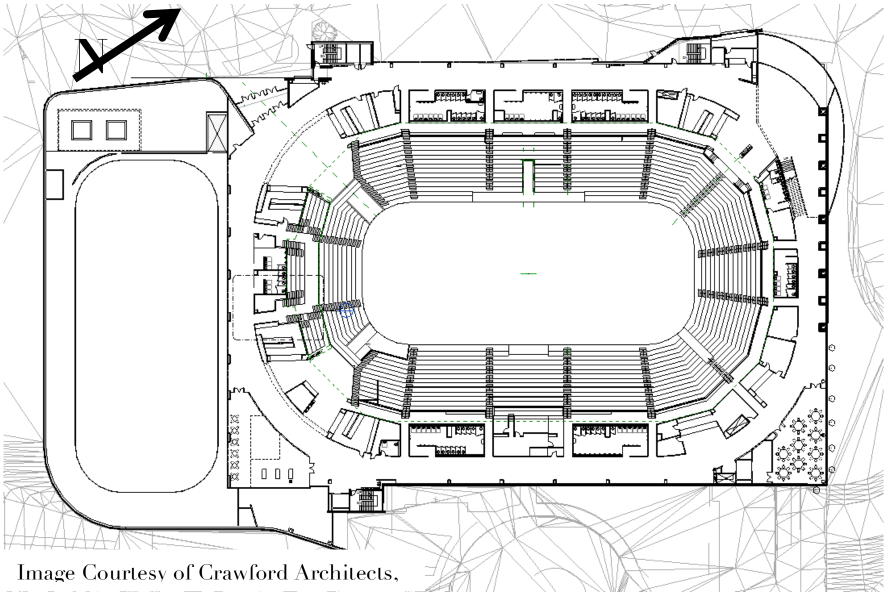


Image Courtesy of Crawford Architects,

Figure 3: Main Concourse Level Floor Plan

Moving to the top level of the facility is the club level (Figure 4); within this level are the club suites, club lounge, a dining space and a kitchen to support the suites and the dining space.

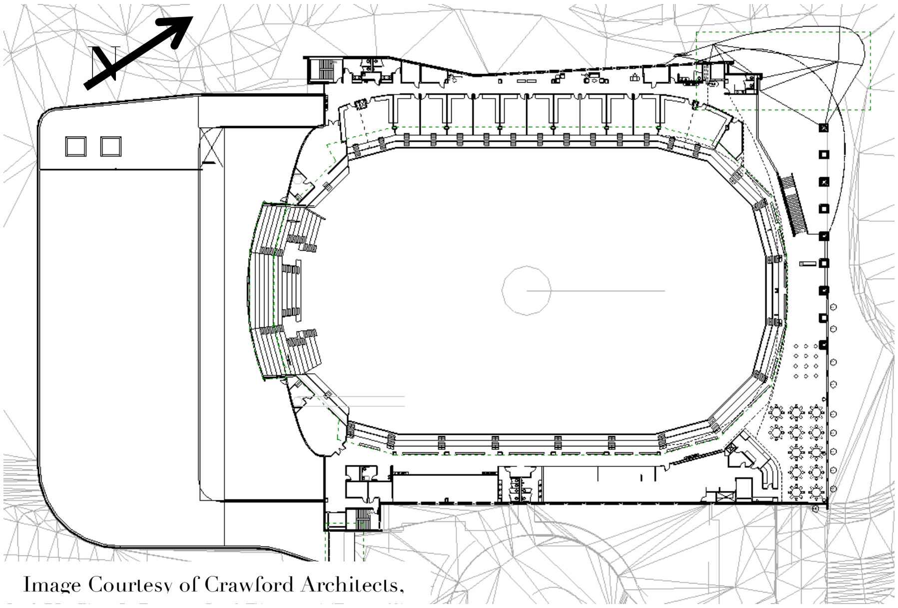


Image Courtesy of Crawford Architects,

Figure 4: Club Level Floor Plan

Existing Façade & Building Enclosure

The existing exterior façade architectural style of the ice arena is one that has graced the Penn State campus for many years. Large facades made of mostly brick with penetrations coming from the windows. One exception to this standard is northeast façade. In the preliminary designs this façade is a large glass curtain wall spanning the entire width of the building and wrapping the corners.

Existing Structural System

The foundation system for the Penn State Ice Arena consists of a combination of micropiles with pile caps, grade beams, isolated footings and strip footings. Micropiles with pile caps are used west of the main competition arena where the elevation of top of bedrock may vary. Isolated footings are used on all interior columns around the main competition bowl and strip footings are utilized around the exterior walls of the arena. Figure 5 shows the current foundation system with the area around the main competition bowl that is anticipated to be micro piles with pile caps.

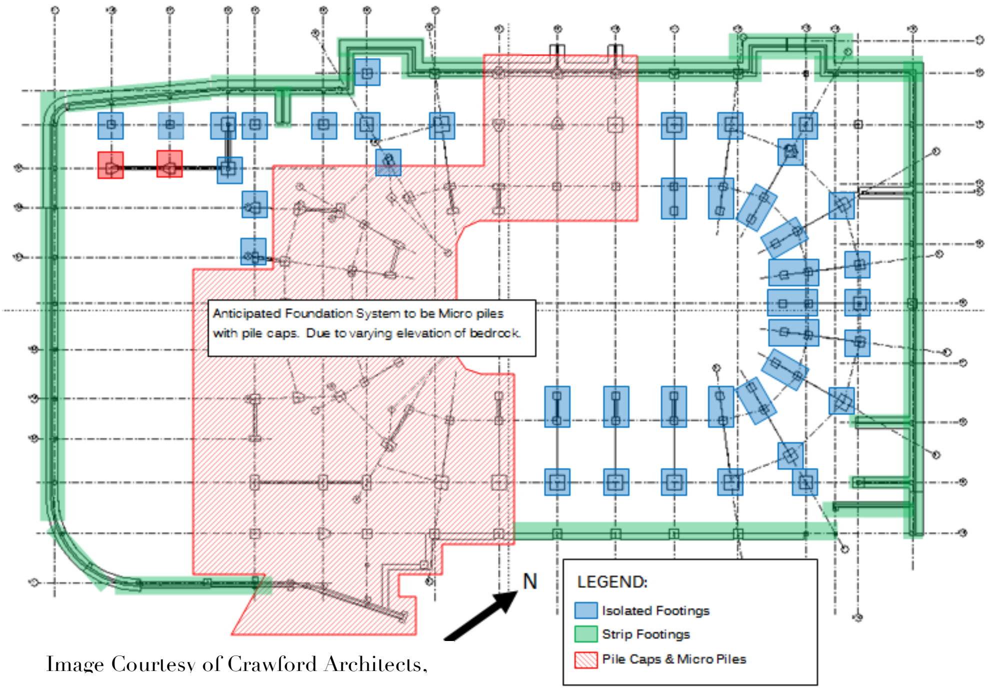


Image Courtesy of Crawford Architects,

Figure 5: Existing Foundations Systems

The event level flooring systems are slabs on grade, all at the same elevation. In the plan northwest corner of the arena, between the event level and the main concourse level, is a depressed floor slab that is utilized for hiding mechanical equipment. This depressed slab consists of a 7 ½" NWC composite slab with W18 beams and W24 girders framing members.

All concrete used on the Penn State Ice Arena project is 4,000 psi with the exception of formed slabs, which utilizes 5,000-psi normal weight concrete. Steel reinforcement both in the foundation system and throughout all other concrete walls is 60 ksi.

The event level is on the same elevation and covers the entire footprint of the arena. There is a 20'-9" floor-to-floor height from the event level to the main concourse level. A 12" concrete foundation wall frames the full 20'-9" dimension between the event level and main concourse level from the northeast corner to the west corner of the facility. The east side of the building footprint has no foundation wall and between the west corner and the south corner of the building, the foundation wall tapers down with the grade change.

Around the main competition sheet of ice, the main concourse level and club level consist of the typical one way, 7 ½" NWC composite slab on 3 inch, 18 gauge VLI composite deck with W18 beams and W24 girders framing. The beams and girders frame into W18 exterior columns and W24 interior columns at the intersection of grid lines. Typical bays on these levels range from 37'-2" x 28'-0" (largest bay) to 28'-8" x 28'-0" (smallest bay).

Special structural framing that is unique to the ice arena consists of the main competition bowl being made up of a precast "tub" which contains precast seating treads and risers supported on W30 sloped beams and intermediate HSS steel members. Additionally, both the competition and practice sheets of ice are installed over top a 6" slab on grade that is insulated to avoid slab upheaval due to freeze/thaw cycles throughout the year.

Long span, simply supported steel trusses span 196'-0" from column line Y3 to Y9 running north-south with bracing trusses spanning 240'-5" from column line X6 to X13 running east-west. The top and bottom chords for all trusses are W14's with double angles utilized as the diagonals.

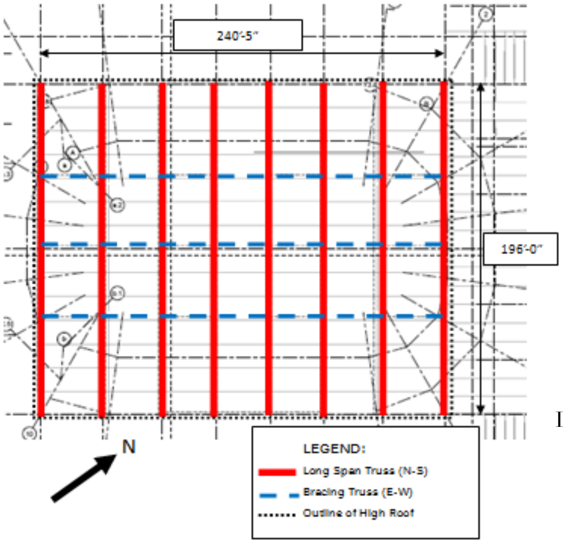


Image Courtesy of Crawford Architects,

Figure 6: High Roof Framing Plan

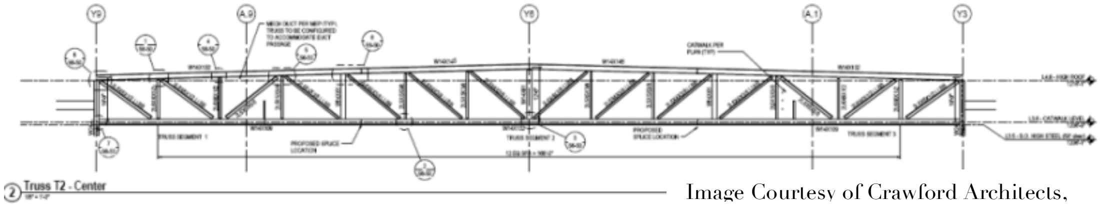


Image Courtesy of Crawford Architects,

Figure 7: Simply Supported Existing Long Span Truss

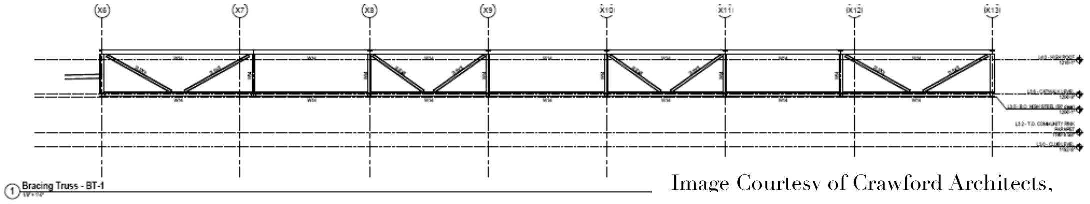


Image Courtesy of Crawford Architects,

Figure 8: Bracing Long Span Truss

Figure 6 shows a simplified high roof-framing plan. The high roof sits approximately 5'-11" above the flat lower roof. The simply supported truss, shown in Figure 7, is sloped slightly to a high point in the middle. These trusses are 10'-0" deep at the exterior supports and 13'-9" at mid-span. The bracing trusses, shown in Figure 8, are not sloped and are a constant 10'-0" deep. Bottom of the high steel is 50'-0" clear from the top of the ice, ideal for an ice hockey arena. Intermediate framing between these trusses support 3 inch, 18-gauge roof deck.

The lower flat roofs on either side of the long span high roof span the 28' wide north and south concourses around the competition arena with 24K8 bar joists. This low roof system slopes up on the north side of the building to meet the high rooftop of steel to create a grand entry at the northern main entrance of the facility. Additionally, the community rink roofing system consists of sloped deep long span trusses that span the 110' wide space.

The lateral system for the arena consists of a combination of moment frames, braced frames and shear walls. Shear walls are designed starting from the event level and terminating at the main concourse level. The main concourse level has a small two bay-braced frame running along column line D between column lines 12 – 13. This is the sole braced frame designed in the facility and extends up another level to the event level.

The majority of the lateral systems are designed as moment frames at the club level. Moment frames run the east-west direction above both the north and south concourse along column lines Y2.3 and Y10 ranging from column lines X7 to X12. Additional moment frames run north- south at these locations on all grids lines from X8 to X13. The lateral system for the Penn State Ice Arena is shown in Figure 9.

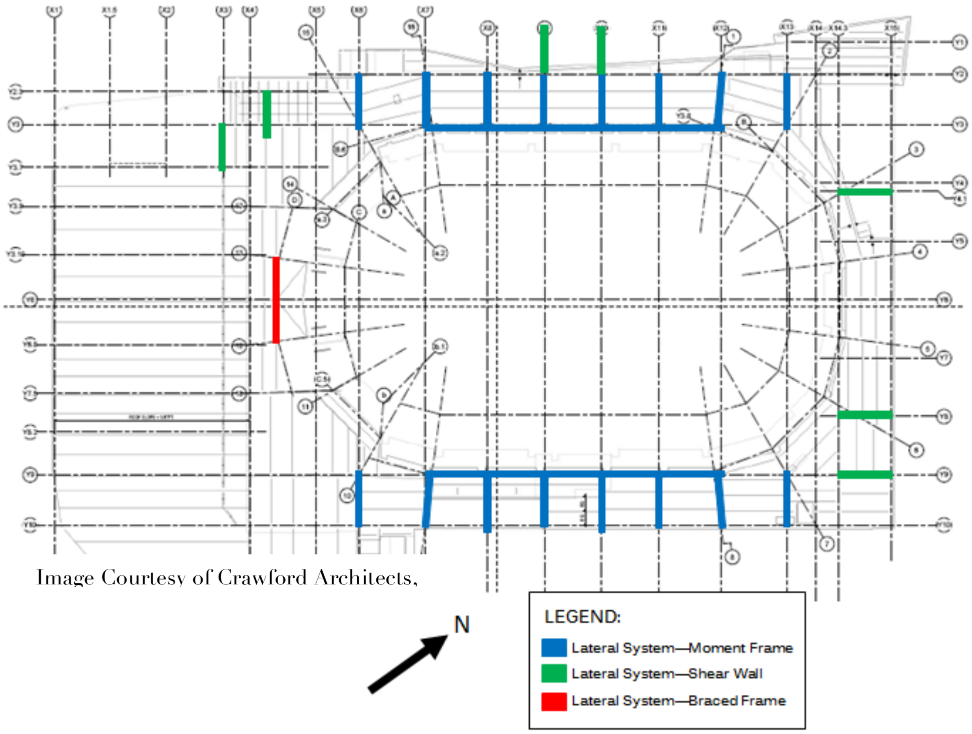


Image Courtesy of Crawford Architects,

Figure 9: Existing Layout for the Arena Lateral Systems

Existing Mechanical System

The current design for the Penn State Ice Arena uses the campus chilled water plant to provide chilled water for space cooling and the campus steam plant to meet loads. The low-pressure steam from the pressure reducing valve (PRV) station puts the steam through a heat exchanger and the building ultimately uses hot water.

The building is served by 12 air-handling units (AHU 1-12), and 2 dehumidifying units (AHU 13, 14). The twelve air-handling units can be divided in to three separate categories:

1. Energy recovery and dehumidification
2. Energy recovery
3. Economizer

Group 1 (AHU 10-12) serves the main competition bowl and the community ice rink where it is important to control humidity. These areas are also served by the two dehumidification units. Group 2 (AHU 5, 7, 8, 9) serves both of the varsity looker rooms and the community looker rooms as well as the offices. The energy recovery is done with a heat pipe. Group 3 (AHU 1-4, 6) serves the concourses, kitchen, restaurant, and weight room. The economizer is important in these areas because the occupancy is transient; if the amount of outdoor air can be controlled based on both outside temperature and occupancy there can be drastic energy savings. The remaining spaces are served by separate fan coil units.

The air-handling units are located on the roof above the concourse level. Supply ducts from the two units serving the main arena bowl are able to penetrate into the main arena while that of the other units must go down through mechanical shafts. AHU 7, 8, 13, 14 are located on the concourse level, not the roof.

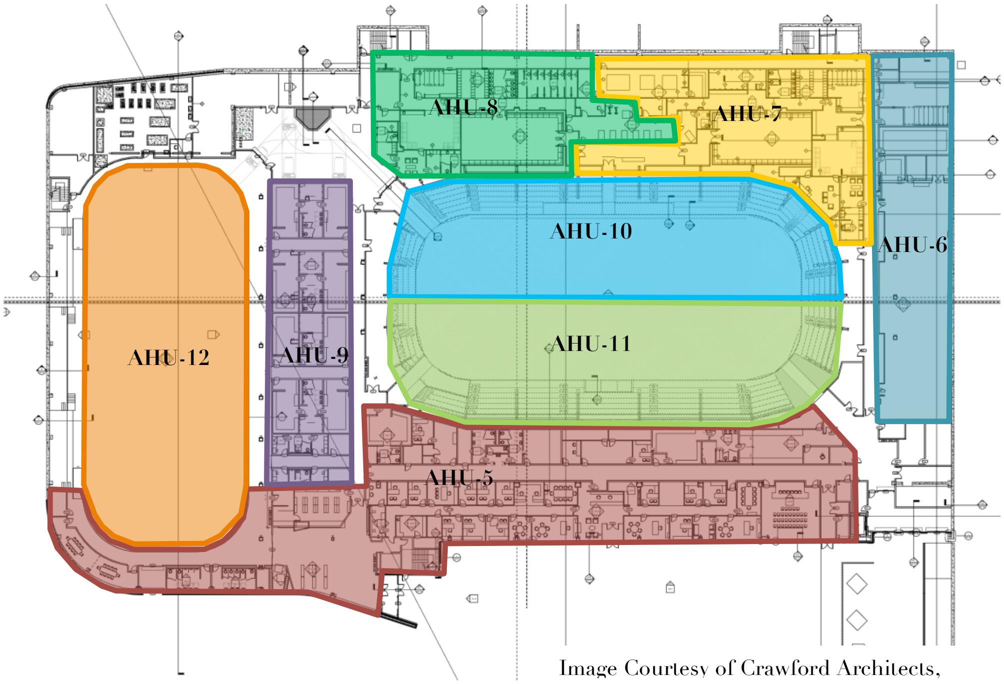


Image Courtesy of Crawford Architects,

Figure 10: Existing AHU Zoning for the Event Level

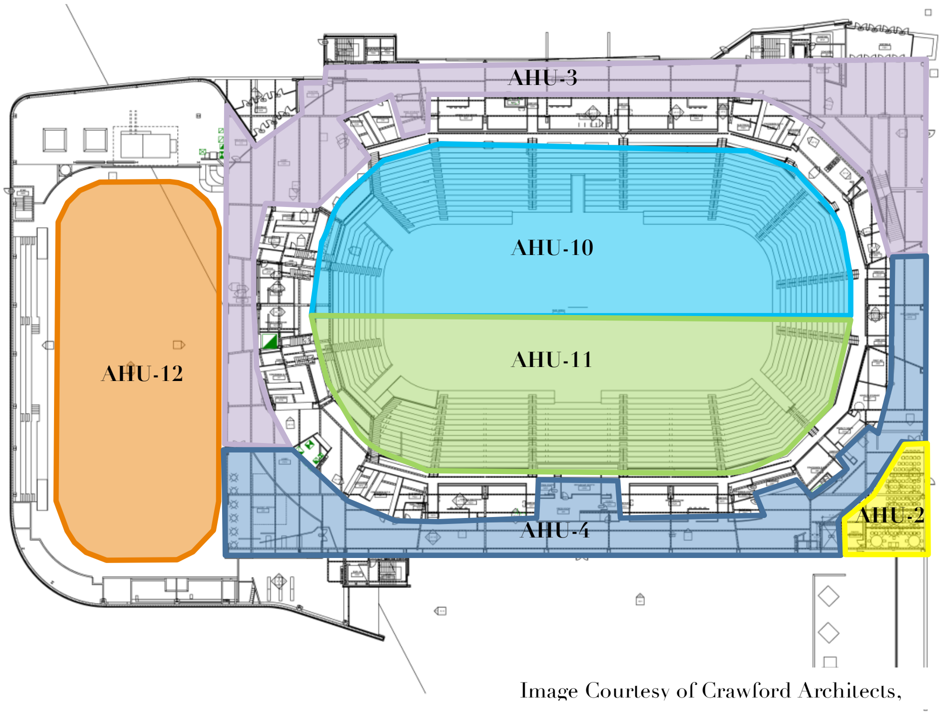


Figure 11: Existing AHU Zoning for the Concourse Level

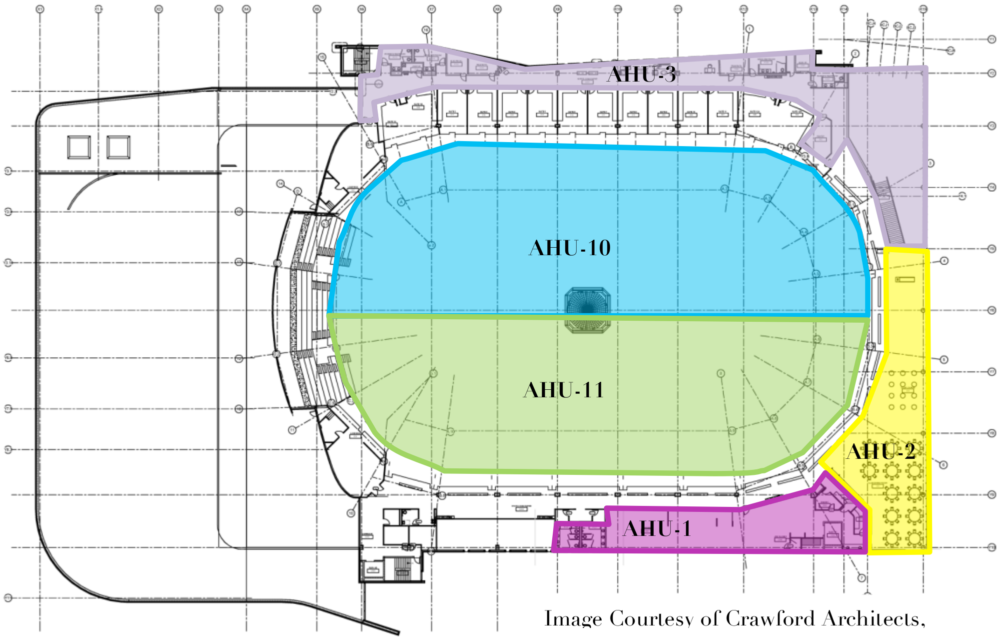


Figure 12: Existing AHU Zoning for the Club Level

Existing Lighting Systems

The lighting systems for the Penn State Ice Arena are all served on a 277V distribution system. The main arena has 1000 watt metal halide indoor sports lighting fixtures with black out shutters. An array of linear fluorescent hi-bay luminaries is placed to light the community rink. Other areas, including the concourse, lockers, concessions, restrooms, and lounges of the building do not have lighting specified in the set of drawings provided at the beginning of the year. Site lighting is provided on both the northwest and the southeast side of the buildings by a pole mounted Louis Poulson fixture that is standard for Penn State. This fixture has a 100 watt metal halide lamp and is mounted at 12' above finished grade. Lighting in the parking lot is provided by Lumark Tribute Series, which contains a 250 watt high pressure sodium lamp mounted at 25', this also is the Penn State standard.

Lighting controls for the building are not specified in the set of drawings provided at the beginning of the year.

Existing Electrical Systems

The normal building electrical service is provided by the Penn State campus loop and is rated at 12,470 Volts. Two pad mounted transformers reduce the voltage to the building operational voltage of 480Y/277 Volts. Each of the transformers is rated at 2,500 KVA and serves one side of the building's double-ended substation (main-tie-main). The substation consists of two main switchboards rated at 3000 Amps each. One of the main switchboards has service disconnects that feed the critical and equipment automatic transfer switches. Beyond the main switchboard lie distribution panels for both equipment and lighting rated at 480Y/277 Volts. An emergency automatic transfer switch is served from the equipment distribution panel. Step down transformers are also used throughout the building to service the receptacle load.

Emergency building electrical services are provided by the Penn State emergency campus loop and are rated at 4,180 Volts. A separate transformer is used to step down the primary voltage to 480Y/277 Volt. This transformer serves the emergency automatic transfer switch, rated at 200 Amps. The emergency distribution system has the same basic hierarchy as the normal system, with a distribution panel serving the load and step down transformers.

Construction Management

In September 2010, a private donor provided Penn State with a gift and the opportunity to build a Penn State Ice Hockey Arena for its Division 1 men's and women's hockey teams. This donation was made in the amount of $88 million, with an additional private donor donating $1 million. Of the $89 million donation, $73 million has been budgeted for the development and construction of this project. Mortenson Construction has been selected as the project management firm. The teams will officially become a Division 1 program in the 2012 to 2013 hockey season, but the facility will not be completed until the 2013 to 2014 season. Preconstruction will begin in January 2012, with construction slated to begin in March 2012. Construction is expected to be completed by September 2013. The project is being delivered as a Design-Build project with a LEED Gold Certification.

Building Information Modeling Process – Actual Project

The Penn State Ice Hockey Arena project is utilizing the use of a building information model and the process of Building Information Modeling (BIM) throughout design, construction and the operations phases of this facility. Penn State University is a progressive institution in research and development of processes for the building industry. The institution requires that all projects exceeding a total project cost of $5 million in new construction, substantial renovation or as directed by the Office of the Physical Plant (OPP), the university owner's representatives, **MUST** be designed and constructed using the BIM process.

The following section of this report will briefly describe the BIM process, the contract language that has been adopted for the project and an overview of the Building Information Modeling Execution Plan that has been established on the project.

Contract Language

The Penn State Ice Hockey Arena project utilizes the standard "Form of Agreement 1-P" Owner and Design Professional contract language, which is a custom contract that has been developed by the Office of the Physical Plant for any new construction or renovations within any of the Pennsylvania State University campuses. HPR Integrated Design has obtained the standard OPP contract language but due to sensitivity with this information, it has not been included as part of this report's appendix per agreement with the University for its release.

This project exceeds the $5 million dollar milestone for new construction and therefore meets the criteria necessary for BIM implementation on the project. In addition to the standard contract language, Form of Agreement 1-P, OPP has developed in-house Building Information Modeling (BIM) Contract Addendum v1.1 to cover the additional requirements that are associated with a BIM project. The Building Information Modeling (BIM) Addendum v1.1 includes contract language about the following:

- The Project Team shall develop a BIM Project Execution Plan (BIM Ex Plan)
- BIM Uses to include Design Authoring and an as-built BIM Model for integration with Penn State's facility maintenance program.
- Quality Control
- BIM Model Submission Requirements
- BIM Model Responsibilities
- Ownership, Rights, and Liabilities in data
- BIM Schedule of Values – Additional Costs for BIM implementation

This information must be developed by all design entities associated with the Penn State Ice Hockey Arena project prior to programming and design. Once awarded the project, the design and construction entities developed a BIM implementation strategy and implementation plan that will be explained in further detail in the following section.

BIM Execution Plan – Actual Project

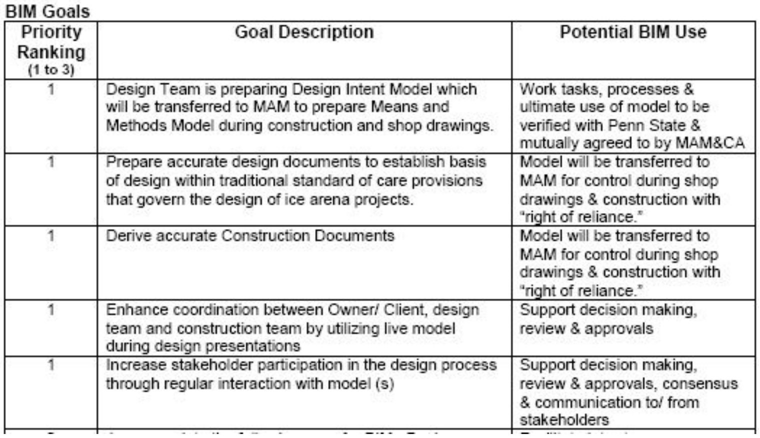
The Penn State Ice Hockey Arena project team developed a BIM Execution Plan that was derived from Penn State University's OPP BIM Project Execution Plan Template v2.0. The development of this document was led by Crawford Architects and includes the following:

- Identified each entities key contacts throughout the process
- Developed BIM goals and BIM uses
- Established the BIM infrastructure (software platforms for design)
- Determined BIM model ownership and liabilities during design and construction
- Developed BIM Information Exchanges and process maps
- Determined Level of Detail (LOD) matrix for the BIM model

The BIM Ex plan was a very important step early in the BIM process to develop key processes that allow for the reduction of liability and increase in efficiency throughout the project. The following sections of this report will briefly touch on the different established processes for comparison to HPR Integrated Design's developed BIM Ex plan and processes.

BIM Goals and BIM Uses

The Office of the Physical Plant requires per contract language in the BIM Addendum v1.1 that BIM uses must include design authoring and operations and facility maintenance data input (6D). The project team developed BIM goals that include increasing field productivity by 10%, conduction conflict resolution during design, creating accurate design documents, etc. Figure 13, shows a portion of the BIM goals chart extracted from the actual project's BIM Execution Guide.



BIM Goals

Priority Ranking (1 to 3)	Goal Description	Potential BIM Use
1	Design Team is preparing Design Intent Model which will be transferred to MAM to prepare Means and Methods Model during construction and shop drawings.	Work tasks, processes & ultimate use of model to be verified with Penn State & mutually agreed to by MAM&CA
1	Prepare accurate design documents to establish basis of design within traditional standard of care provisions that govern the design of ice arena projects.	Model will be transferred to MAM for control during shop drawings & construction with "right of reliance."
1	Derive accurate Construction Documents	Model will be transferred to MAM for control during shop drawings & construction with "right of reliance."
1	Enhance coordination between Owner/ Client, design team and construction team by utilizing live model during design presentations	Support decision making, review & approvals
1	Increase stakeholder participation in the design process through regular interaction with model (s)	Support decision making, review & approvals, consensus & communication to/ from stakeholders

Figure 13: Established BIM Goals - Actual Project

BIM Uses were then determined using the BIM goals that include 3D clash detection, energy analysis, design authoring, facility operation data integration (6D), building envelope analysis and other uses that were in addition to contractual requirements.

BIM Infrastructure – Design & Construction

The actual project team will utilize Revit v.2012 (A/MEP/S) for design authoring, AutoCAD 2012 (2D and 3D), SketchUp v8.0, 3DS Max v. 2012 and other analytical programs for use during the design portion of the ice arena. During construction the project team will utilize BIM technologies such as Primavera P6 (scheduling), Navisworks v.2012, MasterSpec (documentation control) and Synchro for 4D scheduling analysis.

BIM Information Exchanges and Model Ownership

The actual project team will utilize a federated modeling platform, which includes an architectural design basis model only. This model was developed by the architect and MEP designers that is being utilized by the construction manager to develop means and methods only. The BIM model was developed and resided with the architect until design was completed in February 2012.

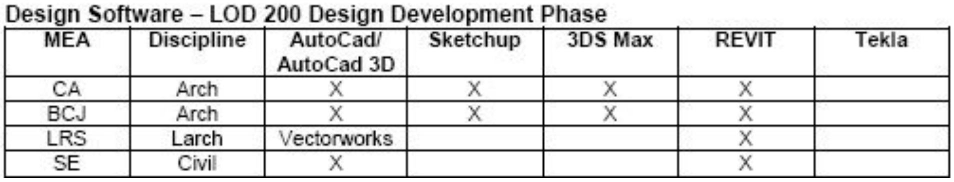
At this time, a federated model approach was adopted which consists of an architectural model and an additional construction model that run parallel throughout the project for liability reasons. Responsibility for these models was not confirmed at the time of this updated BIM Ex release. The construction model will incorporate shop drawing level models for the various systems while the architectural model will continue with updates from bulletins and RFI changes throughout construction. At the end of the construction process the models will be linked together to create an as-built model for integration with Penn State's facility management software MAXIMO.

Level of Development (LOD) Matrix

Level of Development definitions were established in the BIM Execution Guide as a project team with the following as a result:

- Level 100 – Schematic Design
- Level 200 – Design Development
- Level 300 – Construction Documentation
- Level 400 – Construction Administration/ Shop Drawings
- Level 500 – Record Drawings/As-Built

A matrix including all project team entities and software platforms was created to determine to what level of detail the models must be created at each milestone in the project. Below, Figure 14 shows a sample of one of these charts.



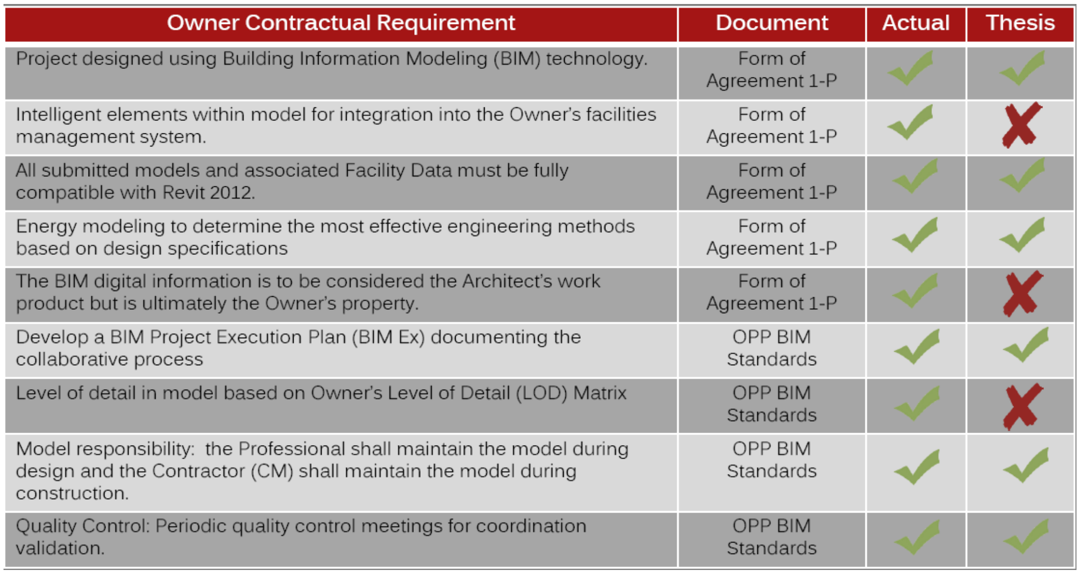
Design Software – LOD 200 Design Development Phase

MEA	Discipline	AutoCad/ AutoCad 3D	Sketchup	3DS Max	REVIT	Tekla
CA	Arch	X	X	X	X	
BCJ	Arch	X	X	X	X	
LRS	Larch	Vectorworks			X	
SE	Civil	X			X	

Figure 14: LOD Matrix - Design Development for Actual Project

Building Information Modeling Process - Thesis

As a part of the BIM thesis, HPR Integrated Design met with the Owner's representative to obtain actual project contractual documentation and requirements to establish real world constraints. Since this academic endeavor does not have contractual constraints HPR Integrated Design did not conform to the University's standard contract language from the Form of Agreement 1-P and 1-C. HPR Integrated Design did recognize OPP's Building Information Modeling (BIM) Addendum v.1.1. The requirements for this document are described in the actual project section for Building Information Modeling above. Figure 15, shows a comparison of how HPR Integrated Design approached the contractual language on this project:



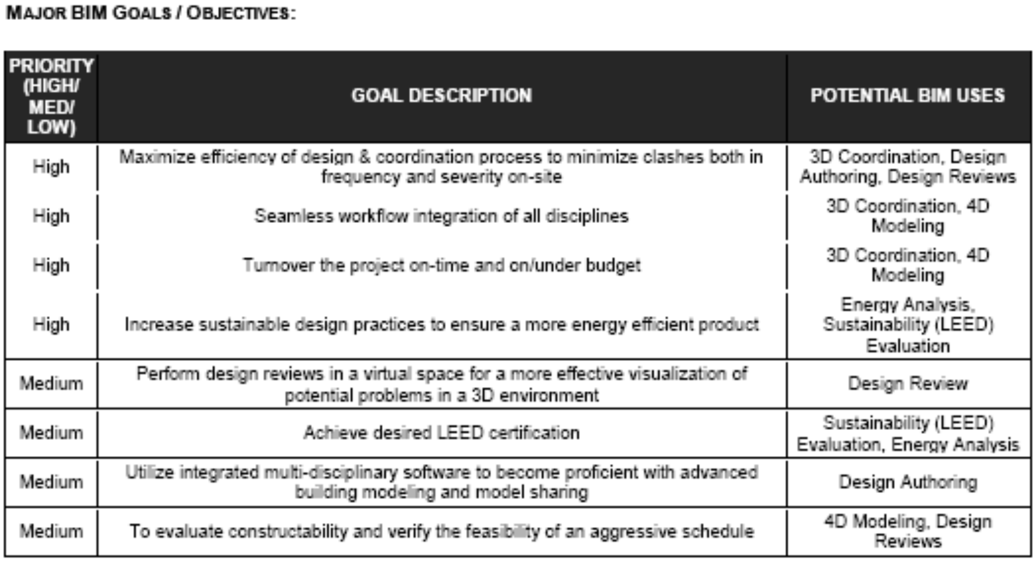
Owner Contractual Requirement	Document	Actual	Thesis
Project designed using Building Information Modeling (BIM) technology.	Form of Agreement 1-P	✓	✓
Intelligent elements within model for integration into the Owner's facilities management system.	Form of Agreement 1-P	✓	✗
All submitted models and associated Facility Data must be fully compatible with Revit 2012.	Form of Agreement 1-P	✓	✓
Energy modeling to determine the most effective engineering methods based on design specifications	Form of Agreement 1-P	✓	✓
The BIM digital information is to be considered the Architect's work product but is ultimately the Owner's property.	Form of Agreement 1-P	✓	✗
Develop a BIM Project Execution Plan (BIM Ex) documenting the collaborative process	OPP BIM Standards	✓	✓
Level of detail in model based on Owner's Level of Detail (LOD) Matrix	OPP BIM Standards	✓	✗
Model responsibility: the Professional shall maintain the model during design and the Contractor (CM) shall maintain the model during construction.	OPP BIM Standards	✓	✓
Quality Control: Periodic quality control meetings for coordination validation.	OPP BIM Standards	✓	✓

Figure 15: Contractual Language Comparison

To conform to the OPP BIM Addendum, HPR Integrated Design developed a BIM Execution Plan utilizing the Penn State University's OPP BIM Project Execution Plan Template v2.0. The following sections of this report will summarize the communication processes, BIM Goals and Uses, model management and level of development matrices.

BIM Goals and Uses

Through collaboration between disciplines and as a team acting as the architect, HPR Integrated Design developed BIM Goals for the BIM thesis project. Major BIM goals include creating seamless workflow integration between all of the disciplines, design a project that is on-time and on/under budget, and maximize the efficiency of the design & coordination process to minimize clashes. A complete list of HPR Integrated Design's BIM Goals can be found in Figure 16 below.



MAJOR BIM GOALS / OBJECTIVES:

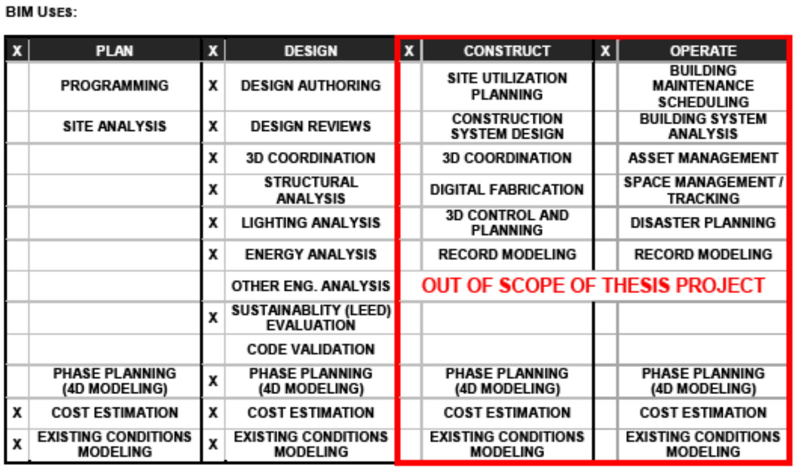
PRIORITY (HIGH/ MED/ LOW)	GOAL DESCRIPTION	POTENTIAL BIM USES
High	Maximize efficiency of design & coordination process to minimize clashes both in frequency and severity on-site	3D Coordination, Design Authoring, Design Reviews
High	Seamless workflow integration of all disciplines	3D Coordination, 4D Modeling
High	Turnover the project on-time and on/under budget	3D Coordination, 4D Modeling
High	Increase sustainable design practices to ensure a more energy efficient product	Energy Analysis, Sustainability (LEED) Evaluation
Medium	Perform design reviews in a virtual space for a more effective visualization of potential problems in a 3D environment	Design Review
Medium	Achieve desired LEED certification	Sustainability (LEED) Evaluation, Energy Analysis
Medium	Utilize integrated multi-disciplinary software to become proficient with advanced building modeling and model sharing	Design Authoring
Medium	To evaluate constructability and verify the feasibility of an aggressive schedule	4D Modeling, Design Reviews

Figure 16: Thesis BIM Goals

Through the creation of BIM Goals for the thesis project, HPR Integrated Design chose appropriate BIM uses from a list derived from OPP BIM Project Execution Plan Template v2.0. Major BIM uses include:

- Design Authoring
- 3D Clash Detection
- Construction Sequence Planning (4D Scheduling)
- Cost Estimation (5D)
- Structural, Lighting, and Mechanical Analysis

Figure 17 shows HPR Integrated Design's BIM Use chart from Section D of the BIM Execution Plan. HPR's entire BIM Execution Plan is located on the HPR website.



BIM USES:

X	PLAN	X	DESIGN	X	CONSTRUCT	X	OPERATE
	PROGRAMMING	X	DESIGN AUTHORING		SITE UTILIZATION PLANNING		BUILDING MAINTENANCE SCHEDULING
	SITE ANALYSIS	X	DESIGN REVIEWS		CONSTRUCTION SYSTEM DESIGN		BUILDING SYSTEM ANALYSIS
		X	3D COORDINATION		3D COORDINATION		ASSET MANAGEMENT
		X	STRUCTURAL ANALYSIS		DIGITAL FABRICATION		SPACE MANAGEMENT / TRACKING
		X	LIGHTING ANALYSIS		3D CONTROL AND PLANNING		DISASTER PLANNING
		X	ENERGY ANALYSIS		RECORD MODELING		RECORD MODELING
			OTHER ENG. ANALYSIS	OUT OF SCOPE OF THESIS PROJECT			
		X	SUSTAINABLITY (LEED) EVALUATION				
			CODE VALIDATION				
	PHASE PLANNING (4D MODELING)	X	PHASE PLANNING (4D MODELING)		PHASE PLANNING (4D MODELING)		PHASE PLANNING (4D MODELING)
X	COST ESTIMATION	X	COST ESTIMATION		COST ESTIMATION		COST ESTIMATION
X	EXISTING CONDITIONS MODELING	X	EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING

Figure 17: Thesis BIM Uses

Communication Processes

HPR Integrated Design continued to develop the BIM Execution Plan early in the fall semester to establish meeting times & locations, communication flow between disciplines and also advisors. HPR developed BIM roles and responsibilities and allocated anticipated time and resources to each BIM use established in section D of the BIM Execution Plan. The information in the following sections can be found in Section E: Organizational Roles/Staffing and Section I: Collaboration Procedures of the HPR Integrated Design BIM Execution Plan.

Communication Flow

HPR Integrated Design documented the process of communication flow between all appropriate personnel involved with the BIM thesis. Communication between course administrators, course advisors, professional practitioners and individual members of the group was established and documented according to Figure 18 below.

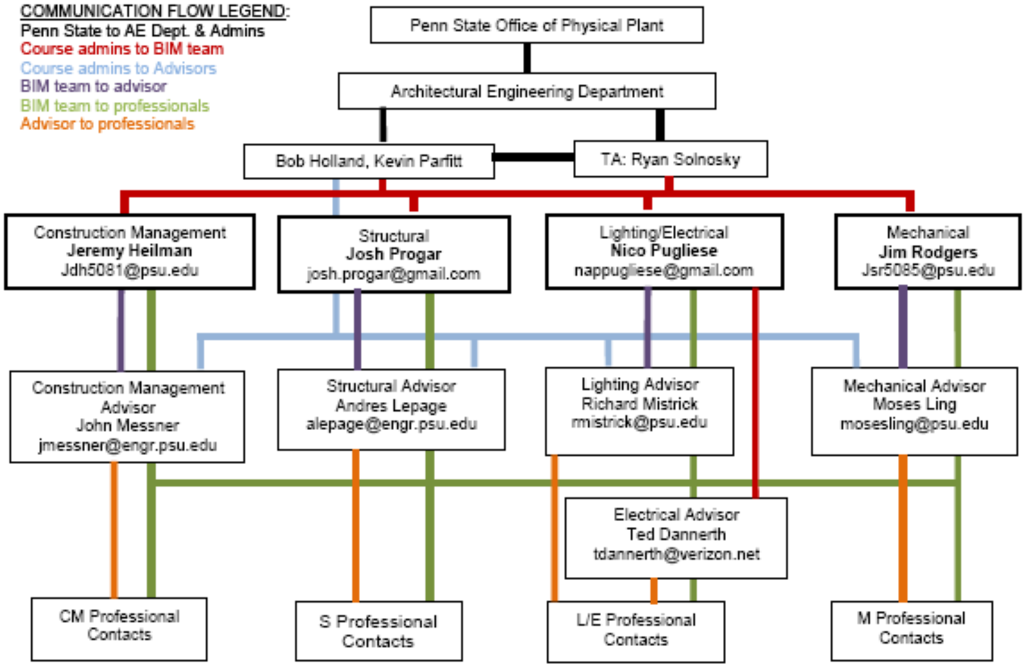


Figure 18: Communication Flow Diagram

This process was completed not out of necessity for this project but as an attempt to follow Owner requirements to develop BIM Implementation strategies which would be much more complex on a real project with multiple entities. Additionally, the construction manager assigned BIM roles and responsibilities to all disciplines and HPR Integrated Design developed an anticipated time and resource allocation for each BIM Use. This information along with the BIM roles and responsibilities can be found in Section E: Organizational Roles/Staffing of the HPR BIM Execution Plan.

Collaboration Procedures

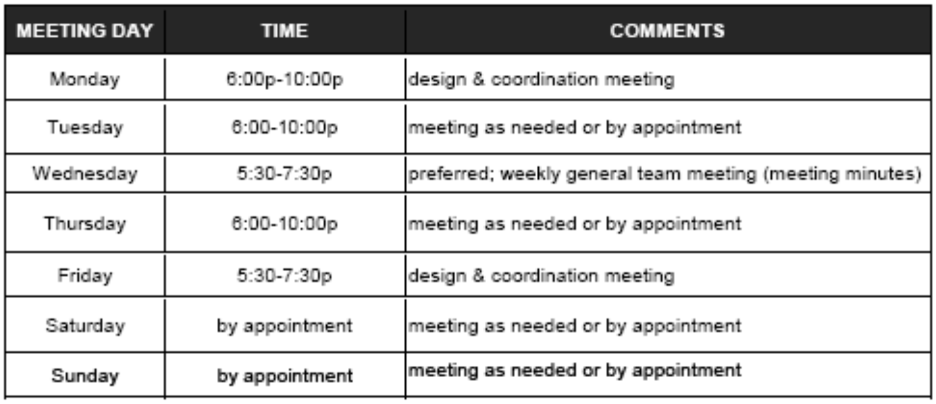
HPR Integrated Design decided as a design team at the beginning of the process that for efficiency design & coordination to occur, collaboration procedures had to be established and refined early in the thesis project to allow for effective team integration. Section I of HPR's BIM Execution Guide was used to document all of the team's collaboration procedures. In this section information about collaboration strategies, meeting procedures, information exchanges and conflict resolution were established in accordance with team discussions early in the project.

Collaboration and Meeting Procedures:

Collaboration procedures were documented to remind the design team of the commitment of collaborative design throughout the project. HPR's commitment to BIM meant valuing other team members input and knowledge supplemented with knowledge of the expert in each discipline to create a high quality product. HPR established that collaboration techniques would include:

- Group Meeting (Primary)
- Autodesk Project Bluestreak
- Texting List-Servs
- Email
- Meeting Minutes

HPR Integrated Design established primary and secondary forms of communication with face to face interactions as encouraged when possible. HPR Integrated Design integrated class and personal schedules using Google Calendars to create a weekly meeting schedule. The schedule is shown in Figure 19, laying out all meetings for different meeting types.



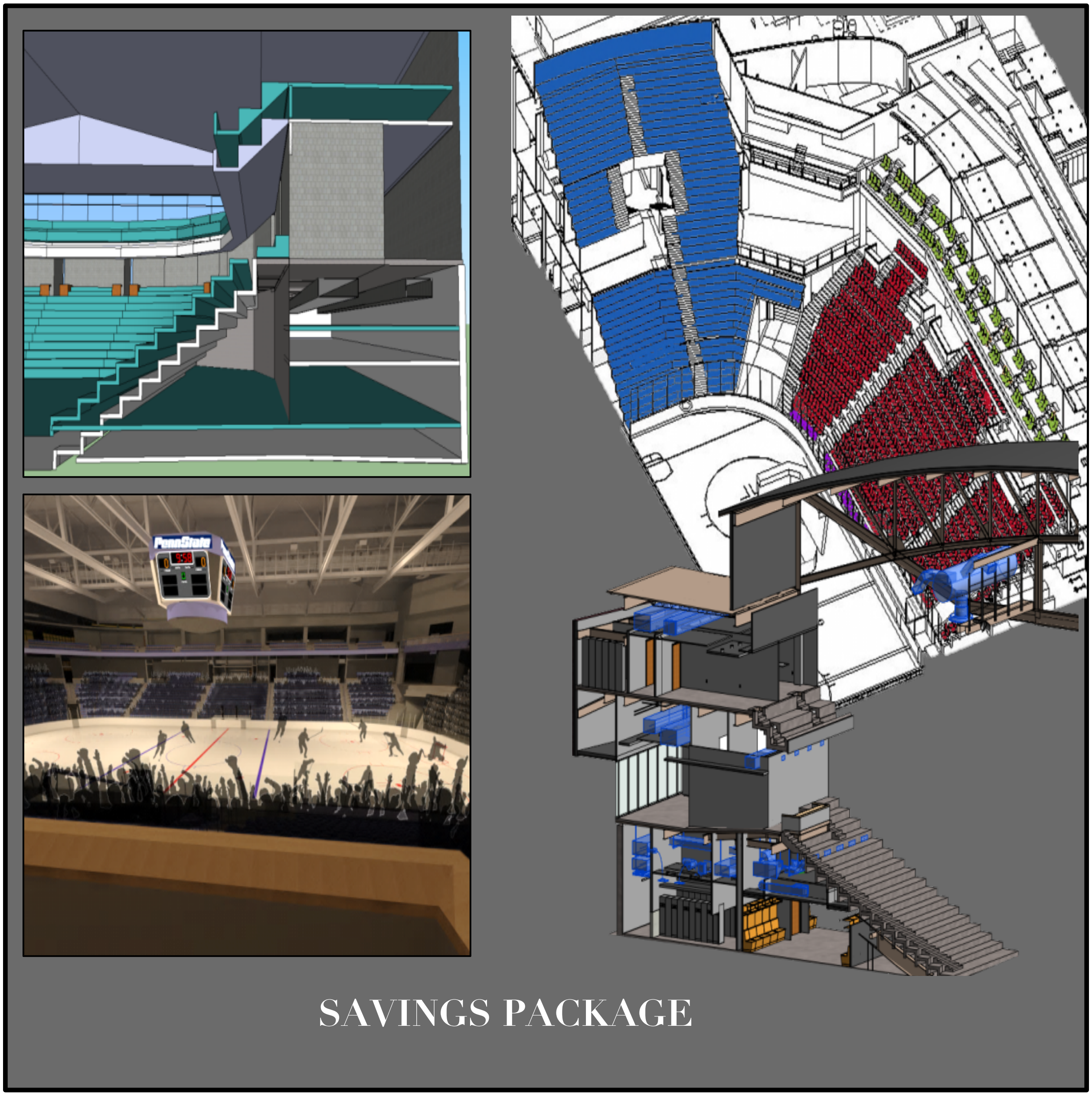
MEETING DAY	TIME	COMMENTS
Monday	6:00p-10:00p	design & coordination meeting
Tuesday	6:00-10:00p	meeting as needed or by appointment
Wednesday	5:30-7:30p	preferred; weekly general team meeting (meeting minutes)
Thursday	6:00-10:00p	meeting as needed or by appointment
Friday	5:30-7:30p	design & coordination meeting
Saturday	by appointment	meeting as needed or by appointment
Sunday	by appointment	meeting as needed or by appointment

Figure 19: Weekly Meeting Schedule

Conflict Resolution:

As a part of the BIM thesis, any architectural decisions had to be made as a collaborative result of all disciplines having equal input. HPR Integrated Design established conflict resolution procedures to allow for the resulting to decision to be as fair and as educated as possible.

Savings Package



Opportunity Statement

Through review of the current design bid packages, it was found that earthwork bid package has a high budget. Digging deeper into this package it was found that the excavation bid package has a budget of $2.5 million. We felt that this was relatively high for a project of this size. Review of the geotechnical report of the site chosen for the new Penn State Ice Arena concluded that the site has bedrock at a shallow depth below grade. Figure 20 gives a visual of the top of rock map for the site. Color scale for bedrock depth shows bedrock in the darkest red is 5 feet below surface and steps down in increments of 5 feet with the yellow portions at 30 plus feet below grade.

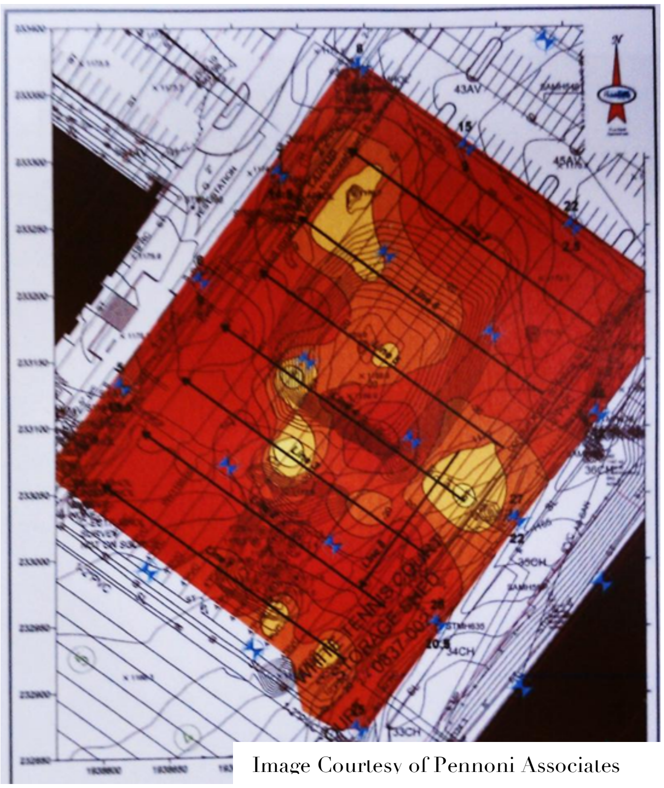


Image Courtesy of Pennoni Associates

Figure 20: Bedrock Depth

The amount of bedrock needed to be removed causes the cost of excavation increase sharply and also extends the schedule due to how laborious nature of rock removal through blasting.

Excavation Budget and Schedule

Total Budget:	**$2,500,000 (3.4 % of overall budget)**
Scheduled Time:	**35 Days – Entire Site**

Building Footprint Cost Break Down

Geotechnical engineering services, Pennoni Associates Inc., provided the project team with a geotechnical report that showed boring holes drilled on the site every 100 feet, occasionally drilling at 117 feet. Based on these boring holes, the project team determined that 44,000 cubic-yards of bedrock would need to be removed. This is due to the numerous spikes of bedrock below the elevation grade. Figure 21 shows the various spikes in elevation in relation to the main concourse level. The dark red shows spikes being of 5 to 10 feet below the elevation grade of 1170 feet.

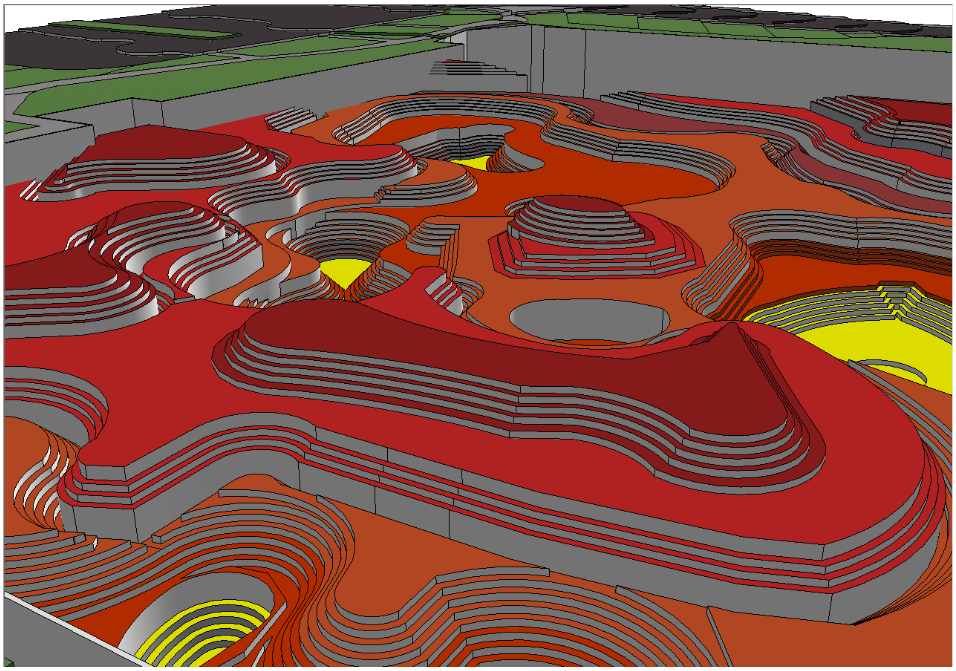


Figure 21: 3D View of Bedrock Below Grade

HPR's construction manager determined the amount of soil and bedrock to removed from the building's footprint by taking an average bedrock elevation at each of the four boring points in a 100 foot by 100 foot section, as well as the 100 foot by 117 foot sections. This was done to give an average bedrock elevation in each of the sections. See Appendix F for the averages of the current design taken for each section.

By taking the averaged elevations, HPR was able to determine the cubic-yardage of rock and soil to be removed. The breakdown is shown below. These numbers include the costs for excavation of foundation footers, elevator pits, the ice melt sump, and the hydro pit. Note, that the amount of rock to be removed is three times less than that of the soil, yet the cost of rock removal due to blasting nearly identical to that of the soil. By interpolation, HPR was able to determine the amount of days needed in the schedule for removal. The overall days to complete the building footprint excavation are 25 days. The costs and durations were determined using *Craftsman's 2012 National Construction Estimator – 60th Edition*. See Appendix F for schedule and cost extractions.

	Soil	Rock
Total Cost:	$582,041	$532,757
Total Excavation:	73,207 CY	25,401 CY
Scheduled Work Days:	13.5	11.5

Goal

HPR set out to deduce the amount of bread rock excavation by raising the entire event level in elevation while keeping the concourse level at grade to preserve the architect's vision. It was important that we keep codes, sight lines, ADA, price points, plenum space, and the architectural vision all in mind when determining a distance to raise the event level up.

Design Approach

As a group we determined all the factors that could influence the distance we would be able to raise the event level. That distance was determined based upon the variables listed below:

- Egress logistics of the main arena bowl
- ADA seating
- Sight lines
- The number of seats at different price points
- Constructability
- Plenum space
- Grading on the southern side of the building
- Loading dock logistics
- Other site restrictions such as building width

Below, Figure 22 shows a sectional view of the proposed changes to the event level. The white surfaces represent the existing conditions and the blue represents the proposed changes. Notice that the plenum below the concourse level shrinks and the slope of the arena seating stays the same. This reduction in plenum space will require a more much closely collaborated plenum space. HPR used a highly integrated Revit model to insure the constructability of this design and used Navisworks to eliminate clashes.

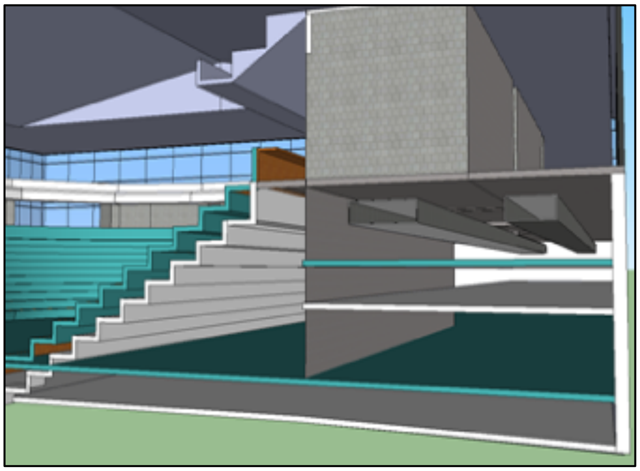


Figure 22: Event Level Elevation Proposed Changes

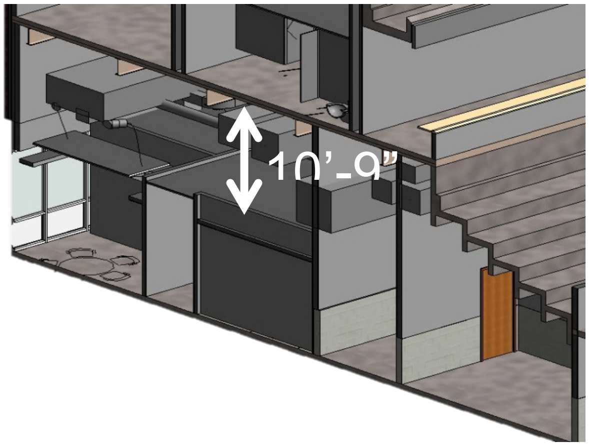


Figure 23: 3D Sectional View of South Corner of Arena Bowl

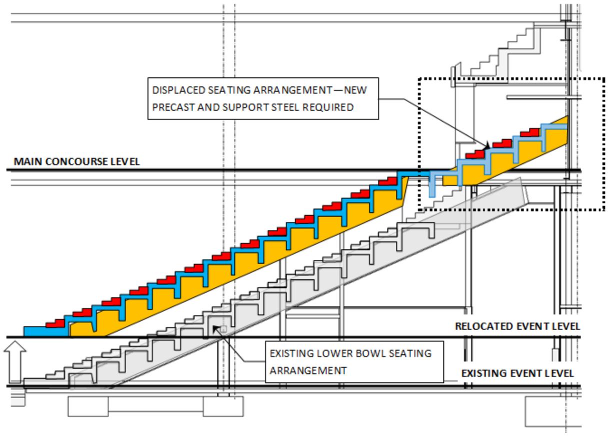


Figure 24: Sectional View of Reallocated Seating

Business Model

HPR Integrated Design established the seating capacity and price points of these seats as a critical design factor during the raising of the Event Level. To become more familiar with the business model for the arena, HPR investigated preliminary feasibility studies conducted by Crawford Architects in 2010 as well as obtain information through continued communication with an Owner's representative within the athletic program's financial sector.

HPR Integrated Design investigated the 2010 feasibility study from Crawford Architects and developed documentation to allow for quality control for both seating capacity and the profitability of any design changes by looking at price points from comparable hockey programs. According to the feasibility study, the Owner asked for the architect to use two different case studies for comparison for the Penn State Ice Hockey Arena project: the Goggin Ice Center at the University of Miami (OH) and the new Compton Family Ice Arena at the University of Notre Dame. The feasibility study also investigated a prior feasibility study that was completed in 1999 to evaluate the necessity for an ice hockey arena.

The results of the 2010 feasibility study concluded the results shown below in Table 1.

Facility - Arena and Auxiliary Ice Sheet	Seating Capacity	Opened	Number of Ice Sheets	Gross Area in Square Footage	University Enrollment
New Penn State Hockey Arena	6,000	2013	2.0	216,240	45,000*
Penn State 1999 Study - Option 5	6,000	-	2.5	214,094	37,000*
Compton Family Arena - Notre Dame University	4,000	2010	2.0	191,197	8,500
Goggin Center - University of Miami (OH)	3,000	2006	2.0	170,033	16,000

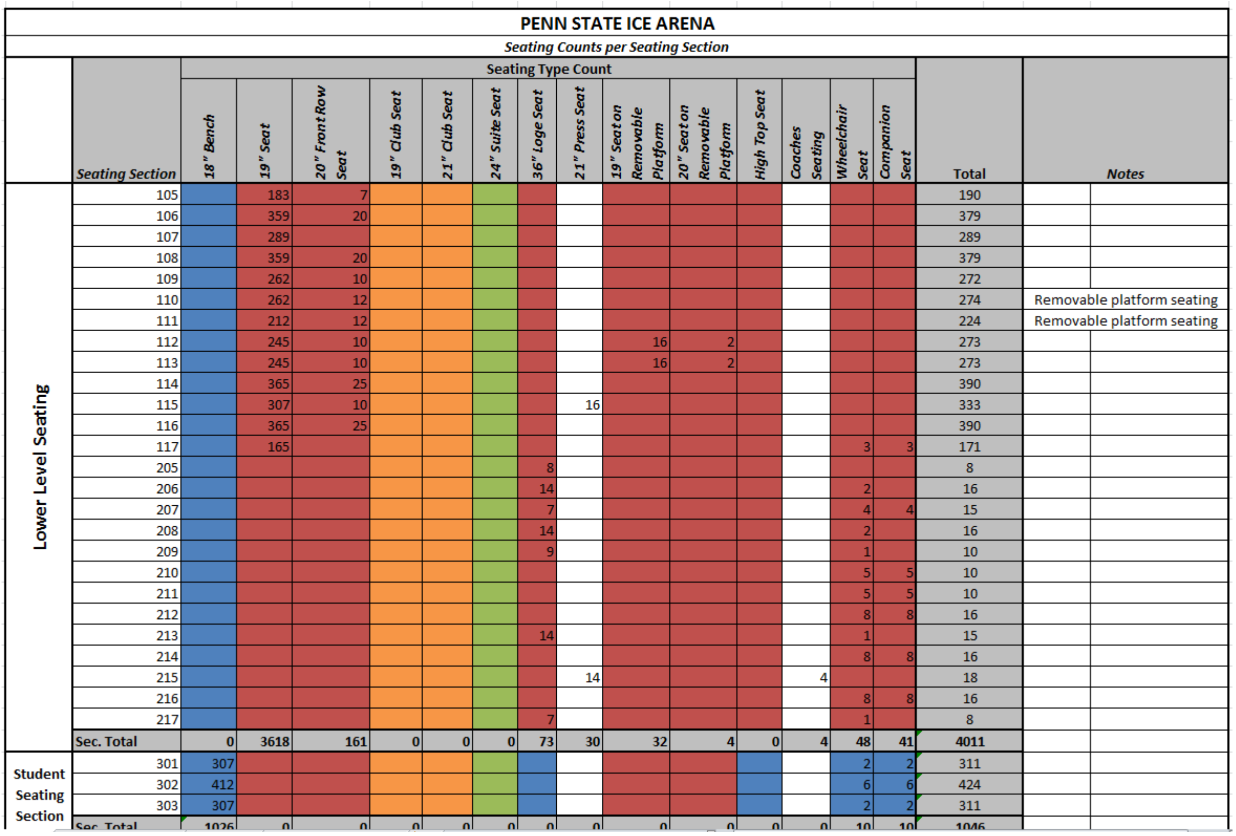
*Penn State University Park Campus Only

Table 1: 2010 Feasibility Study Comparisons

The feasibility study determined that the new Penn State Ice Hockey Arena should consist of a 6,000 seat competition arena with an additional auxiliary or community sheet of ice. The study stated that the 6,000 seat capacity should be broken down into 4,000 general admission seats, a student section or "Section E" that should be around 1,000 seats and 500 club seats on a mezzanine level. The business model developed by the Pennsylvania State University also required a total of 24 luxury suites (12 in the present design and the option for future expansion to another 12 luxury suites.

From this information, HPR Integrated Design looked at the contract documents, specifically architectural drawing A0-20 – Seating Bowl Plans, which detailed the existing seating arrangement which totaled 6,031 seats in the main arena and an additional 300 seats in the community rink for a grand total of 6,331 seats in the entire facility.

HPR Integrated Design extracted the information from the "Seating Counts per Seating Section" chart on A0-20 and established price points for each seating section to track profitability for the redesign changes. Table 2 shows a portion of the seating chart with price points established by color. The entire seating chart can be found in detail located in Appendix F. Through investigation into other programs, HPR Integrated Design decided to follow the Notre Dame Ice Hockey program in terms of ticket prices and profitability because of the similar lower bowl and upper mezzanine seating arrangement. Table 5 shows the assumed ticket prices and profitability for a sold-out hockey game at the new Penn State Ice Hockey arena.



PENN STATE ICE ARENA

Seating Counts per Seating Section

	Seating Section	Seating Type Count														Total	Notes
		18" Bench	*19" Seat*	*20" Front Row Seat*	*19" Club Seat*	*21" Club Seat*	*24" Suite Seat*	*36" Loge Seat*	*21" Press Seat*	*19" Seat on Removable Platform*	*20" Seat on Removable Platform*	*High Top Seat*	*Coaches Seating*	*Wheelchair Seat*	*Companion Seat*		
Lower Level Seating	105		183	7												190	
	106		359	20												379	
	107		289													289	
	108		359	20												379	
	109		262	10												272	
	110		262	12												274	Removable platform seating
	111		212	12												224	Removable platform seating
	112		245	10						16	2					273	
	113		245	10						16	2					273	
	114		365	25												390	
	115		307	10					16							333	
	116		365	25												390	
	117		165											3	3	171	
	205							8								8	
	206							14						2		16	
	207							7						4	4	15	
	208							14						2		16	
	209							9						1		10	
	210													5	5	10	
	211													5	5	10	
	212													8	8	16	
	213							14						1		15	
	214													8	8	16	
	215								14				4			18	
	216													8	8	16	
	217							7						1		8	
	Sec. Total	0	3618	161	0	0	0	73	30	32	4	0	4	48	41	4011	
Student Seating Section	301	307												2	2	311	
	302	412												6	6	424	
	303	307												2	2	311	
	Sec. Total	1026	0	0	0	0	0	0	0	0	0	0	0	10	10	1046	

Table 2: Existing Seating with Price Points

PROPOSED PRICE POINTS:

🟥	General Admission	**3977**	**seats**
🟦	General Admission - Students	**1046**	**seats**
🟧	Club Level	**695**	**seats**
🟩	Suite	**279**	**seats**

Table 3: Existing Seating Capacity per Price Points

	Glass	Lower (non-glass)	Mezzanine	Club
Adults	$ 20.00	$ 14.00	$ 20.00	$ 40.00
Senior/Youth	$ 20.00	$ 7.00	$ 20.00	$ 40.00

http://www.und.com/tickets/nd-tickets-hockey.html

Table 4: Notre Dame University Ticket Prices

EXISTING	**Penn State Ice Arena - Single Game Ticket Sales Profits:**			
	Glass Seats:		161	seats
		$ 3,220.00		**per game**
	Lower Bowl:		3816	seats
		$ 40,068.00		**per game**
	Club Seats:		695	seats
		$ 13,900.00		**per game**
	Suite Level Seats:		279	seats
		$ 11,160.00		**per game**
	*Student Section:		1,046	seats
		$ 5,230.00		**per game**
	*Assumed $5 dollar student tickets			
	GRAND TOTAL	**$ 73,578.00**		**per game**

Table 5: Profitability Study - Existing

HPR Integrated Design established these charts with educated assumptions that would allow the design team to track seating capacity and profitability or price points concurrently as the arena's alternative seating layout was established.

Additionally, HPR Integrated Design conducted interviews with the athletic department Associate Athletic Director, Greg Myford, to understand more about the business model and understand further the cost impact of facility maintenance and financial expectations for the new arena. From this interview, HPR Integrated Design learned that the Owner expects the hockey program to be a self-sustaining varsity sports within five years of its initial conception.

Sight Lines

An in-depth study on sight lines within the main arena was conducted by HPR to consider the consumer experience for all visitors with ADA considerations at the forefront of the decision making process. HPR Integrated Design investigated the contract documents, specifically architectural drawing A0-21: Sightline Sections. Figure 25 below shows the existing seating arrangement with excellent existing site lines.

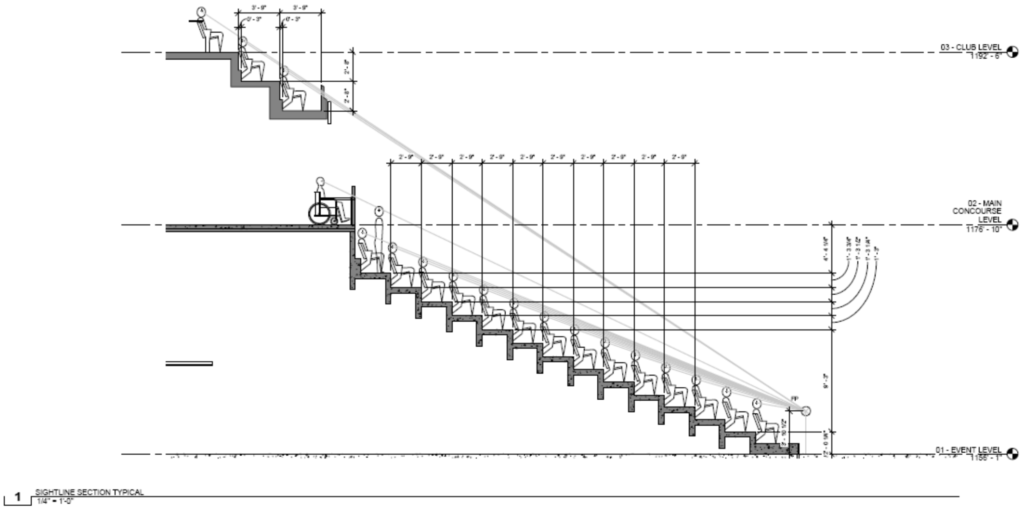


Figure 25: Existing Typical Sightline Section

Studying the typical sightline sections from the existing design revealed that site lines were a critical factor in the design of the lower bowl precast stadia slope. As per ADA code section 4.33 the code does not specify a minimum requirement for ADA occupant sightlines, therefore it was assumed that the sightlines required by IBC 2009 were acceptable for the ADA seats. While this is not a code requirement at the present time, HPR Integrated Design decided that it was important to maintain the best possible sight lines for handicapped customers at any point during an event. The existing seating arrangement included an approximately 4'-0" tall wall behind the last row of seats to allow for a person to stand up and handicapped seating above to still have an unobstructed view of the ice.

It was determined that the architect had created a seating arrangement that was driven by the sightlines of the visitor and any change in Event level elevation would result in obstruction of handicapped sight lines. Therefore, HPR Integrated Design made a collaborative decision to continue to raise the Event Level and address the sightlines of the arena in the following manner:

- Remove seats in rows directly in front of handicapped seating to allow for optimum site lines.
- Redesign the vomitories with ADA compliant (1:12 slope) ramps to allow for handicapped seats to be at a higher elevation to optimize site lines.

HPR Integrated Design decided to allow another variable in the raising of the Event Level control the design and make necessary corrections to the plans to optimize the sight lines for handicapped personnel visiting the arena afterwards.

Architectural Considerations & Applicable Codes

The raising of the Event Level and reallocation of seating could potentially change architectural design code compliance design considerations. HPR conducted an in-depth code compliance check with the 2009 International Building Code (IBC 2009) with guidance from architectural academic advisors.

Accessibility Issues

HPR Integrated Design checked the minimum required number of ADA accessible seats using Table 1108.2.2.1, shown in Table 6, in the 2009 IBC.

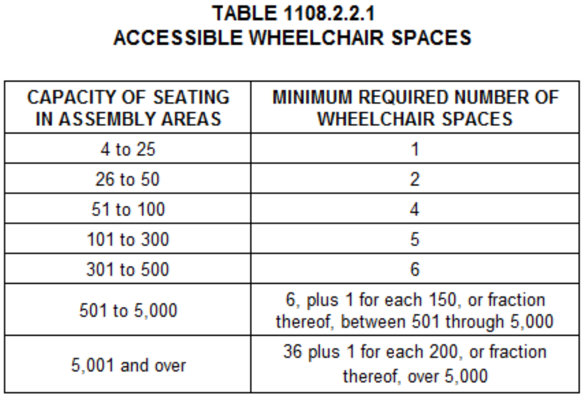


TABLE 1108.2.2.1
ACCESSIBLE WHEELCHAIR SPACES

CAPACITY OF SEATING IN ASSEMBLY AREAS	MINIMUM REQUIRED NUMBER OF WHEELCHAIR SPACES
4 to 25	1
26 to 50	2
51 to 100	4
101 to 300	5
301 to 500	6
501 to 5,000	6, plus 1 for each 150, or fraction thereof, between 501 through 5,000
5,001 and over	36 plus 1 for each 200, or fraction thereof, over 5,000

Table 6: Accessible Wheelchair Spaces

Using Table 1108.2.2.1 and using the 6,031 seating capacity of the main arena, HPR Integrated Design determined the minimum number of ADA seating spaces is 29 total seats. Equation 1 shows the calculation of minimum total ADA seats in the lower bowl section.

Equation 1

Min. Accessible Wheelchair Spaces = 6+ 1((3977 seats – 500 seats/150) = **29 Total ADA Seats**

HPR Integrated Design also kept in mind criteria for providing at least one companion seat with every ADA wheelchair space in accordance with Section 1108.2.3 complying with ICC A117.1. Additional requirements for egress were conducted to ensure code compliance with an alternative seating arrangement in the lower bowl pending the raising of the event level. Occupancy loads for the alternative seating design were calculated per Table 1004.1.1 in the 2009 IBC, which gives the maximum floor area allowances per occupant. Section 1004.7 was utilized for fixed seating, which simply calculates occupancy load based on the number of seats in each seating section.

Minimum required egress width was determined using IBC 2009 section 1005.1 using Equation 2, which states that the minimum width is the occupant load multiplied by 0.3. Below is a sample calculation for egress in Section 106, which is one of the largest sections for occupancy load.

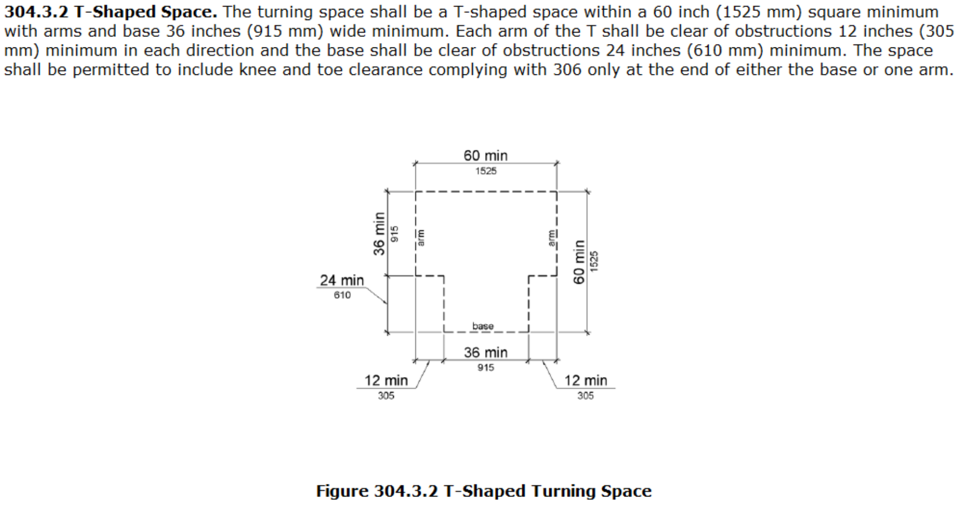
Equation 2

Min. Required Egress Width = 210 occupancy load x 0.3 = **63" or 5.25'**.

The existing aisles are designed to be 6'-0" wide which allowed for an additional 30 seats to be placed in the largest section without any code compliance issues for egress. If necessary for sight line issues described in the previous section, vomitory ramps would need to comply with section 1010.2 that states that the minimum slope of ramps "have a running slope not steeper than one unit vertical in 12 units horizontal (8% slope)."

Another code compliance issue that was determined to be a critical factor to track as the team decided on the dimension to raise the event level was minimum ceiling height in egress areas. The existing design had a 10'-0" ceiling in the vomitories. According to section 1003.2 in the 2009 IBC, the minimum ceiling height in an area for means of egress is 7'-6". Although this is a minimum, HPR determined that this dimension was too low for best practices in architectural design and therefore may require adjustments to the above Club Level elevation even if the minimum head clearance of the alternative design is code compliant.

The 2010 ADA standards for accessible design were also investigated to determine minimum dimensions required for handicapped maneuvering and clear floor space. Figure 26 below shows Figure 304.3.2 out of the 2010 ADA standard, which shows the T-shaped turning space required for ADA compliance.



304.3.2 T-Shaped Space. The turning space shall be a T-shaped space within a 60 inch (1525 mm) square minimum with arms and base 36 inches (915 mm) wide minimum. Each arm of the T shall be clear of obstructions 12 inches (305 mm) minimum in each direction and the base shall be clear of obstructions 24 inches (610 mm) minimum. The space shall be permitted to include knee and toe clearance complying with 306 only at the end of either the base or one arm.

Figure 304.3.2 T-Shaped Turning Space

Figure 26: Figure 304.3.2 - 2010 ADA Standard

Additionally, the ADA accessible seat arrangements must conform to section 305.3 which states that the clear floor space for a code compliant ADA wheelchair seat is 48" min x 30" min. HPR Integrated Design carefully considered all of the above mentioned code compliance issues in the raising of the event level and balanced all of the design variable to maintain a code compliant facility.

Determining the Optimal Distance

Sight lines and ADA Seating

When HPR Integrated design first proposed the raising of the event level it was our assumption that the max distances we could raise the event level would be restricted by the plenum size. As we dove into the design we quickly realized that although the coordination of the plenum space would be a challenge, the biggest limiting factor became a combination of the number of seats, ADA in particular, and sight lines.

Based on the sight line study we knew that seats would have to be removed in front of the ADA seats to make the raising of the event level significant. A quick look at the existing plans shows that there is a row of ADA seats that surrounds the entire rink. Although the plans only show the ADA seats located near the aisle it was HPR integrated Design's assumption that an ADA seat could be put anywhere in that top row to allow for flexibility. Figure 27 shows the seats that would have to be removed to accommodate sight lines in these areas. By doing this we would lose a total of 325 seats or roughly 5.4% of the arena's seating capacity. This was just outside of the range HPR Integrated design deemed acceptable so we would have to relocate the seats we removed. It was our goal to keep the same number of seats or increase them if at all possible.

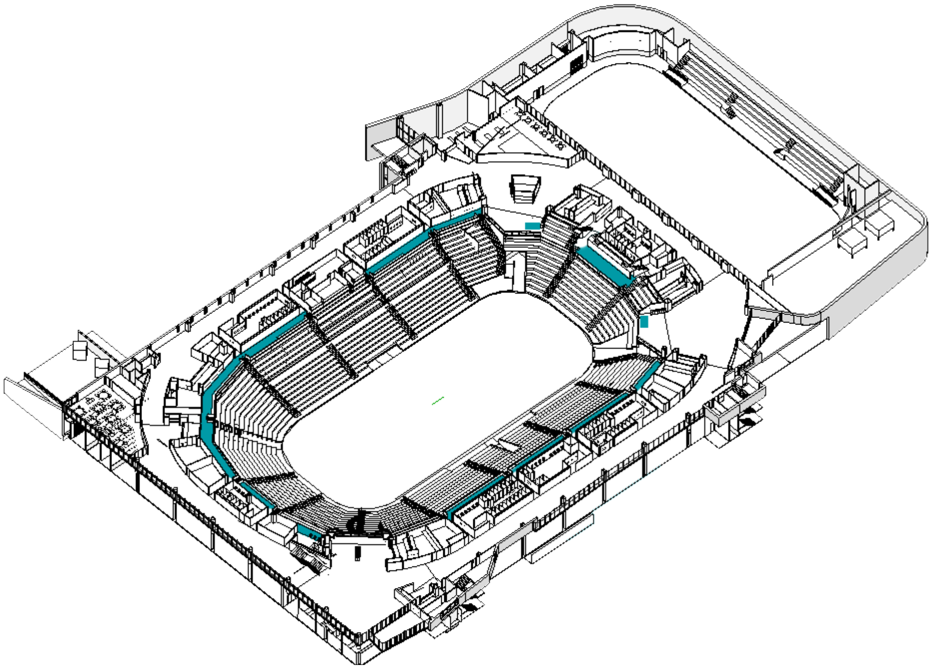


Figure 27: Removed Seating

Based on our code analysis we found that the current design provided more than double the required ADA seats. We could reduce the number of seats that had to be removed by relocating some of the ADA seat and eliminating others. The original design called for 48 ADA seat and after this rearrange our proposed design has 31. Once the ADA seats were located we created a boxed in seating area around them. This allowed us to only remove the seats in front of the ADA seats.

By making the changes previously noted HPR Integrated Design determined that the maximum distance the event level could be raised was 1'-8 ". This number was determined by finding the maximum height that still allowed a person sitting in an ADA seat to see over the shoulder of the first spectator in front of them while standing. Although this is not the ideal sight line it was deemed acceptable for this academic exercise. With the help of some preliminary cost estimation we determined that to make this exercise feasible, the event level would have to be raised more than this. To help increase the amount we could raise the event level we would have to raise the height of the ADA seats. We had no intensions of changing the elevation of the main concourse however; we wanted to maintain that level because it allowed the patrons to enter the arena on the main concourse without any stairs. Increase the elevation of the ADA seats without raising the main concourse HRP Integrated Design proposed the vomitories that link the Main Concourse with the main bowl was sloped up at a rate of 1:12. This adjustment lifts the ADA seats up another 1'-8" and increases the Maximum dimension to 3'-2".

Finalized Sight Lines

HPR Integrated Design investigated sight lines as a design factor prior to figuring out the optimal dimension to raise the event level. It was determined that the site lines had been a critical factor in the design of the lower bowl precast stadia slope and any raise in elevation would result in sight line issues. HPR decided that the raise in elevation would be conducted and then the team would respond to sight line issues accordingly.

By raising the event level only by the determined 38", the sight lines of the lower bowl for regular general admission seating was not affected since the entire level was raised as a whole. ADA handicapped seating was greatly affected however and required design alterations to create satisfactory sight lines once again. Although the 2001 version of the ADA standard is currently adopted by the AIA, HPR Integrated Design decided to follow the new, stricter 2010 version as much as possible to provide the Owner with the best possible product.

According to the Department of Justice's 2010 ADA standard code regulations, the code requires that "*Wheelchair seating locations must provide lines of sight comparable to those provided to other spectators… A comparable line of sight allows a person using a wheelchair to see the playing surface between the heads and over the shoulders of persons standing in the row immediately in front and over the heads of the persons standing two rows in front.*" After the initial raise in elevation of the event level, ADA sight lines did not meet these requirements.

HPR Integrated Design decided to make two modifications to the seating arrangement to try to meet all criteria in the 2010 ADA standard. The first modification was to remove all seats in the row directly in front of the ADA seating to allow clearance and improve sight lines. As shown in figure xx, HPR removed all seats in the top row of the lower bowl to be conservative and replaced these lost seats above the main concourse in a raised seating arrangement. This modification improved sight lines but did not create a satisfactory sight line for ADA seating. Additionally, HPR decided to use ramps in the vomitories that satisfied the IBC 2009 section 1010.2 for ramps that cannot have a slope of greater than

1:12. This allowed for an elevated platform which was raised an additional 1'-8" higher than the main concourse level.

Structural calculations were performed to provide supplementary framing to allow for this elevated platform and steps were added to the lower bowl to accommodate the change. As shown in Figure 30 below, the final sightlines were set for ADA seating which allow meet the criteria for ADA seating to see over the shoulder of the first row in front of the seating platform and over the head of the following rows when standing. Meeting this criterion was not required but established as a critical design factor that HPR decided must be met for best design practices.

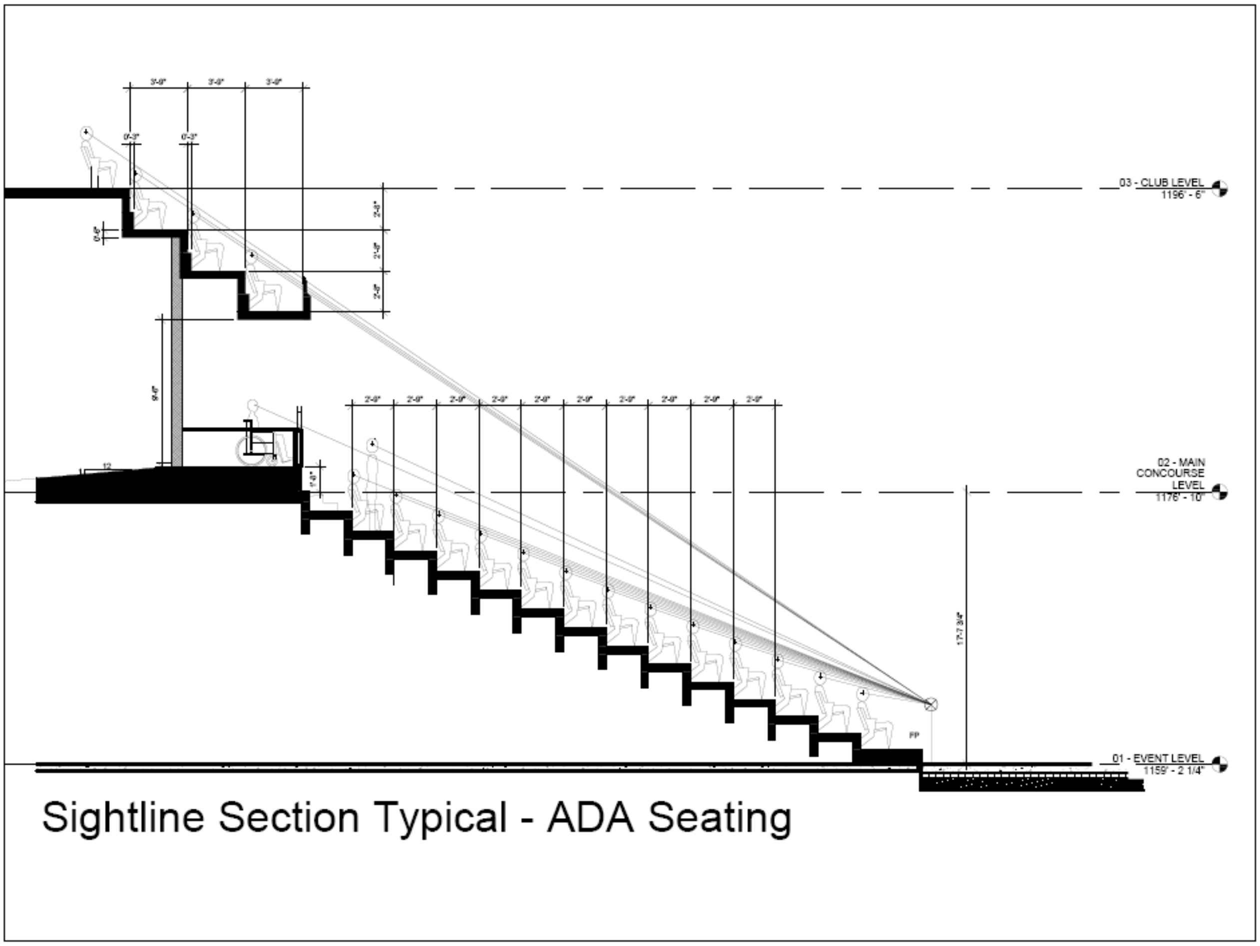


Figure 28: Typical Sightline Sectional View - Lower Bowl

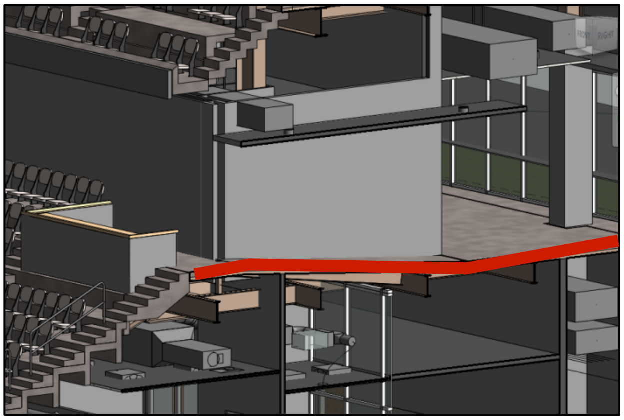


Figure 29: Proposed Sloped Vomitories

HPR Integrated Design also conducted similar sightline studies for the student section and typical lower bowl section without ADA seats to confirm satisfactory sightlines. The new proposed seating arrangement was successful in creating sightlines that allow for all visitors to the arena to enjoy the event equally. Additional sightline sections can be found in Appendix F.

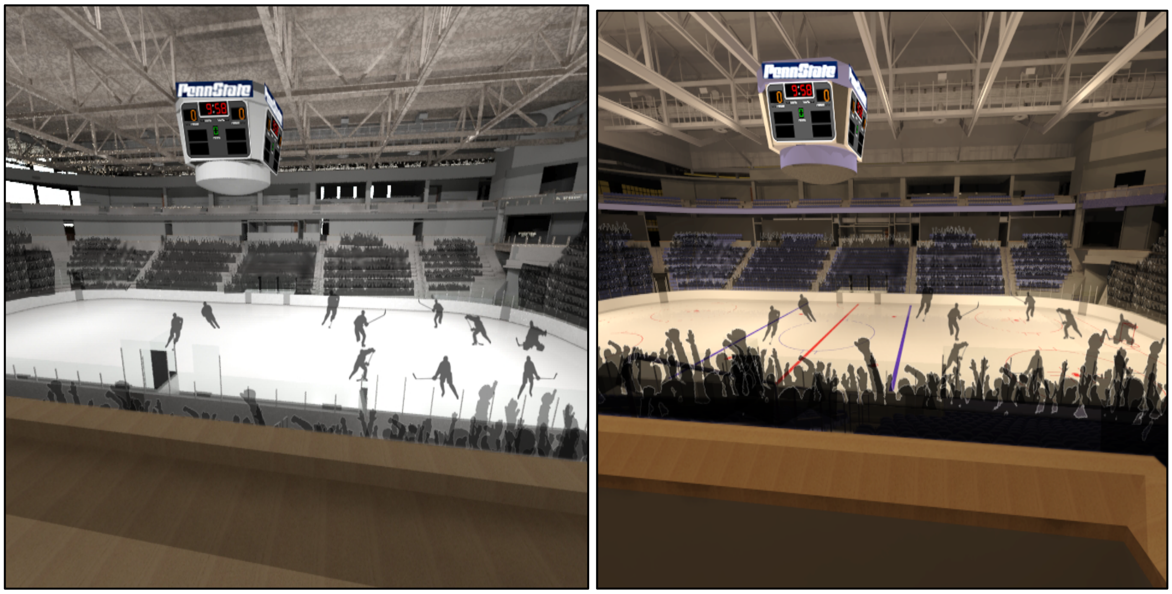


Figure 30: Proposed ADA Sightlines

In Figure 30, the image on the left shows the original design and the image on the right shows the new sightlines

Plenum Check

Once we had determined this distance we began modeling the changes. There is an intense amount of coordination required when you start shifting levels around, especially when not all model elements are linked to levels. The first step was to actually raise the event level up 38". This had to be coordinated in every disciplines model because of the use of a federated modeling system. When all the models had been updated and any conflicts caused by these changes resolved, a check was done to make sure the new plenum size was indeed large enough. The main duct runs were sized and preliminary locations for ducts, pipes, and electrical conduit were determined. Very little was actually modeled at this point. The objective was to determine if the plenum space was adequate for all our systems. Figure 31 shows some of the modeling done at this stage.

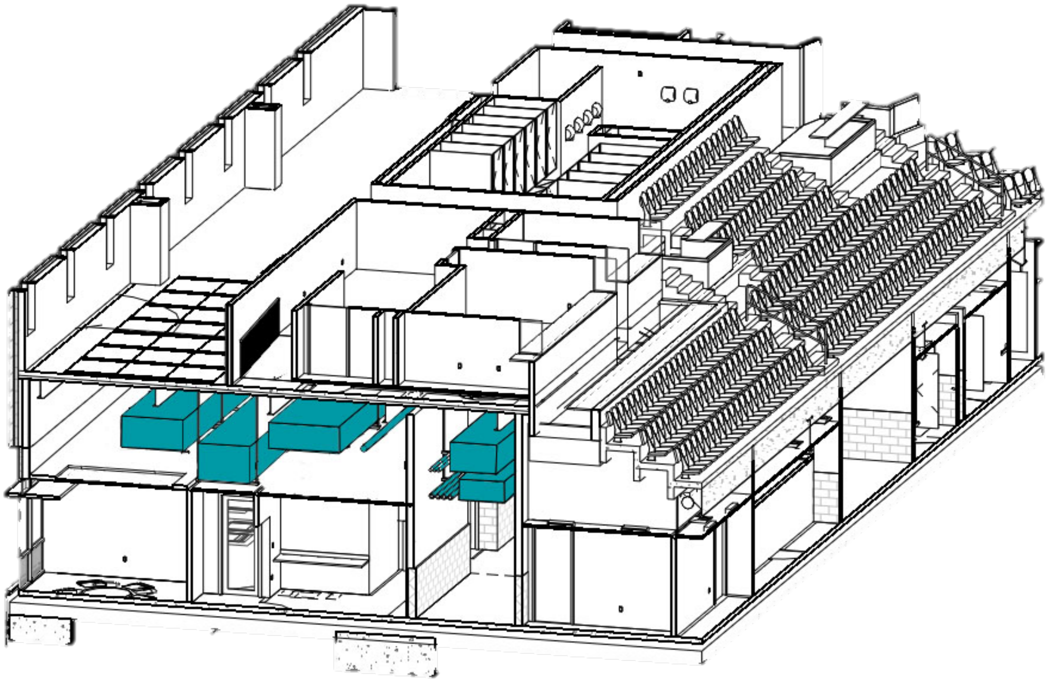


Figure 31: Proposed Plenum Space

Once the plenum was deemed acceptable the mechanical designer went forward with more detailed modeling while the keeping in mind the electrical designer's requirements. At this time the rest of the team went forward with determining the best place to put the displaced seats.

Relocation of Seats

Once the ADA sight lines meet HPR Integrated Design's standards and the plenum space was checked we began the process of adding seats back in the main arena bowl. We want to keep these seats at the same price points as the once removed so no to alter the business model. Figure 32 show a schematic sketch on how HRP Integrated Design planned to replace the lost seats. The lay out called for seat to be placed in the inter aisle the surrounded the main arena bowl. This would force patrons to leave the main bowl and head to the main concourse in order to switch sections.

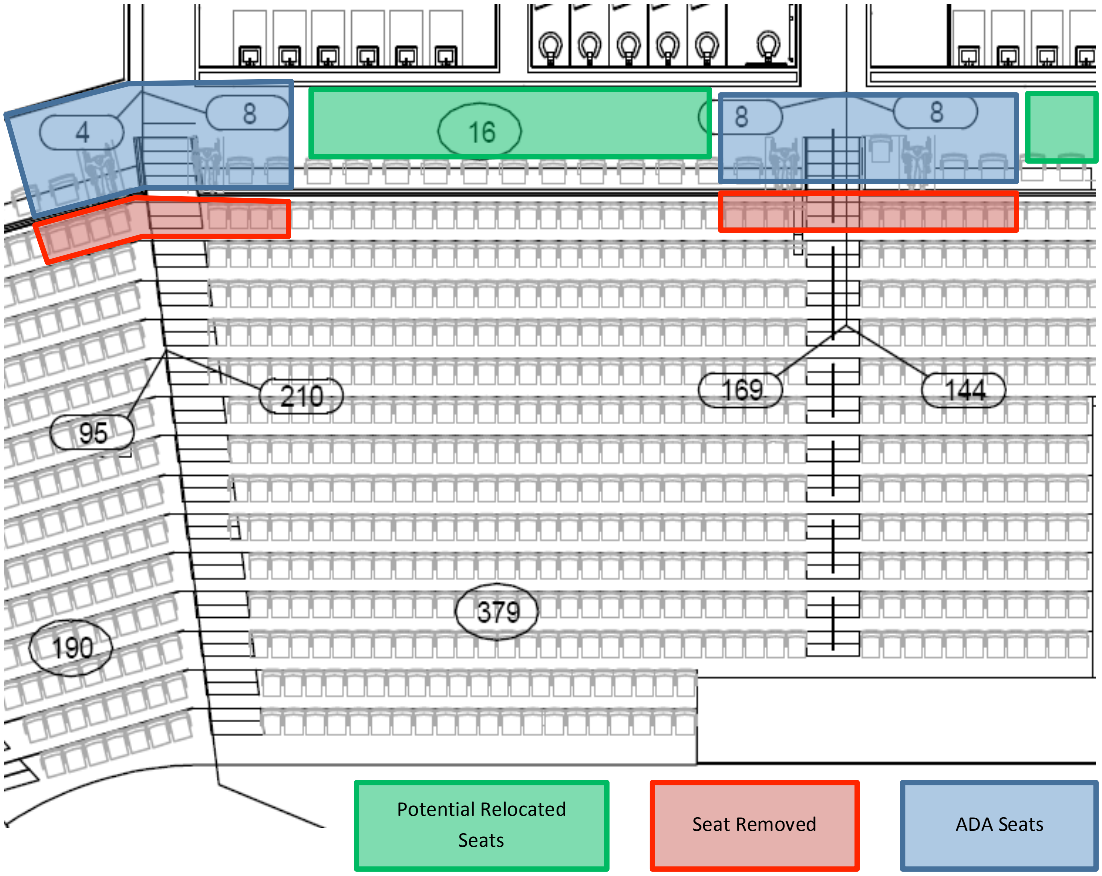


Figure 32: Schematic of Seat Reallocation

To accomplish this extra stairs would have to be added to allow access to the upper seats. Based on the code analysis HPR Integrated Design preformed we determined that two sets of stairs were required for each of the upper sections. Figure 33 shows the final design. This alternative design lead to a total net gain in seats, the total gain was 154 seats, all at the same price point as those that were previously removed.

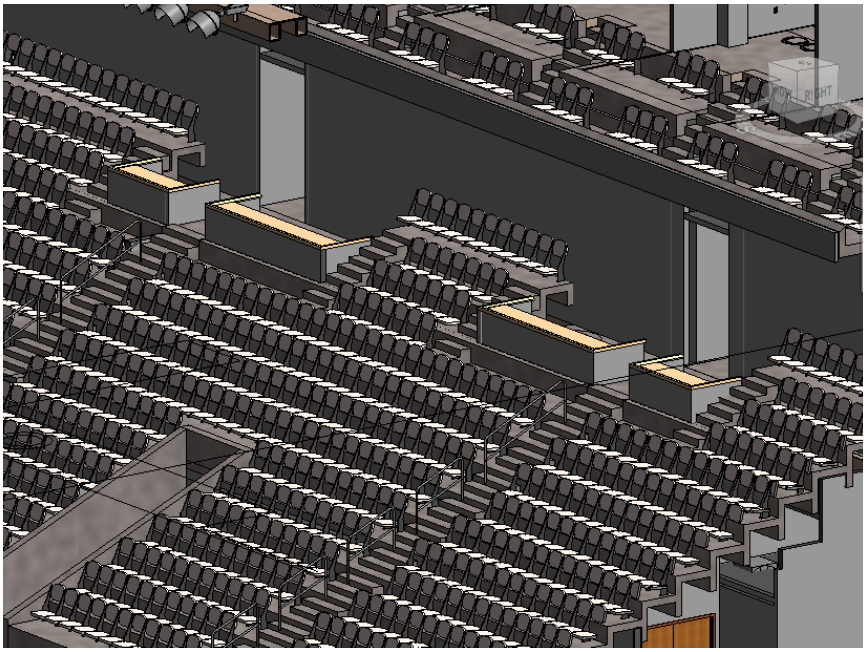


Figure 33: Final Design of ADA Seating with Added Seating

Business Model Implications

HPR Integrated Design used seating capacity and price point charts derived from the contract drawings to track the business model throughout the Event Level raising. Throughout the elevation shifting process explain in the sections prior, real time tracking for seating capacity and price points was conducted. Table 7 shows a comparison of the existing and proposed alternative seating arrangement from the shifting of the event level.

Penn State Ice Arena - Seating Capacity & Profitability Study						
SEATING CAPACITY				PROFITABILITY/PRICE POINTS		
Seating Price Point	**Existing**	**Proposed**	**Net Change**	**Profitability (Exist.)***	**Profitability (Proposed)***	**Net Change**
Lower Bowl (GA)	4,011 seats	4,154 seats	3.57%	$ 43,288.00	$ 45,146.50	4.29%
Student Section (GA)	1,046 seats	1,023 seats	-2.20%	$ 5,230.00	$ 5,115.00	-2.20%
Club Level Seating	695 seats	695 seats	0.00%	$ 13,900.00	$ 13,900.00	0.00%
Suite Seating	279 seats	279 seats	0.00%	$ 11,160.00	$ 11,160.00	0.00%
TOTAL	**6,031 seats**	**6,185 seats**	**2.55%**	**$ 73,578.00**	**$ 75,321.50**	**2.37%**

*Profitability based on a per game basis and the assumption of a sold out game

Table 7: Comparison of Seat Capacity & Profitability

After raising the event level in elevation by 38" (3'-2") and displacing seating lost due to sight lines considerations to above the main concourse level, HPR Integrated Design's alternative seating arrangement gave the arena 154 additional seats, which is roughly 2.55% of the original seating capacity. As shown in Table 7, the lower bowl added 3.57% more seats for general admission ticket sales but lost

2.2% of student section seats. The club level and luxury suites seating capacity was not affected with this alternative seating arrangement.

As described in the rearrangement process in the prior sections, the displacement of seats lost for ADA seating site lines was displaced to above the main concourse which meant that seating capacity in any section in the lower bowl was not lost rather a few additional seats were added. The student section, also known as "Section E" however did not have the ability to displace seats and an entire row of seats was lost below ADA seats to allow for acceptable sight lines and ultimately Section 302 was the only section that lost seating. Note that seating capacity and price point charts can be found it their entirety in Appendix F.

Using assumptions for ticket prices from the comparable Notre Dame ice hockey program and the assumption of a sold out hockey game, HPR Integrated Design was able to project approximately 2.5% more profitability for the arena with an increase in general admission tickets only. Therefore, the price points for the arena seating has not been raised rather a larger supply of general admission seats was provided.

Americans with Disabilities Act (ADA) Seating

The American with Disabilities Act (ADA) requires that all new arenas must be accessible to people with disabilities so they, their families, and friends can enjoy equal access to entertainment, recreation, and leisure. According to the 2010 ADA Standards for Accessible Design, section 28 CFR 35.151G for New Construction, wheelchair spaces and companion seats are to be dispersed equally to all levels that include seating served by an accessible route. The ADA code continues to state that wheelchair seating must be an integral part of the seating plan so that people using wheelchairs are not isolated from other spectators or their friends and family.

It is important to note that the 2001 ADA Standards for Accessible Design are currently adopted by AIA. HPR Integrated Design determined that they would commit to trying to design to the more stringent 2010 ADA code whenever possible. HPR investigated the existing arena's ADA seating plan shown in Figure 34 below to establish the criteria to maintain during the redesign process.

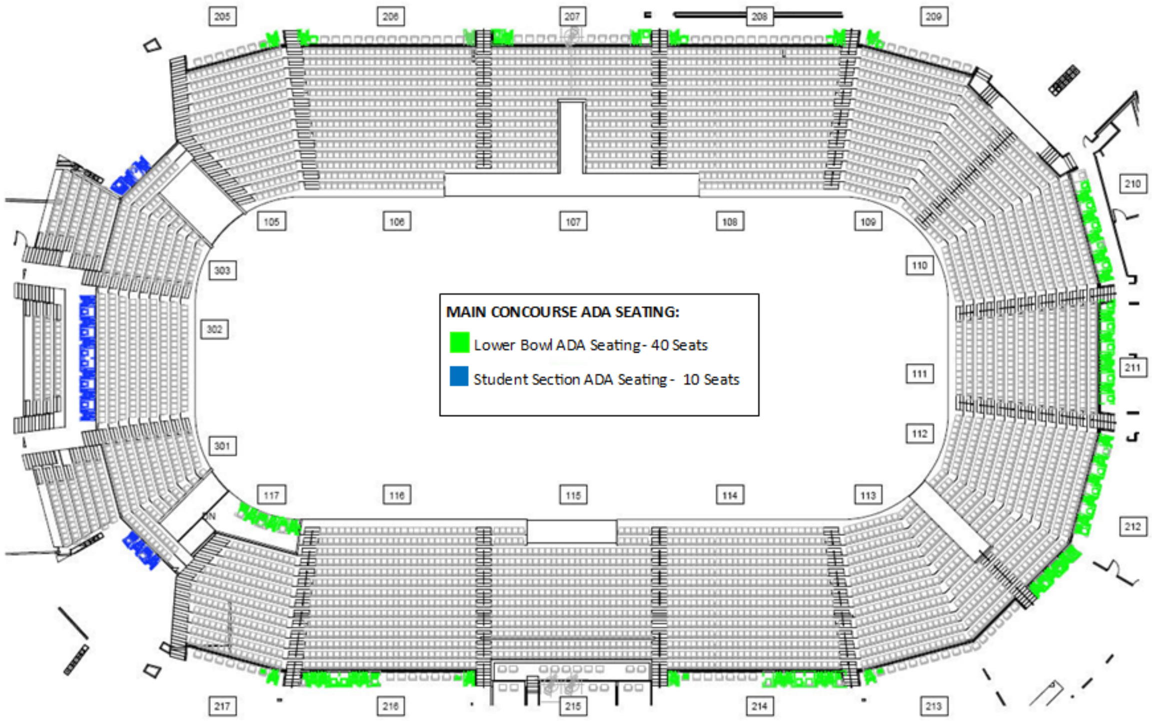


Figure 34: ADA Seating - Main Concourse Level Current Design

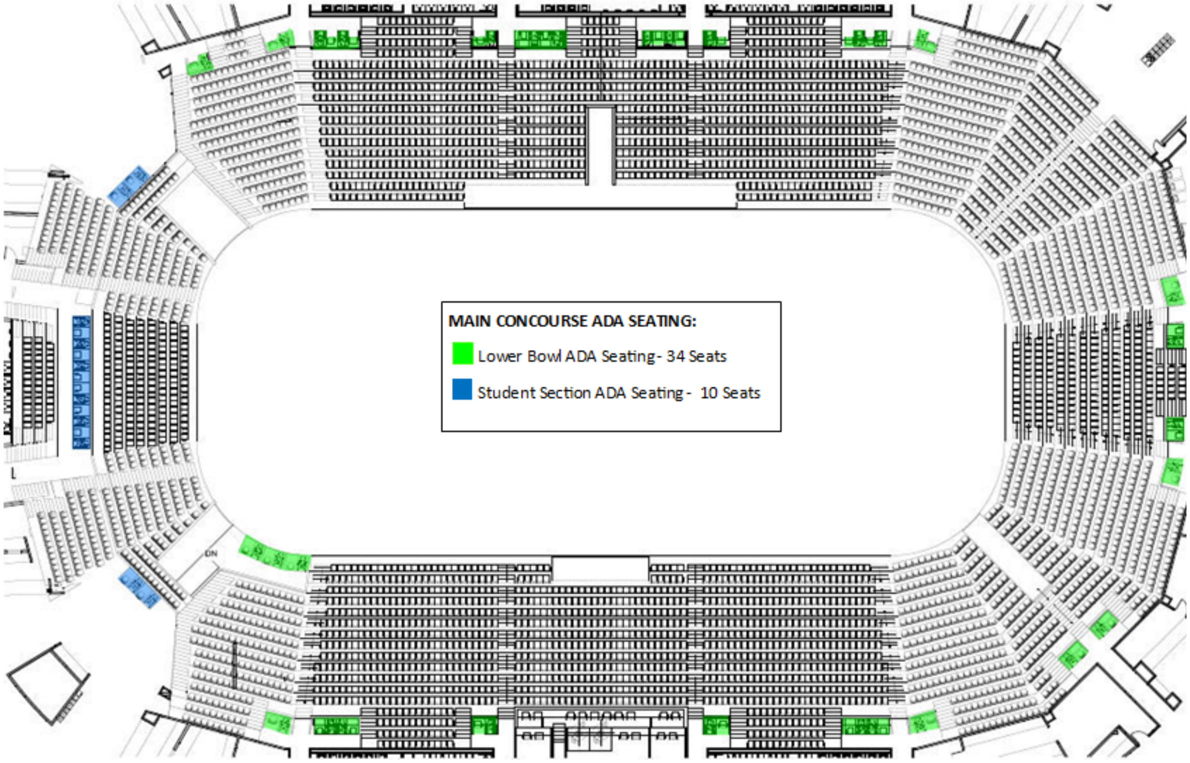
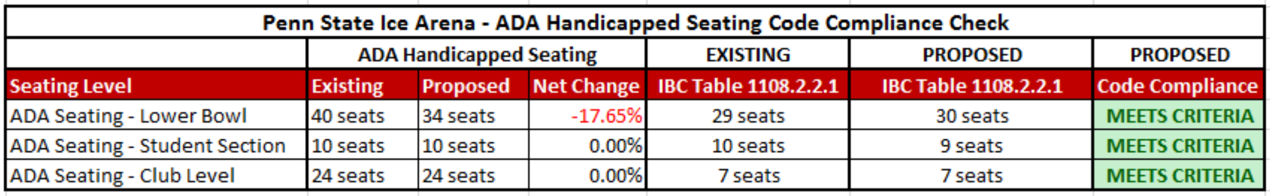


Figure 35: ADA Seating - Main Concourse Proposed Layout

Due to relocation of displaced seating resulting from ADA sight line considerations, the main concourse inner ring design scheme was altered to an alternative seating arrangement that includes seats above the main concourse level. Due to this change in seating arrangement, HPR decided to create flat alcove platforms where ADA wheelchair accessible seating could be provided. All alcoves meet 2010 ADA regulations per section 305.3 and meet criteria for maneuverability and reach requirements.

It was important to HPR to remain code compliant throughout this process; however, due to limited spatial availability not all ADA seats were displaced or relocated to meet the existing design. HPR Integrated Design is compliant with the minimum number of ADA required seats per IBC 2009 Section 1108.1. Table 8 below documents the changes in ADA seating.



Penn State Ice Arena - ADA Handicapped Seating Code Compliance Check						
	ADA Handicapped Seating			EXISTING	PROPOSED	PROPOSED
Seating Level	Existing	Proposed	Net Change	IBC Table 1108.2.2.1	IBC Table 1108.2.2.1	Code Compliance
ADA Seating - Lower Bowl	40 seats	34 seats	-17.65%	29 seats	30 seats	MEETS CRITERIA
ADA Seating - Student Section	10 seats	10 seats	0.00%	10 seats	9 seats	MEETS CRITERIA
ADA Seating - Club Level	24 seats	24 seats	0.00%	7 seats	7 seats	MEETS CRITERIA

Table 8: ADA Handicapped Seating - Code Compliance Check

Alternative Seating Layout

Through the process of raising the event level and the club level, an alternative seating layout was created by HPR Integrated Design. No changes were made to the club level racker seating other than the 4'-0" rise in elevation to allow for comfortable head clearance on the event level. Major changes in the lower bowl seating arrangement included:

- Rows in front of ADA handicapped seating areas were removed to allow for sight lines to meet criteria per 2010 ADA standards around the top row of the lower bowl.
- Displaced seating was added above the main concourse on raised seating platforms that replaced the inner circulation ring of the arena.
- ADA seating alcoves were designed to allow for ADA seating to be located equally around the main concourse level to meet criterion for 2010 ADA standard.

The following figures demonstrate the change in seating arrangement and the location of displaced, removed and new seats. Changes in ADA seating can be found in Figure 35 in the above section. Figure 36 shows the existing seating layout from the contract drawing A0-20: Seating Bowl Plans. Figure 37 shows a diagram of which seats were removed, displaced and/or added to the arena following the changes made as part of this value engineering opportunity. Finally, Figure 38 shows the alternative seating layout that HPR Integrated Design has proposed.

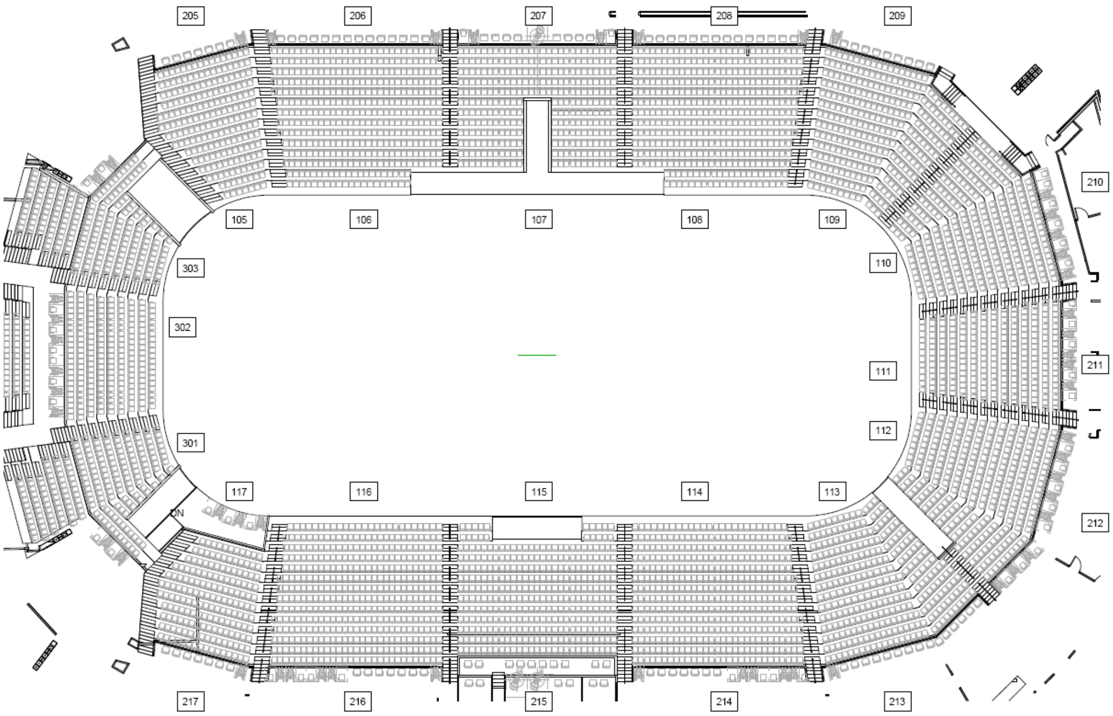


Figure 36: Lower Bowl Seating Arrangement - Existing

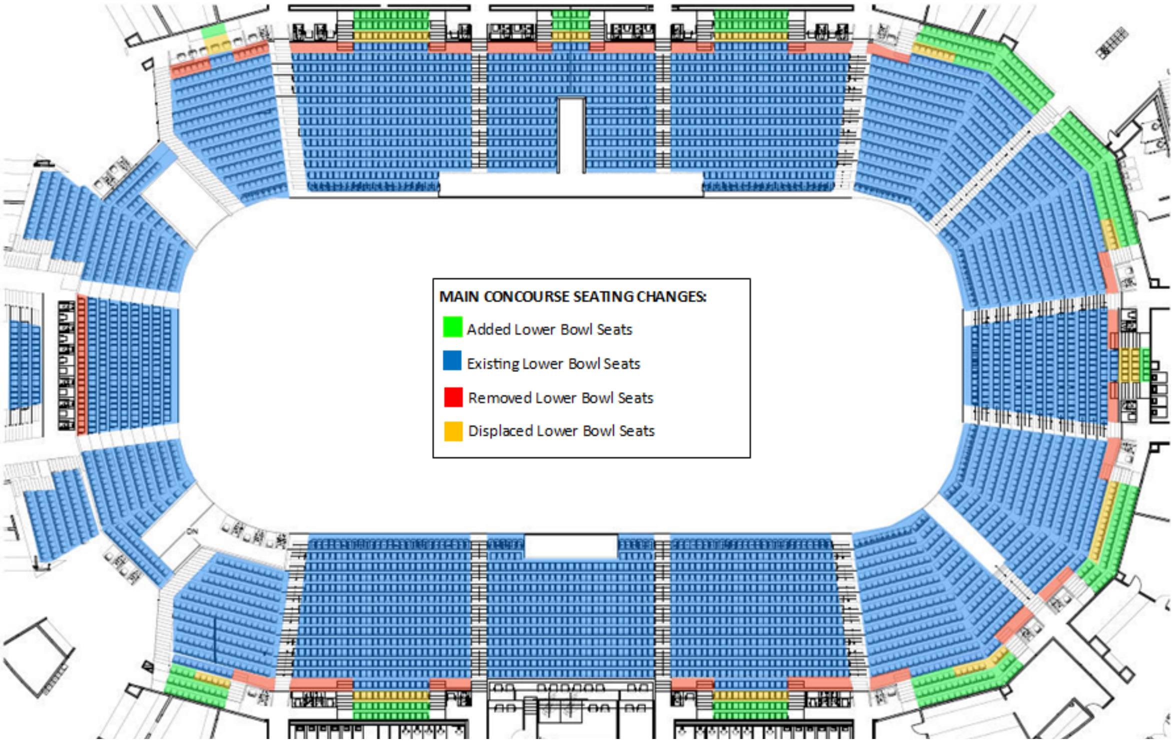


Figure 37: Main Concourse Seating Changes

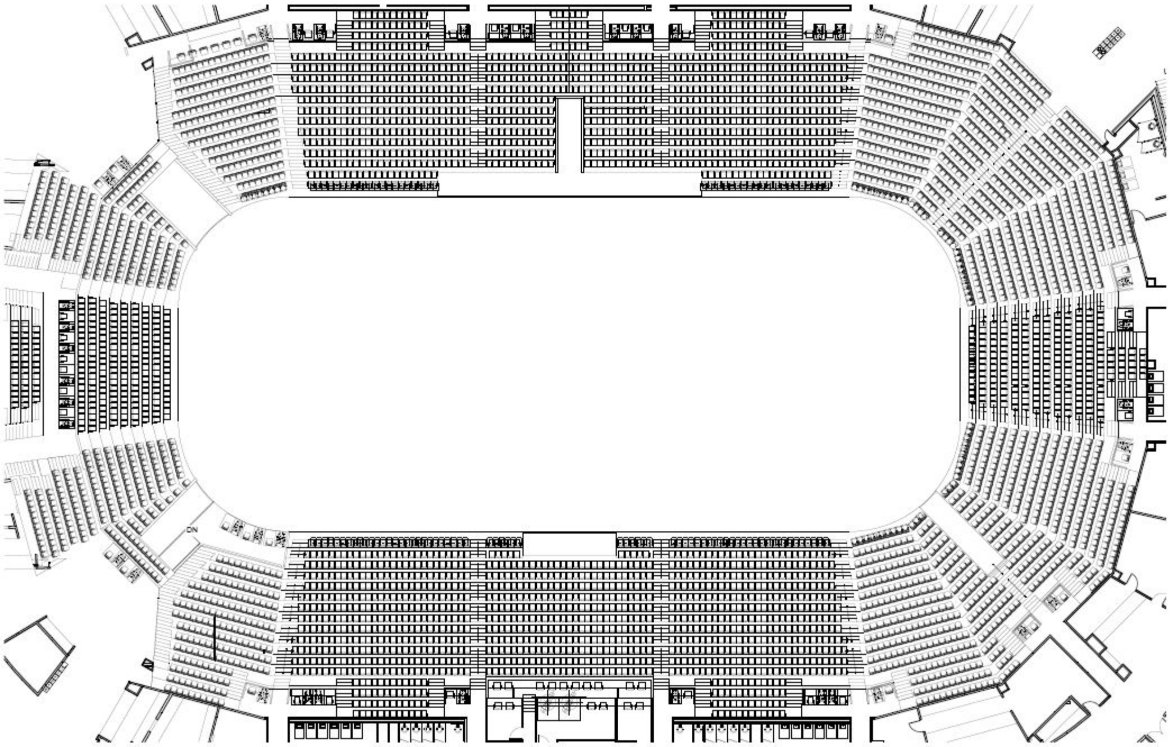


Figure 38: Proposed Lower Bowl Seating Arrangement

Collaborative Plenum Design

The use of BIM technologies was essential for designing a plenum space for the event level that was clash free. The electrical, mechanical, and structural systems were all modeled in their disciplines central model and then shared with the other disciplines via the federated model system. This allowed use to monitor each other's changes and progress throughout the modeling process. We were also able to perform formal clash detection once the design had made substantial progress. HPR Integrated Design went in to the design knowing that integrating our designs from the beginning would help to reduce the number or clashes and conflicts that would have to be resolved later. Using the federated modeling system made it essential to communicate with each other. Simply synchronizing with an individual's central model did not completely update other disciplines changes. It was also important to reload the other linked in central models. This would insure that any changes made by other disciplines would be shown in your central model. When a team member made a significant change to the design they would then notify the other team member to reload in the other central file. Figure 39 shows a graphical representation of this process.

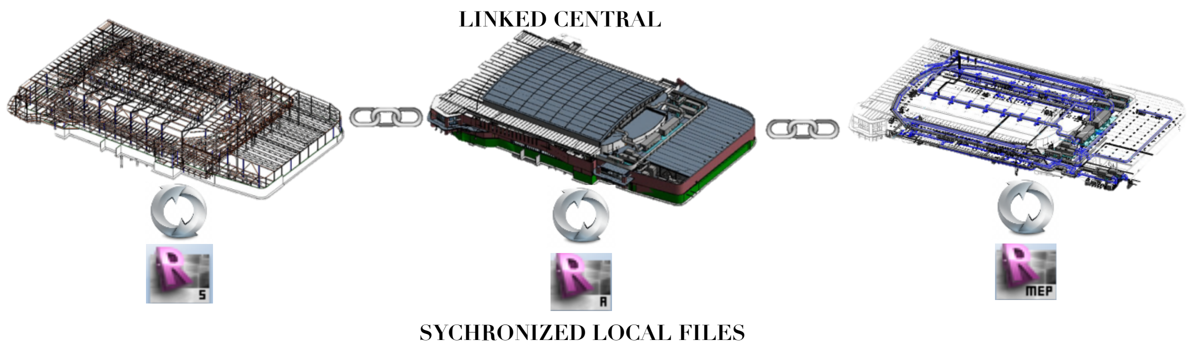


Figure 39: Graphical Representation of Synchronizing of Local Files

Level of Development

While designing the mechanical and electrical systems for the event level HPR Integrated Design had the task of determining what needed to be modeled to prove this was indeed constructible and what would be a waste of valuable time to model. HPR Integrated Design understood that it was important distinguish between both spaces and disciplines, meaning that in certain spaces the mechanical would be taken to a LOD of 2 where the electrical design would only need to go to LOD 1.

In order to verify the validity of the mechanical of the event level plenum it was necessary the HPR Integrated Design model the mechanical system in the rest of the building. This was done to show where the main ducts run for all the spaces in the building. This allowed HPR to determine exactly what ducts would be in the event level plenum space and what duct would not. Since the goal of this modeling was strictly to show general location it was unnecessary to model in a high level of detail. The majority of this modeling was done with a LOD of 1.

In contrast the mechanical systems on the event level required much more detailing. This is directly related to the goal of the modeling procedure. On the event level we wanted to prove the constructability of the system. Knowing that HPR Integrated Design recognized that both location and space where critical. Size of ducts and pipes needed to be accurate and although location was not final we need to be in very close proximity to the final location. This was not just for main duct and pipe runs but also for VAV units, maintenance clearances and diffusers.

Discipline Modeling	Location	Goal of modeling	LOD
Mechanical	Club and Main Concourse	Show general location of ducts to determine which duct would be in the event level plenum	100
Mechanical	Main Arena Bowl	Coordinate the Main Arena Roof System, and needed for main arena renderings	300
Mechanical	Event Level Plenum	Prove the constructability of the tighter plenum caused by the raising of the event level.	300
Electrical	Entire building	Show normal power distribution system to panel boards and motor control centers	300
Lighting	Main Arena Bowl, Event Level	Show location of luminaires for coordinating plenum space	200
Structural	Main Arena Bowl & Event Level Plenum	Show accurate depth of steel dimensions for MEP designers to coordinate systems with	300

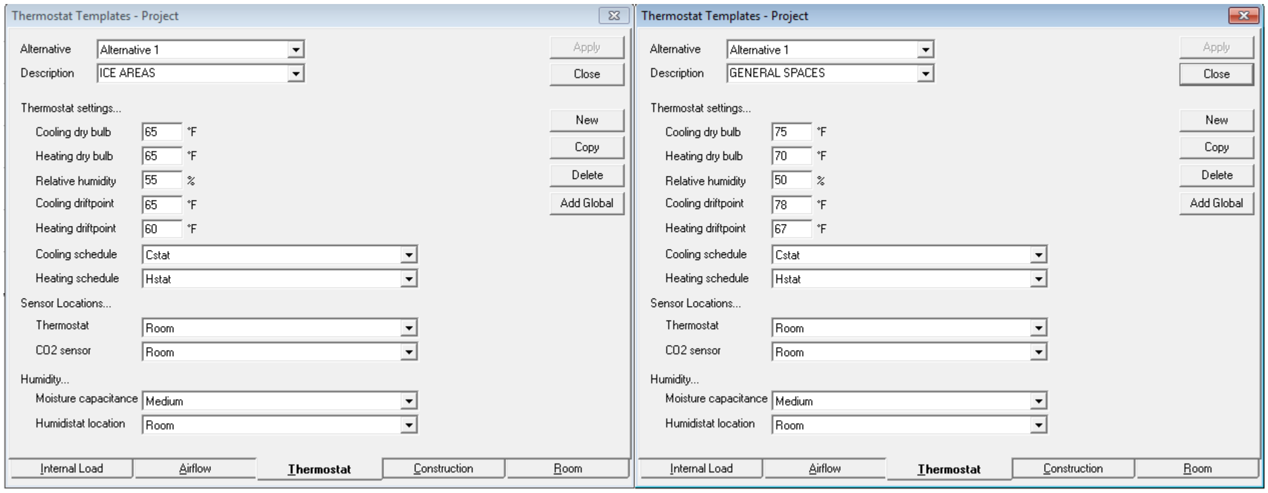
Figure 40: BIM Level of Development

Mechanical Design

HPR Integrated Design used the same general systems as the original design showed in the design development drawings we received. The loads were calculated using a Trane Trace model and compared with the airflows shown on the design drawings, and with rule of thumb design practices. As HPR got deeper into the design we realized that the mechanical drawings were very incomplete at that the systems suggested where at times way oversized to provide and early conservative design. This discovery led to a CFD study of the Men's Locker room and AHU- 7. HPR Intergraded Design was not concerned with Ice generation system from a mechanical point of view. It was our understanding that these systems are generally designed by a special contractor. For us to look in to the design of an Ice Generation System did not fix in to any of our design focuses nor did it facilitate much interdisciplinary collaboration. HPR Integrated Design did however look into the factors that affect the load on the ice generation systems. This research can be found in Appendix F.

Calculating Loads

A trace model was created to calculate the loads on the arena. We used 12 different templates for Internal Loads, Air flows, and Rooms. We created two separate templates for Thermostat, one for general spaces and a separate for ice spaces. The conditions for these spaces can be seen in Figure 41. The twelve templates that were used for Internal Loads, Air flows, and Rooms were; concessions, concourse, corridors, equipment rooms, ice, media, office/suite, restroom/lockers, restaurants, stands, stands and work out areas. People where not entered in the internal load template, but rather individually entered in to the room data based on the DD drawings HPR received.



Alternative: Alternative 1
Description: ICE AREAS
Thermostat settings...
Cooling dry bulb: 65 °F
Heating dry bulb: 65 °F
Relative humidity: 55 %
Cooling driftpoint: 65 °F
Heating driftpoint: 60 °F
Cooling schedule: Cstat
Heating schedule: Hstat
Sensor Locations...
Thermostat: Room
CO2 sensor: Room
Humidity...
Moisture capacitance: Medium
Humidistat location: Room

Alternative: Alternative 1
Description: GENERAL SPACES
Thermostat settings...
Cooling dry bulb: 75 °F
Heating dry bulb: 70 °F
Relative humidity: 50 %
Cooling driftpoint: 78 °F
Heating driftpoint: 67 °F
Cooling schedule: Cstat
Heating schedule: Hstat
Sensor Locations...
Thermostat: Room
CO2 sensor: Room
Humidity...
Moisture capacitance: Medium
Humidistat location: Room

Figure 41: Thermostat Templates for Different Spaces within the Arena

This process was very straight forward except for modeling the sheet of ice. Since HPR Integrated Design was not interested in designing the ice generation system we only needed to find how the sheet of ice would affect the building loads. This was done by creating a partition in the space that had the ice sheet that was the same area as the floor and had an internal surface temperature of approximately 20ºF

Sizing Duct

Sizing duct in the event level had to be done very accurately, under sizing the duct could cause the duct not to fit if changes had to be made and oversizing could cause it not to fit in the plenum space in the first place or an added cost in material. Low pressure duct was generally round and sized with a duct-ulator at 0.08 inch friction loss per 100'. Medium pressure was generally rectangular and sized at 2,000 fpm. The ducts in the Event level plenum space included supply for AHU-5,6,7,8,9, return for AHU-5,6, exhausts for AHU-7,8,and 9. The return for AHU-5 is mainly a plenum return with a few transfer grilles. AHU-5 serves the office spaces. There is also the return from the main arena bowl (AHU-10 and 11).

IAQ and CFD study of Men's Locker Room

The men's and women's locker rooms are served by (2) 11,000 CFM 100% OA AHUs. This comes out to roughly 1.75 CFM/SQFT. This number takes the CFM supply of the AHU and divides it by the entire area served by the AHU. That area includes the locker room, showers, restrooms, trains rooms, and corridors. Code requires 0.5 CFM/SQFT. To meet the MAE requirements HPR Integrated Design will perform a CFD analysis on the locker room to see if the code number is satisfactory or if the ventilation rate calculated using equations from and indoor air quality course (AE 552).

Plans

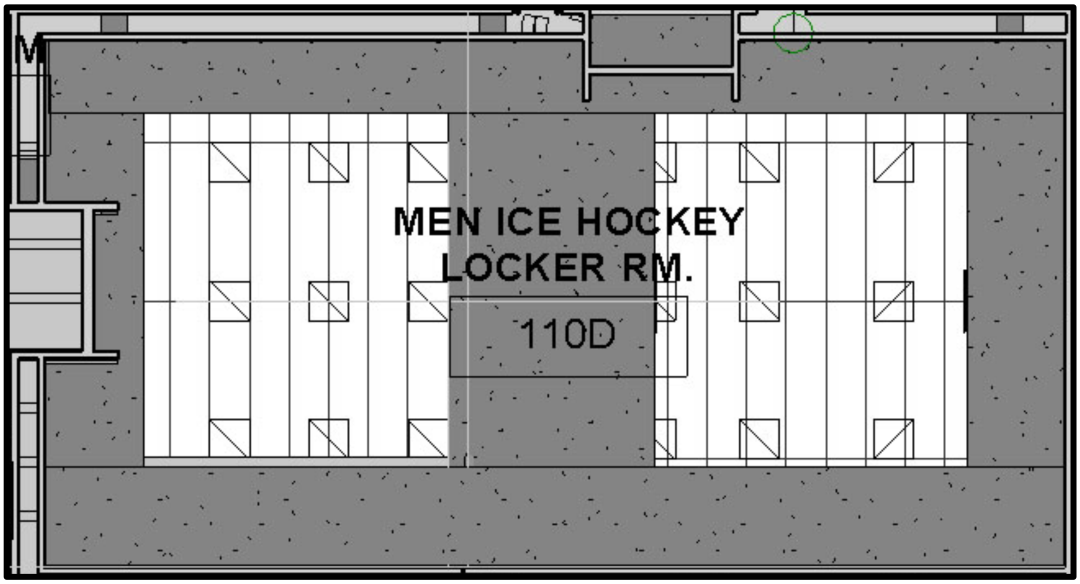


Figure 42: Ceiling Plan for Men's Locker Room

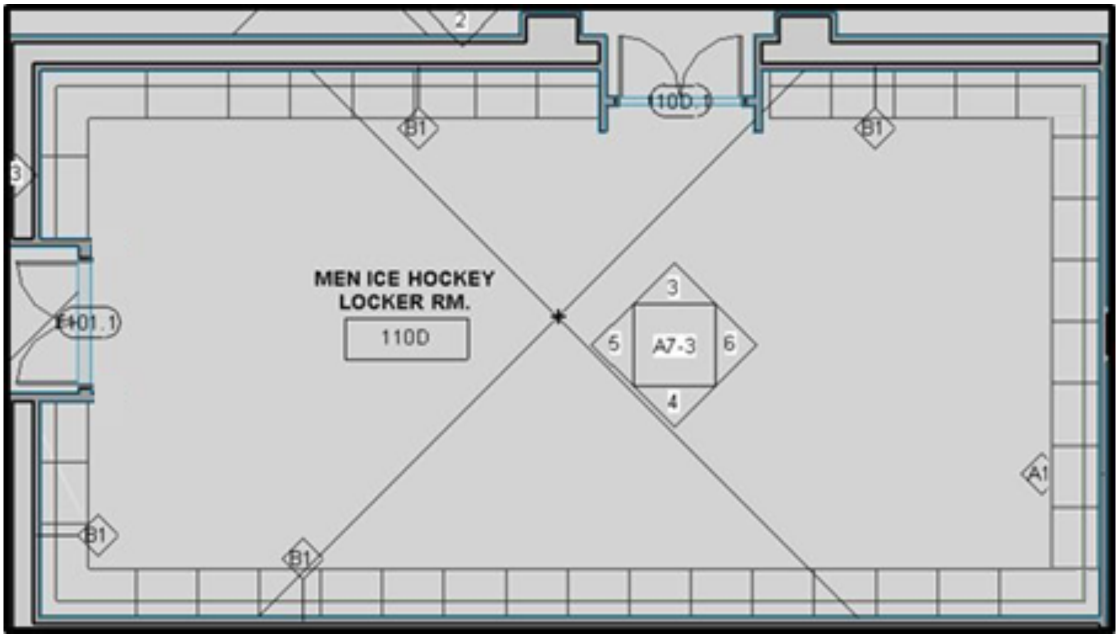


Figure 43: Floor Plan for Men's Locker Room

Code Requirements

According to ASHRAE Standard 62.1 the Minimum Exhaust Rate for a locker Room is 0.5 CFM/sq-ft. Since this space is served by a 100% outdoor air unit the exhaust rate is also the supply rate.

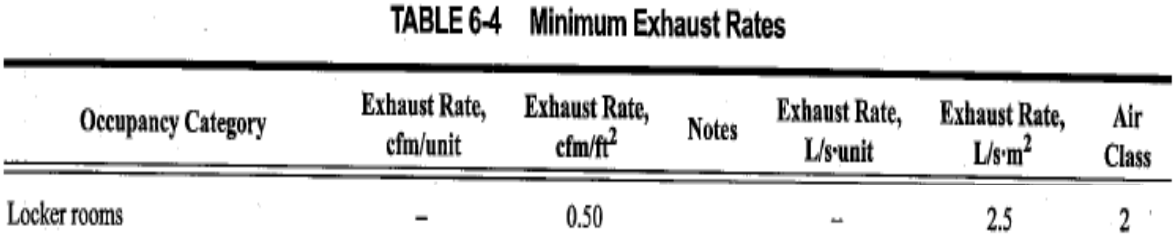


TABLE 6-4 Minimum Exhaust Rates

Occupancy Category	Exhaust Rate, cfm/unit	Exhaust Rate, cfm/ft^2	Notes	Exhaust Rate, L/s·unit	Exhaust Rate, L/s·m^2	Air Class
Locker rooms	–	0.50		–	2.5	2

*See table 6-4 in its entirety in Appendix A

Figure 44: Code - Minimum Exhaust Rates

Hand Calculating Exhaust Rate

Using knowledge gained in AE 552 on indoor air quality I calculated the amount of fresh air that must be supplied to a space to remove one olf from that space. This calculation was done assuming only 20% of the occupants would be dissatisfied.

$$PD = 395 \times e^{(-1.83 \times q^{0.25})}$$

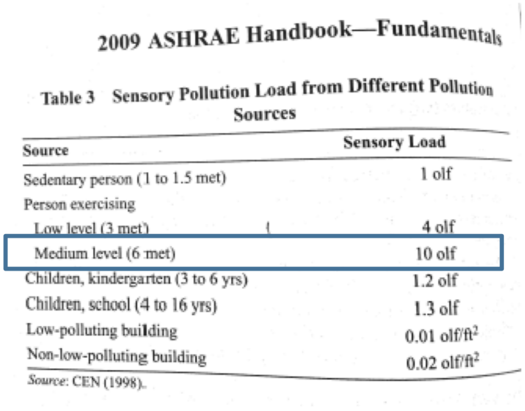
$$PD = 20\%$$

$$20 = 395 \times e^{(-1.83 \times q^{0.25})}$$

$$\ln(.051) = e^{(-1.83 \times q^{0.25})}$$

$$q = 7.06 \cong 7 \frac{\frac{L}{s}}{olf} \cong 15\,CFM$$

15 cfm must be supplied to remove a single olf to maintain a 20% dissatisfaction. Next, I had to calculate the number of olfs in the space. I assumed 22 people and a moderate activity level would be in the locker room at any time. Based on the numbers in Figure 45,the 22 people at moderate activity levels produce 10 olfs each.



2009 ASHRAE Handbook—Fundamentals

Table 3 Sensory Pollution Load from Different Pollution Sources

Source	Sensory Load
Sedentary person (1 to 1.5 met)	1 olf
Person exercising	
Low level (3 met)	4 olf
Medium level (6 met)	10 olf
Children, kindergarten (3 to 6 yrs)	1.2 olf
Children, school (4 to 16 yrs)	1.3 olf
Low-polluting building	0.01 olf/ft²
Non-low-polluting building	0.02 olf/ft²

Source: CEN (1998).

Figure 45: Table 3 Sensory Pollution Load from 2009 ASHRAE Handbook

$$(22\,people)\times\frac{10olf}{esp}=440\,olf$$

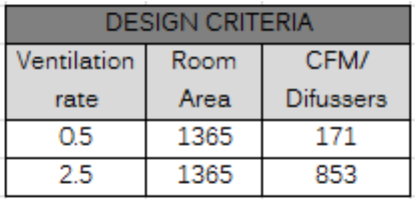
$$15\frac{cfm}{olf}\times 220\,olf=3300\,cfm$$

$$3300\,cfm\ \div 1365\,sf=2.4\,cfm/sf$$

Though these calculations the design ventilation rate should be roughly 2.5 cfm/sf. This does not account for the odor that could be added by the equipment each player would have in their locker

Ventilation Rates

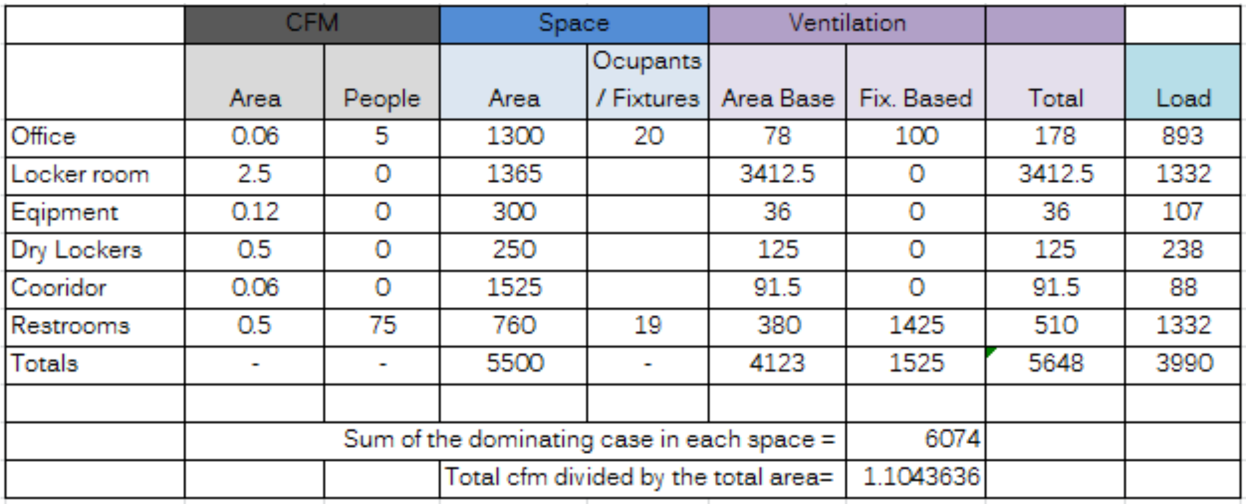
Once completing the above calculations, 0.5 and 2.5 cfm/sf were chosen as the two cfm for the CFD model shown in Table 9. Although the DD drawings called for 1.75 cfm/sf, HPR Integrated Design decided that this number was a conservative number for the DD submission. After looking at detail at the area served by AHU-7 if was determined that the more realistic number for this space was 1.1 cfm/sf. Table 10 below show a summery that determined this 1.1 cfm/sf. It is also important to note that these spaces where highly dominated by ventilation rates and that the reduction of supply air is still adequate to meet the loads.



DESIGN CRITERIA		
Ventilation rate	Room Area	CFM/ Difussers
0.5	1365	171
2.5	1365	853

Table 9: Ventilation Table

Neither 1.1, nor 1.75 cfm/sf were used in this analysis because they were not recommended flow rates for a locker room but rather for an entire AHU's zone.



	CFM		Space		Ventilation			
	Area	People	Area	Ocupants / Fixtures	Area Base	Fix. Based	Total	Load
Office	0.06	5	1300	20	78	100	178	893
Locker room	2.5	0	1365		3412.5	0	3412.5	1332
Eqipment	0.12	0	300		36	0	36	107
Dry Lockers	0.5	0	250		125	0	125	238
Cooridor	0.06	0	1525		91.5	0	91.5	88
Restrooms	0.5	75	760	19	380	1425	510	1332
Totals	-	-	5500	-	4123	1525	5648	3990
	Sum of the dominating case in each space =					6074		
			Total cfm divided by the total area=			1.1043636		

Table 10: Ventilation Table

The locker room represents the worst case scenario as far as ventilation requirements are concerned. The model was run at each different ventilation rate with the maximum design odor concentrations.

Determining Concentration and Flux

For this experiment HPR will be modeling odor as CO_2. It is difficult to model odor so instead we have calculated a CO_2 concentration for a given activity level. This concentration will relate to the odor level at that same activity level. This experiment assumed that the occupants of the locker room would be at moderate activity level.

Assumptions:

- 30 breaths per minute (faster than resting)
- 1.1 Liters per breath (deeper than resting)
- Fraction of CO_2 in an exhaled breath is .036
- Moderate activity produces 10 olf

$$30\left(\frac{breaths}{min}\right)\times1.1\left(\frac{liter}{breath}\right)=33\frac{L}{min}=.55L/s$$

$$.55\frac{L}{s}\times.036=0.0198\frac{L}{s}=1.98\,E^{-5}\,m^3/s$$

$$1.98\,E^{-5}\times10^6\times1.2=23.76\,ppm\,\frac{kg}{s}per\,person$$

$$\boxed{\dot{m}=1.2\,\frac{kg}{m^3}\times\frac{1m}{1000L}\times.55\frac{l}{s}=6.6\times10^{-4}\,kg/s}$$

$$\boxed{C=\frac{23.76\,ppm\,\frac{kg}{s}}{6.6\times10^{-4}}=36{,}000\,ppm}$$

Calculations for expected steady state temperatures

$$\dot{N}=1.98\,E^{-5}\frac{m^3}{s}\times60\times60\times20\,people=1.568\,m^3/h$$

$$\dot{V}_{code}=289.85\frac{m^3}{h}\qquad\qquad\dot{V}_{calc}=1449.1\,\frac{m^3}{h}$$

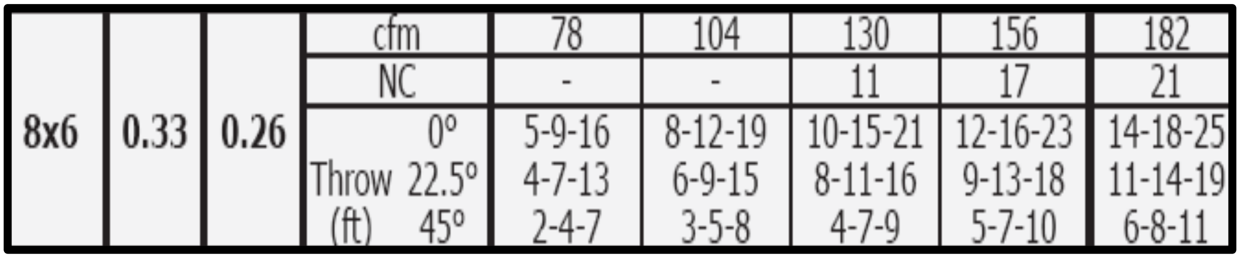
Code: $$289.85\,\frac{m^3}{h}=\frac{1.98\,E^{-5}}{(C_r-C_s)}\quad C_s=0\quad\therefore\quad C_r=5409.7\,ppm$$

Calculation: $$1449.1\,\frac{m^3}{h}=\frac{1.98\,E^{-5}}{(C_r-C_s)}\quad C_s=0\quad\therefore\quad C_r=1082.05\,ppm$$

These calculations provided us with a concentration to input into the Phoenics software for the concentration generated by each person. In this case I entered a mass flow of 6.6 x 10^4 and a concentration of 3600 parts per million. It is expected that my room steady state be 5410 ppm when my ventilation is set to code and 1082 ppm when it is set to the calculated value. Also these calculations allow me to relate CO$_2$ production to Olfs. It can be assumed that 360 ppm of CO$_2$ is equal to 1 Olf.

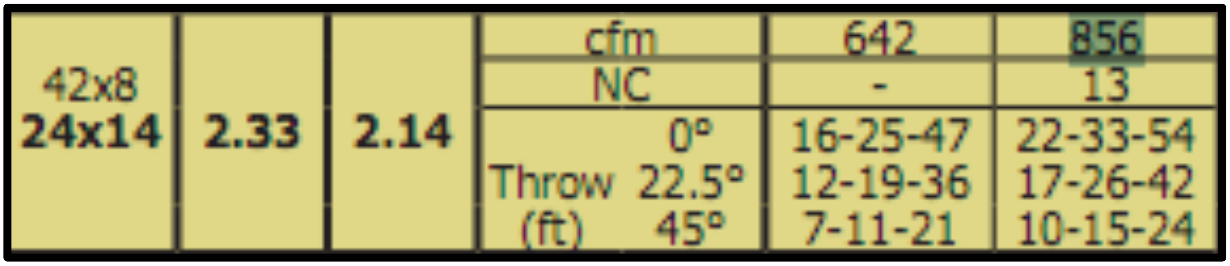
The Model

The CFD model was created using Phoenic's graphical user interface. The model consisted of 20 people which each model with four surface temperatures, one on each of the vertical sides. There were four 15 watt lights, four supply grille diffusers, choose from a titus catalog based on CFM and noise criteria, and two exhaust that negatively pressurize the locker room. There is also a transfer grille in the door to provide make up air. The diffuser selected for the code ventilation rate can be seen in Figure 46, while the diffuser selected for the calculated ventilation rate can be seen in Figure 47.



8x6	0.33	0.26	cfm	78	104	130	156	182
			NC	-	-	11	17	21
			0°	5-9-16	8-12-19	10-15-21	12-16-23	14-18-25
			Throw 22.5°	4-7-13	6-9-15	8-11-16	9-13-18	11-14-19
			(ft) 45°	2-4-7	3-5-8	4-7-9	5-7-10	6-8-11

Figure 46: Diffuser Selection Table



42x8 24x14	2.33	2.14	cfm	642	856
			NC	-	13
			0°	16-25-47	22-33-54
			Throw 22.5°	12-19-36	17-26-42
			(ft) 45°	7-11-21	10-15-24

Figure 47: Diffuser Selection Table

I used a hybrid differencing scheme and a K-E turbulence model. The final results where yielded from a calculation of 5,000 iterations. Several calculations where done using 7,000 iterations but no added accuracy was noted.

Results

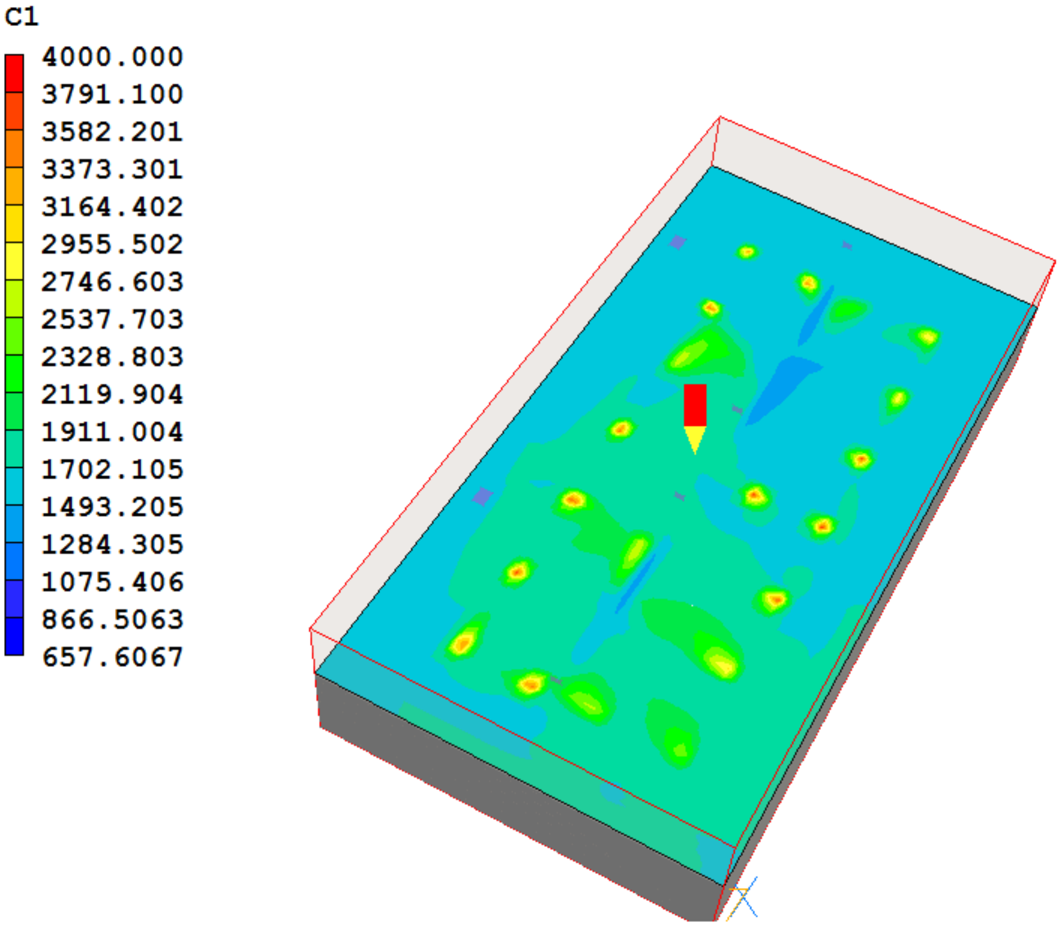


Figure 48: Contamination Distribution for Code Required Ventilation Rate

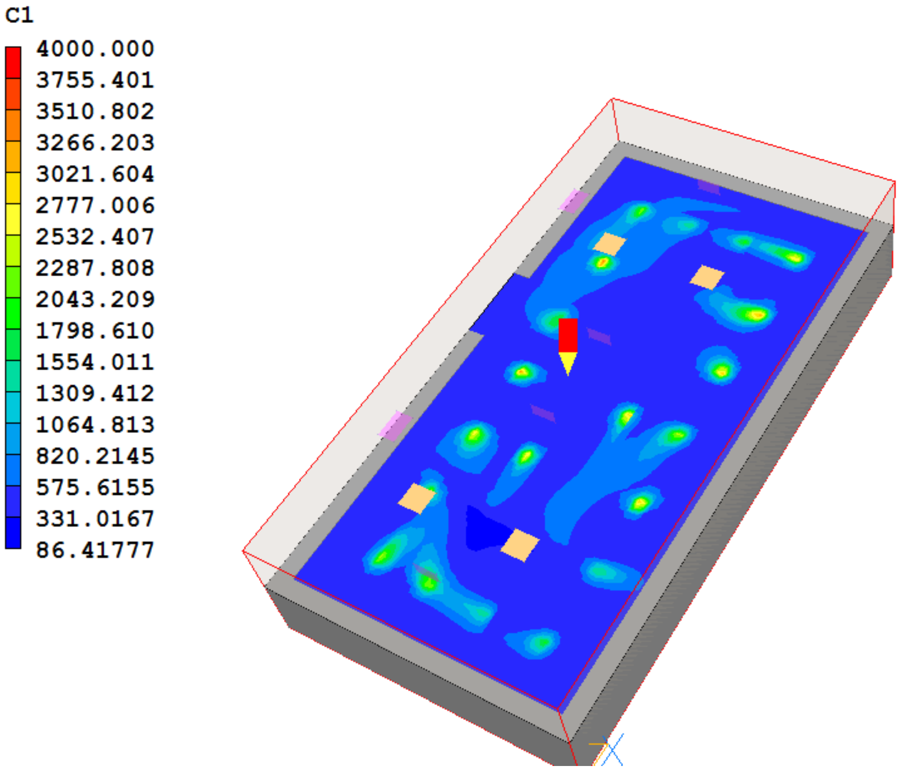
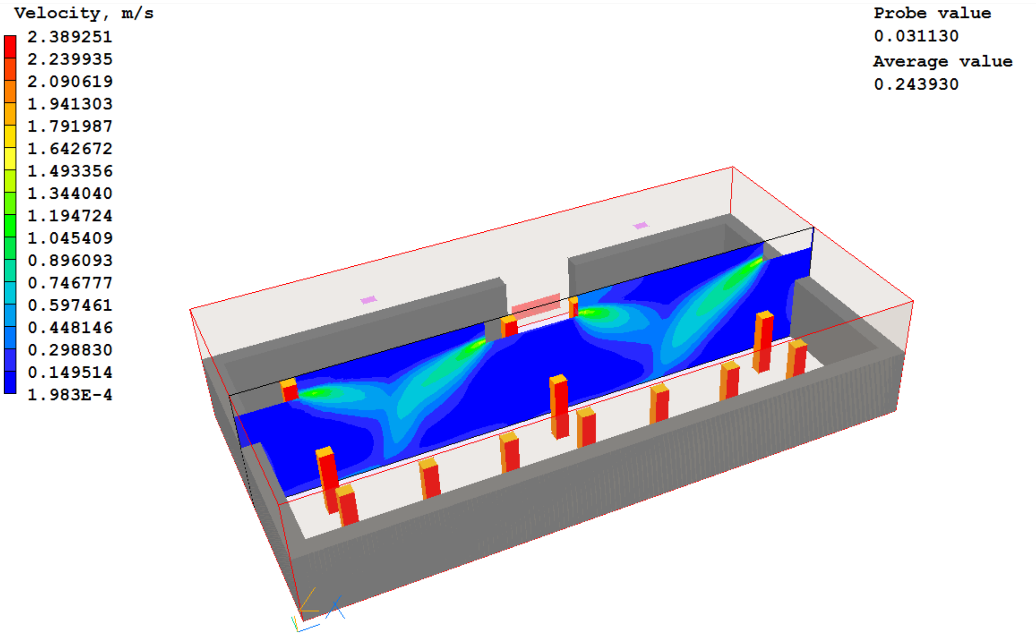


Figure 49: Contamination Distribution for Calculated Ventilation Rate

The rest of the results can be seen in Appendix F.



Conclusion

As previously stated, 360 ppm can be related to one olf of odor left in the room. Using the code ventilation rate of 0.5 cfm/sf the space would maintain a level of approximately 4.7 olfs. With the calculated ventilation rate the space reaches a steady state of less than 1.5 olfs. With the code ventilation the steady state of odor is roughly three times higher than that of the calculated value. This is a significant difference so HPR Integrated Design will use the calculated ventilation rate in my design of the men's locker room. This shows that using the code is not always the best design practice and the many times future calculations are required.

Since human odor is difficult to quantify it is also difficult to use a CFD analysis to determine exactly what the level of dissatisfaction would be. The CFD was useful in comparing, on an order of magnitude, how much more odor causing particles would be in the room. Both of the CFD results yielded average room concentrations lower than the hand calculations predicted. This was because the CFD turned out to be a relatively pour example of a well-mixed room.

It is important to note that using the calculated ventilation rate you can achieve odor levels that are similar to those of the outdoor air. Since the outdoor air was model to have a concentration on 350ppm and the steady state on the room was just above 500ppm. When this is compared to the steady state of the code required ventilation rate the 350 and 500 are very close.

Table 10 shows a general break down of the spaces by both their heating/cooling load and ventilation rates. A more detailed break down can be found in Appendix F. From this you can see the majority of the spaces are dominated by the cooling load. To meet the ventilation load and cooling load the 100% outdoor air handler will supply the greater of the ventilation and cooling requirement with a supply temperature of 55ºF. In the few cases where the ventilation dominates the cooling load reheat will have to be used. This was determined to use less energy and have a lower first cost than using fan powered terminal units in all the load dominated spaces to eliminate any reheat. It is also mandatory to cool the air to 55^{O}F to meet the dehumidification load on the space.

This study allowed HPR Integrated Design to more accurately determine the amount of supply and exhaust that was needed for the men's and women's locker rooms. With this new information we were able to reduce the size of AHU-7 and AHU-8 from 11,000 CFM to 7,000 CFM a piece. With this come the reduction of fan energy and added cost saving in the initial cost of the two air handling units. This savings is not reflected in the total savings for the Savings Package mainly because the required data to perform such an analysis was not accessible to our construction manager.

Structural Design

Structural design for the savings package was limited in scope due to the architecturally driven nature of the design focus. The structural designer's role through the investigation into the savings package was to facilitate and check the structural system of the facility after major architectural design changes. A small scale structural design and analysis would be completed to allow for architectural changes to be made within the lower arena seating bowl.

In addition to this, HPR Integrated Design proposed changes to the gravity system from the existing steel to a reinforced concrete section only below grade at the main concourse and event levels. Investigation into alternative floor framing systems and gravity column design was completed by the structural designer for collaborative decisions to be made on the project. The following section of this report will overview a view of these investigations and their determined feasibility or benefit to the overall project.

Two-Way Flat Plate Investigation

HPR Integrated Design proposed the redesign of the main concourse floor system from the existing composite slab and steel beam framing system to a two-way post tensioned flat plate system. This proposed change was a result of HPR Integrated Design believing that the controlling dimension in the raising of the Event level would be the effective depth of the above ceiling plenum coordinated with MEP systems. This change was investigated because of the potential decrease in overall floor system thickness of the floor framing system to optimize the ceiling plenum space for MEP coordination.

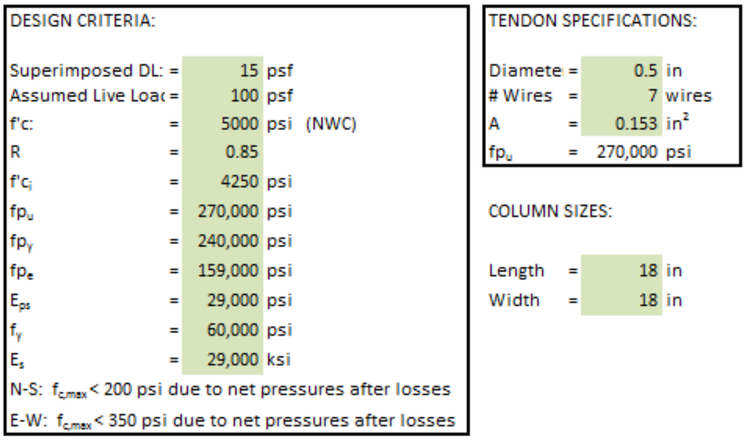
The structural designer completed the two-way post-tensioned flat plate flooring system per ACI 318-08, Building Code Requirements for Structural Concrete and Commentary. The system was designed to a substantial level of detail before HPR Integrated Design with advice from academic advisors deemed it necessary to abandon the alternative flooring system. Investigating factors of design and construction of a two-way PT system revealed that the alternative floor framing solution would not be beneficial to the project for the following reasons:

- Raising of the Event level was dictated by ADA sightlines and the effective depth of the plenum was more than sufficient using the existing composite framing floor system.
- Two-way PT system was designed for a one bay span in the short direction, which is not an efficient design.
- Post tensioning adds considerable cost to the proposed concrete structural system that would negate any anticipated savings in designing the alternative system.
- Bay sizes exceeded typical design criteria for effective design of two-way, post-tensioned flat plate designs.
- Constructability: Post-tensioning requires expertise by a local contractor which State College, PA lacks and therefore would require a specialized contractor for installation.
- Curved tendons in the two-way PT design could create issues with the concrete crushing from lateral forces during stressing. Lateral arches are also a consideration that is dangerous in design that results from the curved tendons.

The structural designer and construction manager collaborated and made a final decision that the two-way post-tensioned system was not a beneficial solution for the Penn State Ice Arena project and therefore was not used in this project. The structural designer completed the design for this two-way PT system using hand calculations. Complete hand calculations and layouts for the two-way PT flat plate framing system can be found in Appendix F.

Although not utilized for the project, the two-way, post-tensioned flat plate flooring system would have reduced the overall thickness of the main concourse floor system from the existing 32" depth (7.5" NWC slab and W24 steel girder) to a reduced 10" thickness with the two way slab system.

The two-way, post-tensioned flat plate system was design for bay sizes ranging from 32'-0" x 28'-0" to larger bays of 37'-2" x 28'-0" along the outer concourses of the main concourse level. The application of a two-way, post-tensioned flat plate system is most efficient at bay sizes of about 28' x 28' and up to 32' x 32' at the high extreme. The system was designed to use (7) ½" diameter, 270 ksi high strength mastic-coated tendons. The system was successful in balancing 100% of the target balanced dead loads using 26 tendons in a typical continuous span. Additional design criteria can be seen in Table 11 below.



DESIGN CRITERIA:

Superimposed DL:	=	15	psf	
Assumed Live Loa	=	100	psf	
f'c:	=	5000	psi	(NWC)
R	=	0.85		
$f'c_i$	=	4250	psi	
fp_u	=	270,000	psi	
fp_y	=	240,000	psi	
fp_e	=	159,000	psi	
E_{ps}	=	29,000	psi	
f_y	=	60,000	psi	
E_s	=	29,000	ksi	

N-S: $f_{c,max} <$ 200 psi due to net pressures after losses

E-W: $f_{c,max} <$ 350 psi due to net pressures after losses

TENDON SPECIFICATIONS:

Diamete	=	0.5	in
# Wires	=	7	wires
A	=	0.153	in^2
fp_u	=	270,000	psi

COLUMN SIZES:

Length	=	18	in
Width	=	18	in

Table 11: Two-Way, Post-Tensioned Flat Plate Slab Design Criteria

For complete hand calculations completed by the structural designer see Appendix F.

Reinforced Concrete Gravity System

HPR Integrated Design proposed the change of all gravity columns below the main concourse level, or below grade, from the existing steel design to a reinforced concrete alternative. The perceived benefits of this change were anticipated savings in cost from an expedited schedule and the ability to start construction earlier in the schedule directly after the concrete foundations were poured. HPR Integrated Design decided that this change was not beneficial to the project and decided to abandon this design before it was started. The feasibility of this system was rejected by HPR Integrated Design for the following reasons:

- The two-way, post-tensioned flat plate flooring system had been determined as not beneficial to the project resulting in constructability issues with reinforced concrete columns.
- Concrete columns were not required for the post-tensioned system for sufficient confinement of proposed arched tendons.
- Constructability concerns with having steel and concrete trades on site trying to complete work around each other.

The design of concrete columns was deemed unnecessary shortly after the determination of the two-way, post-tensioned slab as not feasible for our project.

ADA Alcove Structural Considerations

To meet ADA requirements for sightlines per the 2010 ADA Standard and team goals of the reallocation of seats to maintain the arena's business model, HPR Integrated Design had to develop an alternative ADA seating arrangement. As mentioned earlier, the inner ring of the arena that was design to allow for flexibility of ADA compliant seating anywhere around the interior of the lower bowl was replaced with ADA alcoves that met the 2010 ADA standard for both wheelchair accessible seating and distribution.

In this process, HPR Integrated Design decided to ramp up the 20'-0" long vomitories to enter the arena at a slope of 1:12 per the 2010 ADA standard, section 1010.2. This allowed for the additional 1'-8" dimension to allow for improved sightlines. With this redesign, structural considerations were taken into consideration.

To replace seats lost in the raising of the event level, two additional rows of seating were added above the main concourse level. In addition to the added load of the precast stadia, new steel members had to be design for the raised platforms of the new ADA alcoves. The structural designer performed hand calculations to design the simply supported steel for the new ADA alcoves. Figure 50 shows a section of the new raised ADA alcoves with support steel below the slab.

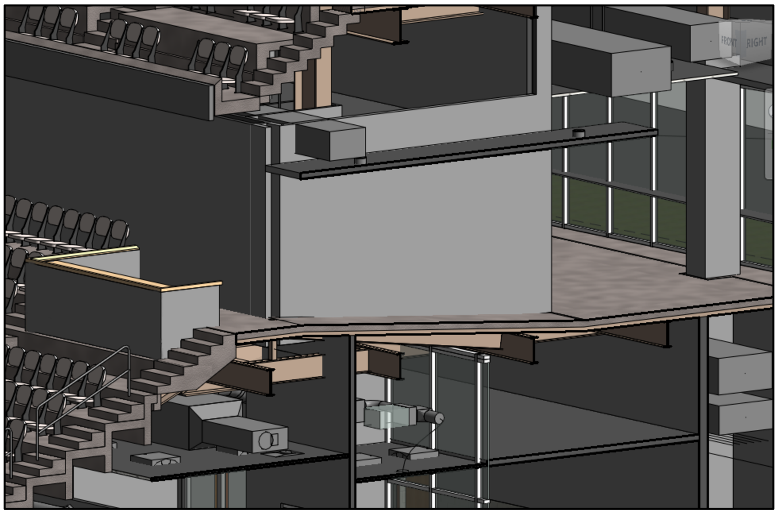


Figure 50: Ramped-Up Vomitorities at ADA Alcoves

Supporting steel members for the ADA alcoves were set 1' 1 ½" above the main concourse level and therefore could not frame into the structural framing below. The structural designer decided to allow this support steel and the precast stadia above the main concourse level to bear on a 8" thick masonry wall which runs around the interior wall of the main concourse's lower bowl.

An 8 inch ungrouted masonry knee wall was designed per the 2008 Building Code Requirements for Masonry Structures (TMS 402-08/ACI 530-08/ ASCE5-08). In this calculation, lateral loads were neglected and it was assumed that the stadia would concentrically load the wall. The 8" CMU face shell embedded masonry wall was designed as ungrouted using Type S PCL mortar cement mortar. The full calculation can be found in Appendix E.

Foundation Capacity Checks

With the raising of the Event level and reallocation of seating above the main concourse level, the structural designer checked certain deep and shallow foundations for capacity. Only spot checks were completed at this time at specific locations where load was added above the main concourse level. This additional load was transferred through the aforementioned masonry wall to the flooring system and finally to the foundations.

Micropiles were investigated primarily to determine if their boring depth would be sufficient to carry the loads from the large interior columns. Typical micropiles on this project consisted of 10" ø A53 Grade B steel pipes that were drilled between 20' and 30' down into the bedrock layers of the site. The geotechnical report called for the casing of the micropiles to be filled with 5,000 psi concrete that was neglected in the calculations for capacity.

After hand calculations, results showed that the micropiles in all cases were sufficient for capacity with the additional loads from the new seating above the main concourse level. An example of this typical calculation can be found in Appendix F. Strength requirements per calculations showed that the micropiles had capacities of near 120 kips/pile, which is much lower than the 300 kips/pile that was specified in the geotechnical report. This discrepancy is most likely due to the fact that the grouted condition of the piles was not taken into consideration and drastically affected the calculations.

Lighting Design

The lighting design for the event level was narrowed down to a typical office on the southern façade and the men's and women's locker room on the northern side.

The lighting solution in the office area needs to have a high level of user controllability. This is particularly important for the offices adjacent to the exterior. These offices are exposed to an intense amount of morning sun creating glare sources and extremely high illumination levels in these spaces; also due to the direct sun that these spaces see a daylight control system will be designed to decrease the amount of direct sun. The IES 10th edition lighting handbook has illumination criteria outlined in the table below. This criteria is for handwritten office work.

Horizontal Illuminance	300 lx @ 3' AFF
Vertical Illuminance	75 lx

The lighting solution in the office area needs to meet the IES recommendations outlined in the table below.

Horizontal Illuminance	50 lx @ Floor
Vertical Illuminance	50 lx @ locker face

Along with the illumination criteria in the 10th edition lighting handbook this space needs to provide a captivating first impression for recruitment reasons. Providing a space that is impressive follows HPR main theme in giving Penn State more value for every dollar spent.

AHSRAE Standard 90.1 section 9 dictates the allowable power density for these spaces. The office is allowed 1.11 watts per square foot, this gives 158.4 watts total for each office. The locker room is allowed to have a power density of 0.75 watts per square foot, giving a total connected allowable wattage of 1043.5 watts for each locker room.

Typical office

HPR has designed each office to have 2 dimmable LED zones, the first provides the required illumination on the desk/task plane and the second provides accent zone on the wall opposite of the desk.

The task illuminance is achieved using four 25 watt LED downlights Appendix F. These luminaires provide more than the required 300 lx of illumination. This was done for two main reasons. First as the human eye ages the amount of light transmitted through the eye and reaching the retina is reduced substantially. The IES 10th edition handbook outlines that at the age of 65 the amount of light reaching the retina is half of what someone younger than 65 would receive. Therefore the amount of light needed is double. The second reason is due to the fact that one entire wall is composed entire of glass. Having such a large source of daylight may cause the task area to appear dim when and occupant is doing work. Therefore having the option of more light on the task plane would mitigate the contrast between the task surface and the bright exterior.

The second zone of light on the wall is used to give the room balance. Having the first zone centered over the desk area of the room causes scallops on the wall. Therefore providing a wall grazing fixture Appendix F opposite of this wall will give the opportunity for highlighting artwork or other wall mounted objects.

Figure 51 below shows a pseudo colored AGI rendering of the typical office.

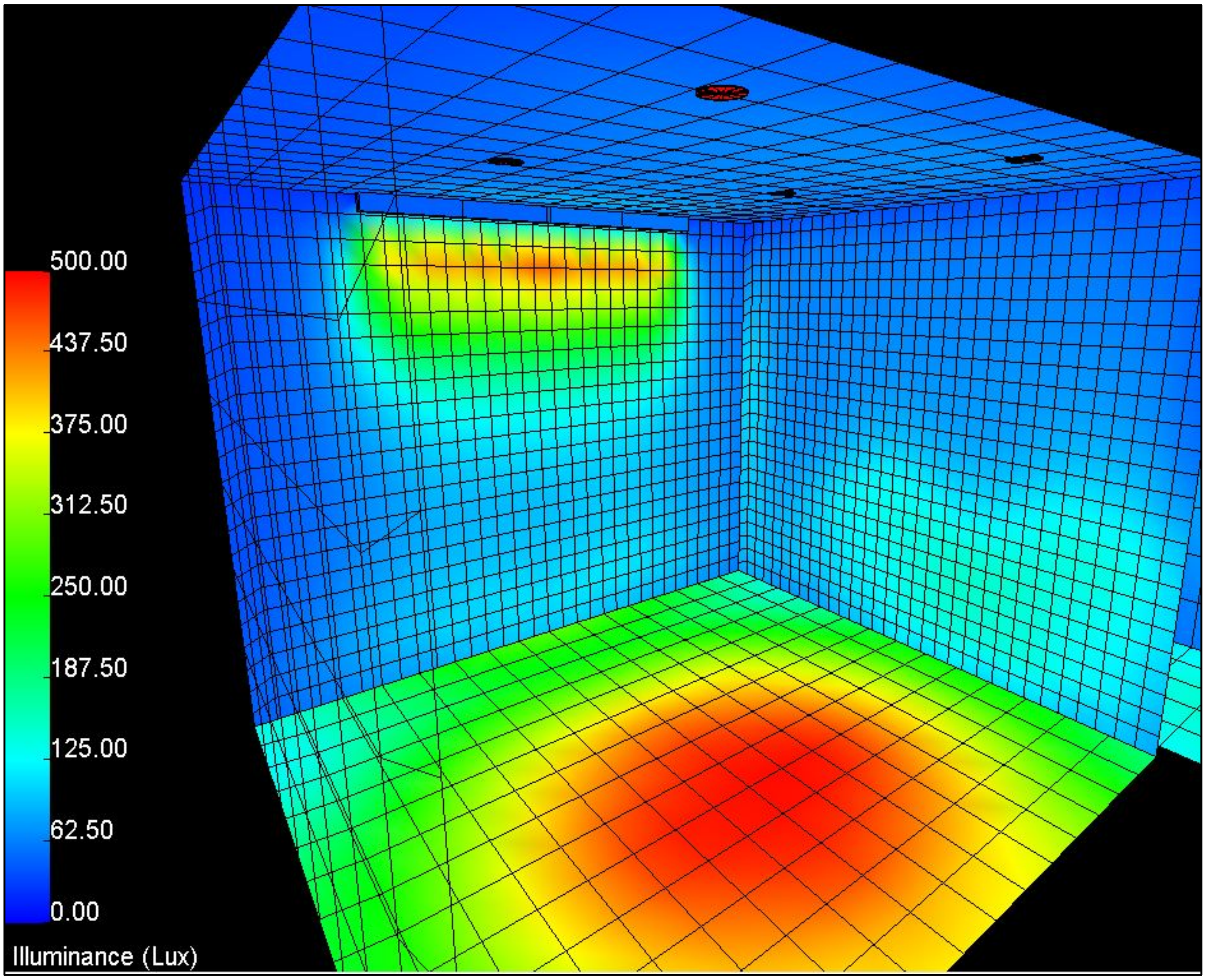


Figure 51: Typical Office AGI Pseudo Color Rendering

The numbers below compares the design criteria to the actual design metrics. The connected total power is 137 watts giving a 21 watt savings over the code allowable.

Horizontal Illuminance	300 lx @ 3' AFF	350 lx
Vertical Illuminance	75 lx @3’ AFF	83 lx

Locker Room

The lighting solution for the locker room, as stated before, must create a great first impression on perspective recruits, having this criterion for the locker room as well as the fundamental design objective for light to enhance the architectural appeal of a space. The following lighting solution was designed by HPR.

To provide the required vertical illumination at the locker face a recessed LED wall washing fixtures were placed along the perimeter of the locker room. Using a wall washing fixture gave enough light on the locker face while providing the necessary illumination on the floor.

To give an impressive appeal to the room the ceiling alcoves were illuminated with a linear fluorescent cove fixture. Using this fixture gave the ceiling another dimension, almost giving the feeling that it is not a ceiling at all. An AGI pseudo color rendering can be seen in Figure 52 showing this effect.

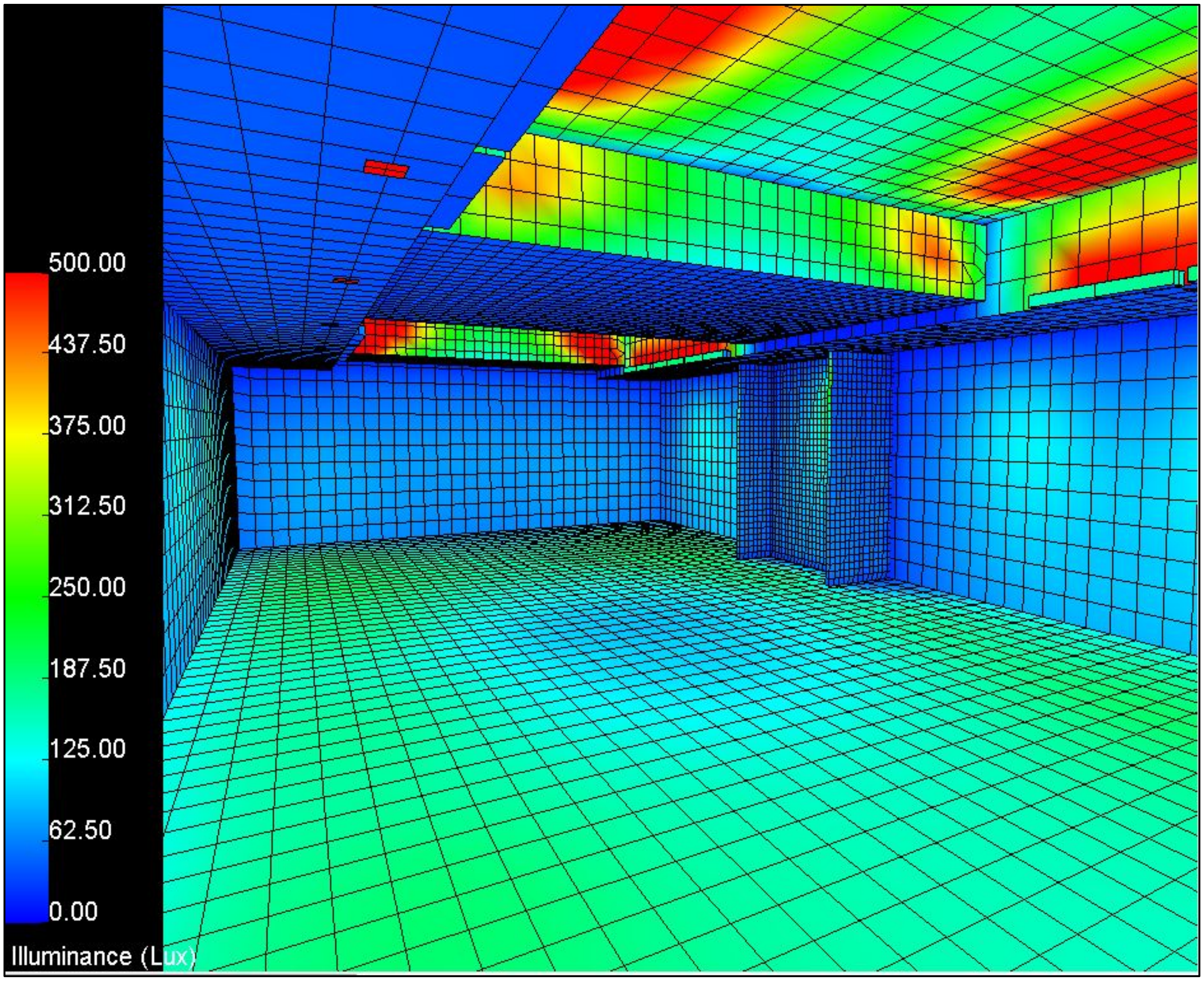


Figure 52: AGI Pseudo Color Rendering of Women's Locker Room

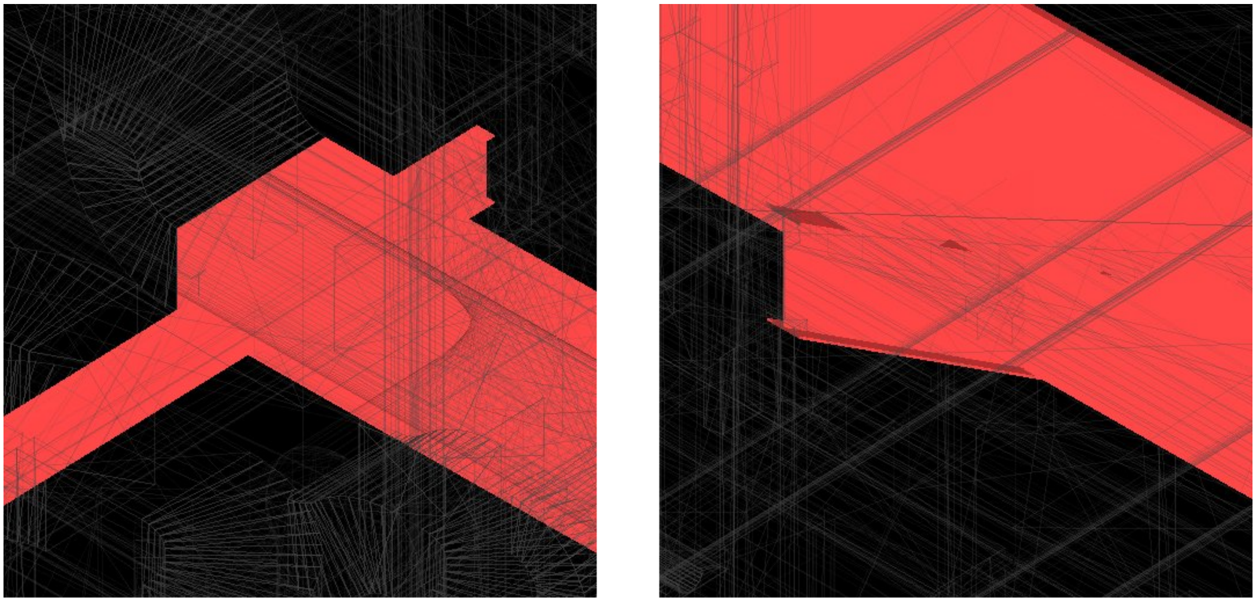
The results of the lighting solution are tabulated below. The total connected load in the locker room is 370 watts creating a savings of 673.25 watts over the allowable.

Horizontal Illuminance	50 lx @ Floor	153 lx
Vertical Illuminance	50 lx @ locker face	128 lx

Clash Detection

Throughout the design of the project, it was important for the team to try and minimize as much rework and redesign as possible. Clash detection was performed in Navisworks bi-weekly to ensure there were no instances where the MEP systems were intersecting with each other or the structure. Each time Clash Detection was to be performed, the current architectural model, MEP models, and structural model, needed to be exported into Navisworks. Clash detections of each model were not only performed one-on-one against one another, but also a clash detection of a model was performed against itself to ensure the designer did not make mistake in their own model. Detections were only performed on the building level or plenum space that was being designed for at the given time.

HPR was able to reduce the amount of rock and soil needing to be excavated, resulting in the reduction of the plenum space between the event level ceiling and the main concourse floor. Clash detections of the plenum space reported that the majority of the clashes were between the mechanical duct and structural beams. As tests were continued being performed, other minor clashes throughout the building included structural members intercepting places where there is concrete. These are minor due to the fact that some small sections of concrete needed to be deleted where a steel beam would be passing through such as a concrete floor. Figure 53 shows examples of detected clashes.


Mechanical Duct & Structural Beam Clash

Precast Stadia & Structural Beam Clash

Figure 53: Clash Detections

Cost and Schedule Implications

HPR Integrated Design designed efficient MEP systems passing through the plenum space between the event level ceiling and main concourse floor that allowed for the reduction of excavation needed by 3 feet 2 inches. By raising the event level, excavation of rock was reduced by 47.7%, while soil was reduced by 8.4%. The new proposed design breakdown is shown below. Note, that the numbers in parentheses reflect the increased savings. These reductions improved the schedule allowing for the start of foundations work to begin 7 workdays sooner.

	Soil	**Rock**
Total Cost:	**$533,589** (8.3%)	**$268,300** (49.6%)
Total Excavation:	**67,061 CY** (8.4%)	**13,275 CY** (47.7%)
Scheduled Work Days:	**12** (11.1%)	**6** (47.6%)

Raising the event level allowed the structural designer to reduce the size of the foundation walls, event level interior walls, and concrete columns. The construction manager exported the structural and architectural models into Quantity Takeoff, along with the costs and daily output per unit from *Craftsman* to determine these savings. Figure 54 shows an image of the main arena in Quantity Takeoff.

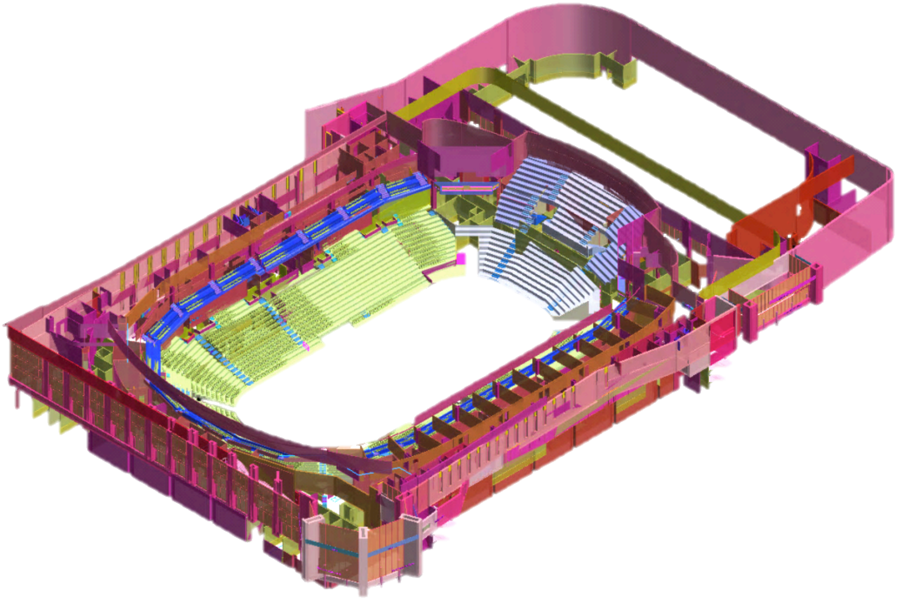


Figure 54: Quantity Take Image of Main Arena

The results from Quantity Takeoff determined that the schedule for the foundations work could be reduced by an additional 8 workdays, a total of 15 workdays, with a total savings of $627,314 (19.9%). These materials are shown below reflect savings.

Foundation Walls	**$162,354** (14.7%)
Event Level Interior Walls	**$122,689** (16.0%)
Concrete Columns	**$29,342** (18.5%)

It was important to maintain the architects original intent and for HPR to deliver a high quality product to the owner. For this proposed design to be efficient and for the team to achieve the goals set out, HPR used best design practices to modify or reinforce the current design for the main concourse, the main arena bowl, and the club level. HPR initially focused on the main arena bowl, but then found that the main arena ceiling needed to be raised while attempting to keep the club level ceiling locked in place. However, systems passing through the club level ceiling required that the ceiling be located at the original height. The following changes were made, with increased spending listed first, followed by additional savings.

Increased Spending

Main Arena Precast Stadia	**$25,317** (22.3%)
Main Arena Seats	**$16,599** (71.2%)
Main Concourse Interior Walls	**$79,777** (24.4%)
Club Level Interior Walls	**$19,776** (14.8%)
Glazing (**not including East Façade**)	**$22,813** (24.0%)
Exterior Walls (**not including East Façade**)	**$137,972** (11.0%)
Steel Columns	**$28,189** (4.5%)
Steel Beams & Concrete Footings	**$29,764** (3.0%)

Addition Savings

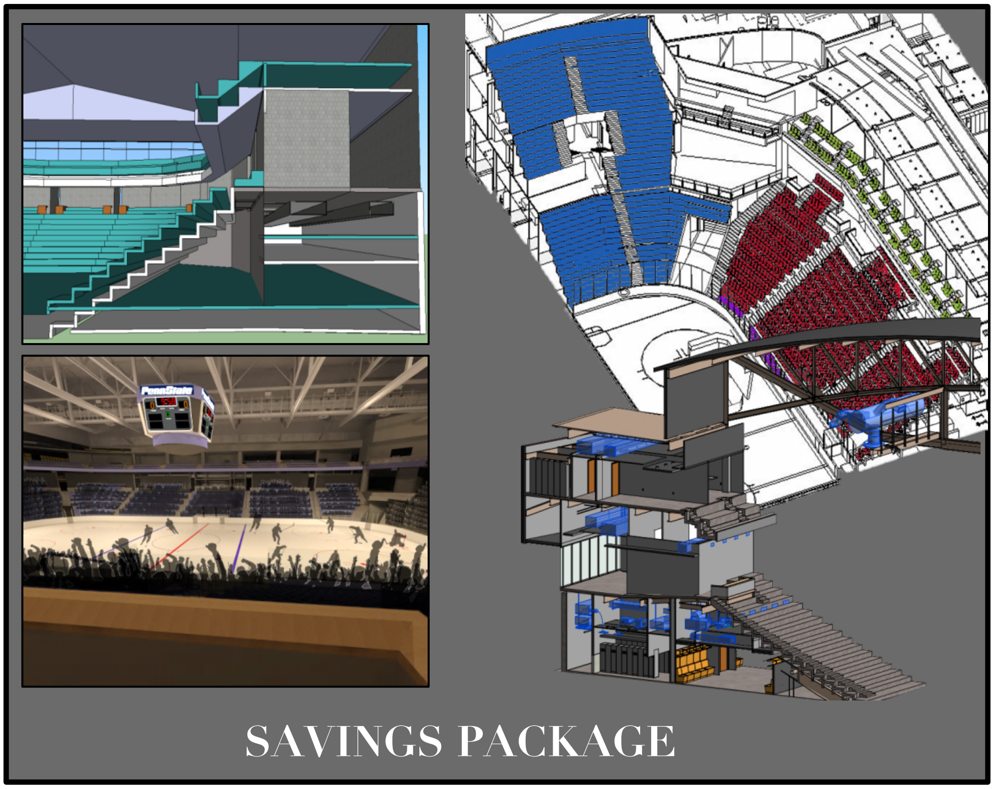
Main Arena Bowl Steps	**$5,493** (33.9%)
Shaft & Column Walls	**$5,679** (6.4%)
Shaft Stairs	**$6,240** (4.3%)
Remainder Steel	**$45,889** (1.6%)

The architect's current design calls for two types of brick on the façade in various locations, using normal brick and Norman brick. To help save costs and create a uniform look to the building, HPR changed the Norman brick to normal brick. With these additional designs, HPR was able to maintain a total savings of $330,407 of the overall budget for this design package. These savings will be reallocated in the enhancement packages for this building. All costs incorporate 24.8% overhead and profit markup. See Appendix F for complete breakdown of differences in cost and the schedule impact for this design package.

Package Summary

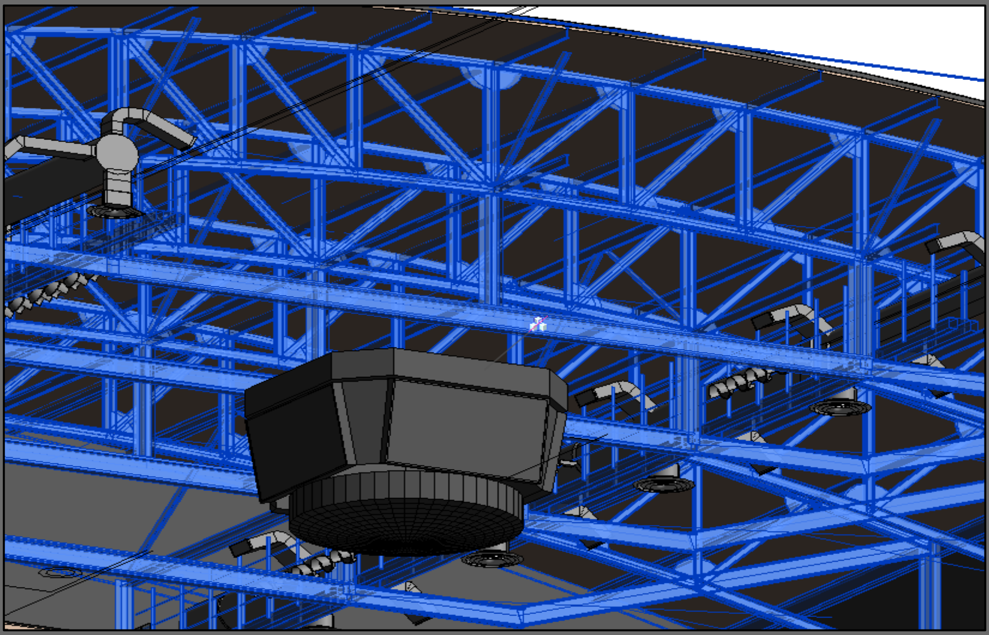
The main goal of the Savings Package was to save money in the excavation phase by raising the event level. HPR Intergraded Design also strove to maintain code compliance. The secondary goal was to maintain the business model that Penn State had created. We wanted to remain within 5% of both total seats and on total profit from a sold out arena.

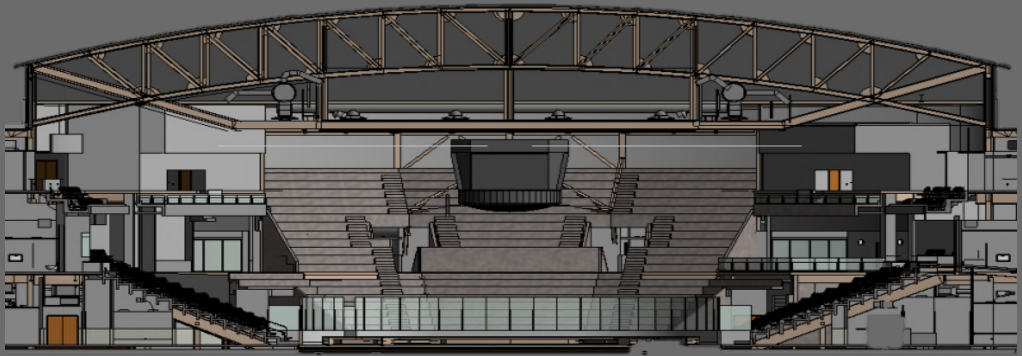
Through all the engineering shown throughout the previous sections HPR Integrated design was able to deliver on all of our goals. The total savings were $330,407 caused by raising the event level up 3 feet 2 inches. We also added 2.7% of the original seats and 2.37% of game day profit, both within our allotted goal. We also reduced the construction time by 15 workdays. All of this was done while maintaining the costumer experience.



ENHANCEMENT PACKAGE: Prominence

PROMINENCE





ENCHANCEMENT

Opportunity Statement

Through the investigation into the Penn State Ice Arena, HPR Integrated Design discovered that the reasoning for the utilitarian roof design was due to the expensive excavation of bedrock. The Pennsylvania State University is proud of its rich sports tradition and that is reflected in the state-of-the-art facilities located in the northeast corner of campus. HPR Integrated Design also believed that the Penn State Ice Arena is located at a critical site on campus that acts as a transition from the academic core of campus to its athletic sector.

The opportunity to add prominence to the facility by creating a more recognizable roof profile was a blend of savings from raising the event level, the assumption that the roof had not been fully designed where design was a thesis objective and the fact that HPR Integrated Design feels that this facility should rival adjacent sporting facilities on campus. Other prominent athletic facilities neighbor the Penn State Ice Arena with the Bryce Jordan Center, pictured in Figure 57, located directly across the street. The Multi-Sport Complex also is located within view of the arena and all athletic facilities are overshadowed by Beaver Stadium, the 110,000 seat football stadium that is iconic for the University. These facilities are pictured below are shown in the Figures below.

Figure 55: Bryce Jordan Center, Penn State

Figure 56: Multi-Sport Complex, Penn State

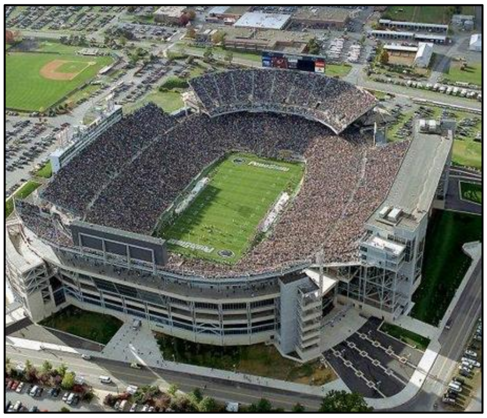


Figure 57: Beaver Stadium, Penn State

HPR Integrated Design proposed using the cost savings from the Savings package and reallocating the money back into the facility through a re-design of the high roof framing system, specifically the long span trusses for a more prominent roof profile. With cost savings from the savings package totaling more than $330,000, HPR Integrated Design could upgrade the utilitarian roof profile to a more dominant look that rivals these adjacent structures.

After seizing the opportunity to enhance the roof profile, HPR Integrated Design began to develop a goal and strategy for measures of success in this design focus. Through collaboration and in-depth conversation about the direction of this effort, the team decided that the goal of this design focus should be to give the owner the building they first were presented in the feasibility studies, shown in Figure 58 below.

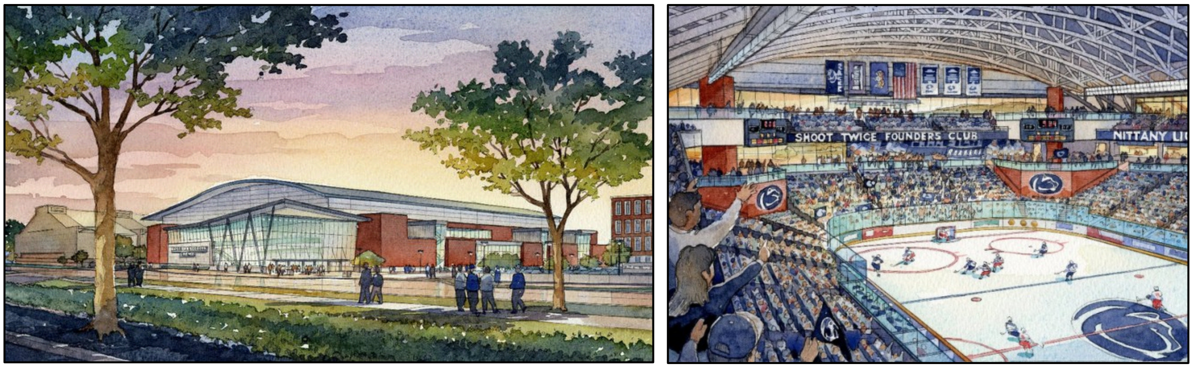


Figure 58: 2005 Feasibility Study Drawings

The renderings convey an original design scheme that included an arched roof profile that revealed a large, open interior volume in the main competition arena. From the exterior, the renderings show that the high roof systems are clear in expressing where the main function of the facility occurs, an architectural consideration that had to be relaxed due to the incurred cost of bedrock removal. The design team understood that these feasibility studies were completed without a baseline budget and purely as an architectural exercise. With that stated, the team decided that the new roof profile should return the high roof framing systems to the prominent design that was schematically designed.

With the main direction of the prominence package set, HPR Integrated Design turned towards secondary goals that were considered stepping stones to the ultimate design goal set forward. These secondary goals included:

- Creating a clean interior and exterior high roof framing system with seamless integration of mechanical systems, catwalks and high roof lighting systems
- Provide optimum, uniform NCAA compliant lighting design that enhances the visitors experience whether they are watching the game live or via broadcast.
- Track the high roof framing costs and schedule impacts in real-time along with keep constructability and sequencing at the forefront of the design process.

Keeping these goals in mind HPR Integrated Design moved forward into design strategy.

Shape and Dimensions

Selecting the roof profile was a continuously evolving process for HPR Integrated Design. Initial design concepts included mimicking the Bryce Jordan Center's geometrically intricate saddle like shape. The schematic shape of the roof, shown in Figure 59, quickly lost its momentum as constructability and cost analyses were performed on the design.

To obtain this geometry, the structural designer would need to design extremely deep, heavy trusses that would be challenging during construction and not economic. Another option was to vary the bottom of steel dimension and raise and lower the long span trusses to obtain the high and low points on the roof system. HPR Integrated Design decided that this would not allow the team to match their team design goal of a clean roof design as MEP systems would need to raise and lower creating a cluttered ceiling aesthetic. Ultimately, this design concept was determined not feasible for the type of structural system that was being designed for the project.

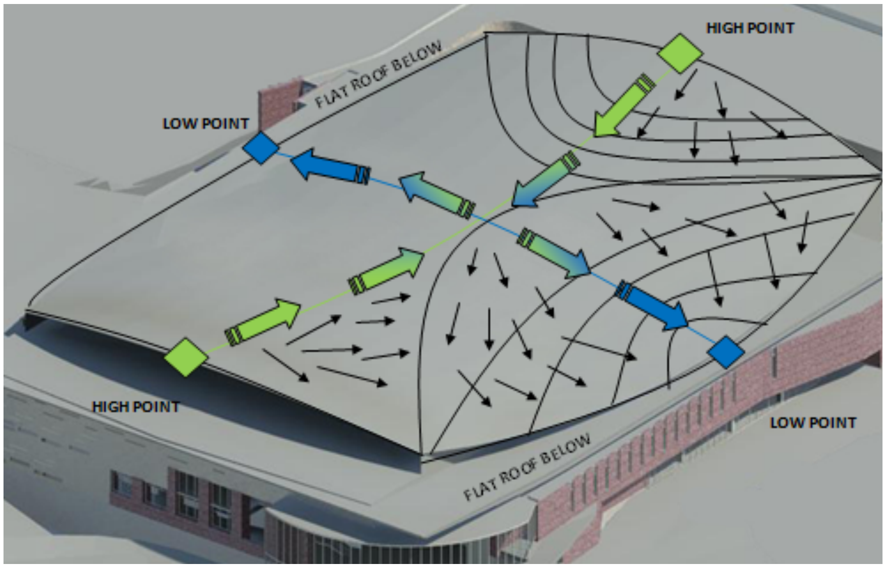


Figure 59: Schematic "Saddle" Roof Design Concept

HPR Integrated Design turned to a more conventional design, both consistent with the feasibility studies and without large constructability concerns. The collaborative design decision, led by the structural designer, is to move forward with an arched roof profile design that will be raised in elevation to allow for the main competition arena to be prominent and easily distinguishable as the most important space in the arena. This design strategy also helped pull the idea of functionality through the rest of the façade that was being designed concurrently.

Additional design decisions were made which included raising the overall elevation of the high roof framing, maintain the existing high roof dimensions, both the 196'-0" span of the trusses and the 240'-4" width through the building while also keeping all trusses at the same dimensions/elevations for constructability and the opportunity for prefabrication savings during construction. At this point, the mechanical designer was able to perform analysis on the amount of volume that could be added without major resizing of the existing two 45,000 CFM air handlers that were supplying the space.

Early Design Strategy

The integrated project delivery (IPD) method allowed HPR Integrated Design to get early input from the MEP designers and the construction manager which allowed the structural designer to complete a more efficient design not just for the trusses but for the high roof systems as a whole. After the mechanical designer had performed a volumetric expansion study for the arena, the team began to collaboratively determine the new shape of the roof. Analysis showed that the volume of the arena could be increased significantly without resizing the air handlers.

The lead/lag nature of this thesis was highlighted during the following weeks. A workflow (or lead/lag) diagram for the early design process is shown in Figure 60.

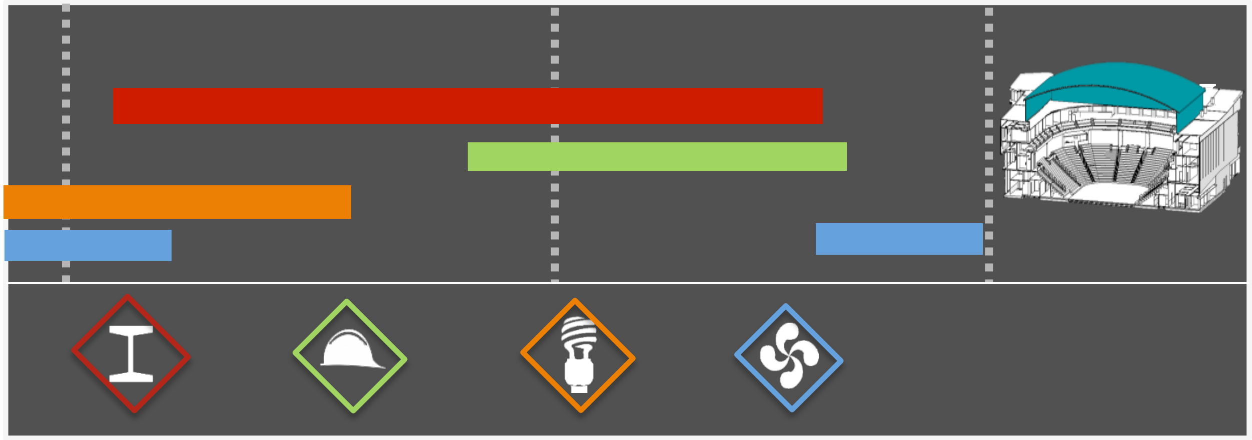


Figure 60: Partial Workflow Diagram for the Prominence Package

The mechanical designer and lighting/electrical designers were given free reign to determine the optimum location for their systems to enhance the overall performance of the arena. Preliminary duct sizing and catwalk locations were chosen at this time and the design criteria were given to the structural designer. This information allowed the structural designer to have all systems information up front, which is not typical in the traditional design process. The additional information did create a more difficult design process since the structural designer was not only thinking of his system but the project as a whole. Benefits to this process allowed for minimal redesign later in the thesis as major considerations had already been observed.

The construction manager was brought into the design process shortly after the MEP designers had completed their schematic system designs. As shown in Figure 60 above, the construction manager worked collaboratively with the structural designer throughout the remainder of the high framing systems design to ensure a constructible, cost effective design.

Case studies

Case studies were selected by HPR Integrated Design to investigate and learn more about high roof system designs based on similar arenas. Two key variables were considered during the selection of case studies: the span of the trusses and the seating capacity of the arena. Although many case studies were studied for preliminary considerations, HPR Integrated Design ultimately selected two case studies that were also studied by the actual design team during preliminary design of the arena.

The Compton Family Ice Arena at the University of Notre Dame and the Agganis Arena from Boston University were selected by the structural designer for heavy consideration into the design of the new Penn State Ice Arena long span trusses. HPR Integrated Design also chose to recognize the preliminary design for the actual Penn State Ice Arena project as a third case study. Below is a quick summary of each case study with key information that was beneficial to the HPR design team during the research phase of this focus.

The Compton Family Ice Arena

University of Notre Dame
Notre Dame, Indiana

Figure 61: Compton Family Ice Arena

University of Notre Dame

The Compton Family Ice Arena is a state of the art, two rink facility located in the heart of campus for the University of Notre Dame. The 5,022 seat arena was opened in October of 2011 and was closely studied for the business model and design of the Penn State Ice Arena. The high roof system is designed consistently with the Penn State Ice Arena with simply supported long span trusses which span 156'-0". The barrel truss shape of the long span truss, shown in Figure 63, is 14'-9 ¼" tall at its mid-span and consists of primarily W14 chords and W8 web members.

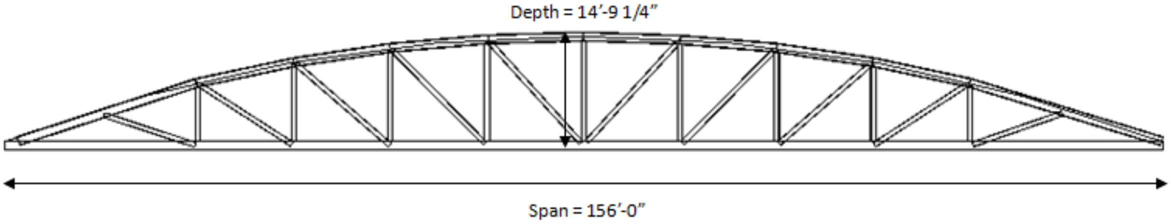


Figure 62: Long Span Truss Profile - Compton Family Ice Arena

The Compton Family Ice Arena was opened for its inaugural season in the fall of 2011 and the construction cost of the facility was roughly $50,000,000. The arena also served as a case study for the business model of a similar arena. The arena is laid out very similarly to the Penn State Ice Arena with a large lower bowl for general admission seating with a mezzanine level with additional seating and suites. The Compton Family Ice Arena served as a case study for a slightly smaller arena in both seating capacity and long span truss.

Agganis Arena
Boston University
Boston, Massachusetts

Figure 63: Agganis Arena

Boston University

The Agganis Arenas a slightly older, yet still state-of-the-art , multi-purpose arena located on the campus of Boston University in Boston, Massachusetts. The 7,200 seat arena was opened in 2005 and boasts not only a large multi-purpose arena but also is part of the John Hancock Student Village Complex that has an Olympic size natatorium and multiple basketball courts. The arena is not exclusively used for ice hockey like the Compton Family Ice Arena and has been the host of many large concerts and events for the University. The entire complex, including the arena, culminated in a construction cost of $225,000,000.

The high roof framing system consists of 13 different trusses that hold up the domed roof profile with a diaphragm ring around the base of the high roof system. Long span trusses run both directions with the larger trusses spanning 204'-0", slightly larger than the 196'-0" span that the Penn

State Ice Arena boasts. Member sizes for the long span trusses include W14 wide flanges for the chords and W12's for the web members. The truss is 24'-0" deep. These large long span trusses can be seen in Figure 64 below.

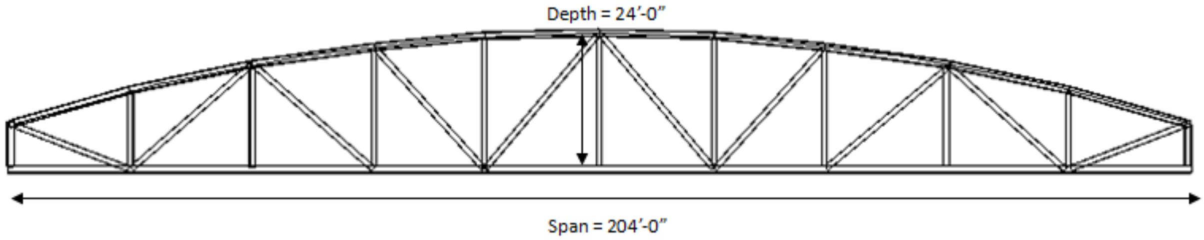


Figure 64: Long Span Truss Profile - Agganis Arena

The high roof framing system is much more complex and is designed with a rigging grid much more extensive than both the existing design for the Penn State Ice Arena and the Compton Family Ice Arena. This arena was also studied by Penn State University in its programming portion of the design process and was visited by the University's high level officials before design started. The Agganis Arena was utilized as a larger case study both in terms of seating capacity and overall truss span length.

<u>Penn State Ice Arena – Existing Design</u>
The Pennsylvania State University
State College, Pennsylvania

Figure 65: Penn State Ice Arena – Existing Design

HPR Integrated Design made a collaborative decision to recognize the high roof framing system for the existing Penn State Ice Arena. This decision was made for two reasons: to obtain a baseline value for the high roof framing system for cost control and to prove the utilitarian design and cost of the roof due to the excessive rock excavation.

The existing high roof framing system consisted of eight (8 simply supported long span trusses spanning 196'-0" with bridging trusses running perpendicular for stability in the opposite direction. The existing trusses are 10'-0" deep at their supports and gently slope to 12'-6" at midspan. Top and bottom chords consist of W14 wide flange members with double angles acting as the web members. Figure 66 below shows the existing truss design for the Penn State Ice Arena.

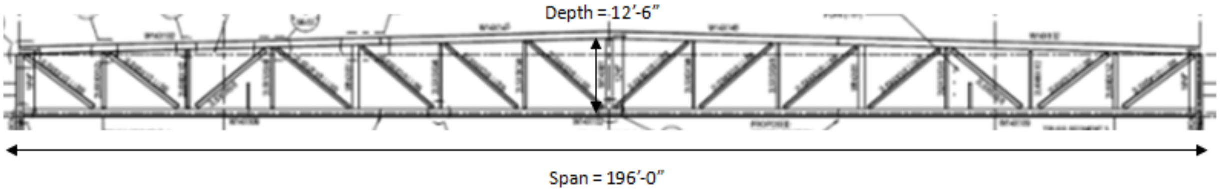


Figure 66: Long Span Truss - Penn State Ice Arena

HPR Integrated Design felt that although the assignment brief for this thesis project was to design the facility without a roof, it was important, for cost comparison and schedule, to observe the existing truss design and erection sequence. HPR felt that the structural drawings level of detail was past the design document stage when the project contract documents were obtained.

Regulations

HPR Integrated Design investigated NCAA regulations for minimum clear dimensions for ice hockey regulations and found that the American Collegiate Hockey Association (ACHA) did not have any minimum set as official requirements. The team turned to best design practices of architectural design of typical arenas and information gained from research into case studies listed above. Research revealed that a minimum clear dimension of 50' to 60' was ideal for NCAA hockey regulations.

The existing Penn State Ice Arena had a 50'-0" clear dimension between the ice and bottom of steel and the Agganis Arena designed for a 54'-6" bottom of steel dimension. HPR Integrated Design decided that part of the design criteria to maintain excellence in design would be to observe this design consideration and utilize this knowledge in the design of the new high roof framing system.

Integration of Mechanical Electrical and Structural Systems

Structural System

Design Decisions & Key Assumptions:

The structural designer's most critical challenge throughout this thesis was to design long span trusses that created a clean high roof design and gave the new arena a more prominent look from both the interior and exterior of the facility. Key decisions were made as a design team before the design of these trusses could begin. These decisions included locking the architectural layout of the building and also deciding to not change the spacing of the long span trusses which ranged from 32'-0" to nearly 40' apart.

HPR Integrated Design also decided that the span of the arena would not be changed as the current architectural layout seemed to be efficient for the function of the spaces within the building. A major part of the team concept was to maintain the architect's intent throughout the design/redesign process.

Investigation into the preliminary design of the Penn State Ice Arena's roof led to more design considerations that were kept in mind throughout the design process. The existing section of the building, as seen in Figure 67, shows two key dimensions that were continuously checked and considered in the redesign of these trusses: the bottom of steel dimension and overall building height.

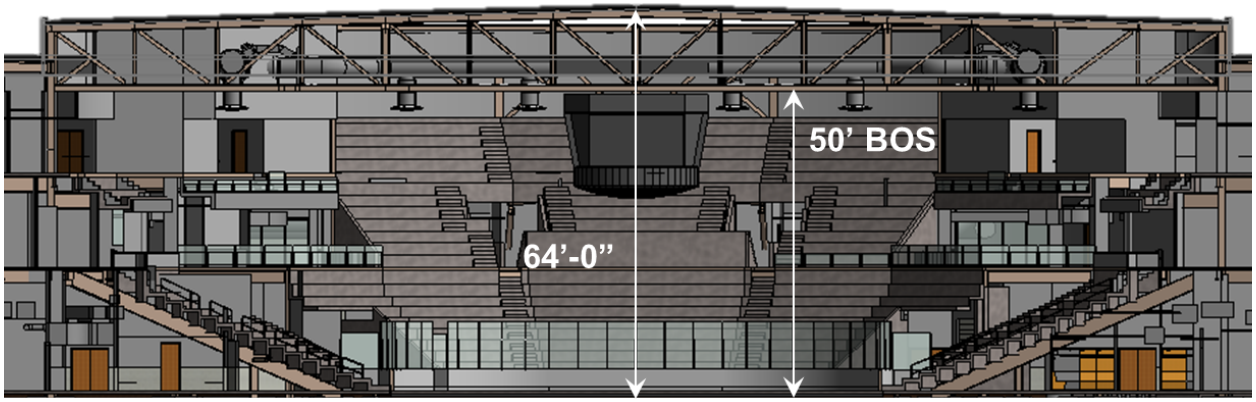


Figure 67: Existing Transverse Section

Through research and professional practioner's input, it was determined that a 50' to 55' clear dimension was ideal for NCAA hockey gameplay regulations and was determined by HPR as a best design practice which must be maintained. Additionally, the existing building was 64' tall which was mostly because of the relatively flat 12'-6" deep existing long span steel joists. To add prominence to this facility, HPR Integrated Design decided that this dimension must be increased to add volume to the arena and give the space a larger, more impressive feeling like that depicted in the feasibility studies conducted in 2005.

The process of design for the long span trusses was a collaborative, thesis long effort that resulted in multiple design iterations to optimize both the dimensions and efficiency of the system with the high framing MEP systems. All disciplines had critical input into engineering decisions throughout the process in terms of MEP system coordination and constructability considerations.

The mechanical and lighting/electrical designer had early input into their ideal system layout locations and gave the structural designer preliminary sizes for consideration. The mechanical designer provided information for schematic supply duct sizes and the lighting/electrical designer provided ideal locations for catwalks that would also be utilized to house the arena's main competition and broadcasting lighting system.

Tied Arch Truss Geometry

The trusses were schematically sized for overall depth using two different design considerations: the typical length to depth ratio equal to 12 for most long span trusses and a limitation of 14'-8" deep pieces which is driven by the width of a flat bed, which is standard for normal transportation.

Research into tied arch truss design quickly revealed that this type of system was considered to be a highly efficient system. It was also determined that the deeper the geometry of the truss, the more cost effective. Therefore, the structural designer decided to create a 14'-0" deep geometry that would maximize the efficiency of the truss members and also allow for a larger volume in the arena, consistent with the team approach for a new prominent system design.

Panel spacing for the upper chord of the truss was chosen based on the design of the acoustical steel decking for the arena roof system. Spacing for the verticals in the top chord were chosen to be 12'-0" apart as this spacing allowed for the roof system to be design with 3N18 acoustical roof deck.

Figure 68 below shows the typical architectural detail for the roof assembly. The acoustical decking was designed based on loads in Table xx. The flat roof snow load was included in the live load calculation to be conservative and also the minimum code required roof live load per ASCE 7-10 4.8.2. The 3N acoustical decking from the Vulcraft steel deck catalog is commonly used in structures like auditoriums, theatres and arenas were sound control is desirable. The deck is filled with batt insulation and can absorb up to 70% of sound that hits the deck. The architectural intent and Owner's desire is for the sound to be trapped in the arena creating a boisterous atmosphere for gameplay consistent with a "home ice advantage." The selection of the roof deck can be found in Appendix G.

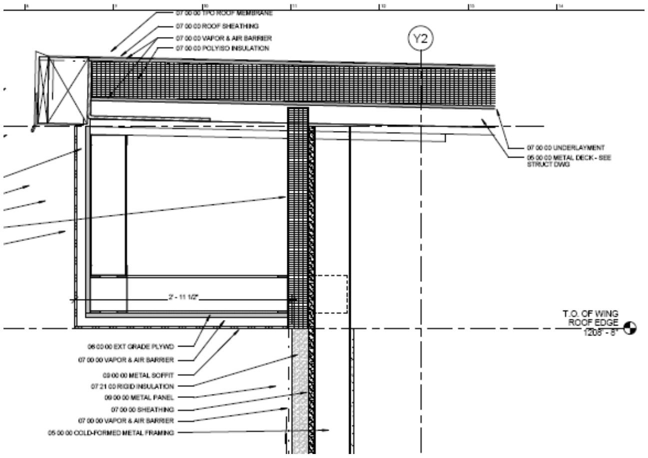


Figure 68: Partial Detail H1/A4-14

Element	**Type**	**Load (PSF)**	
TPO Roof Membrane	Dead	1	
3/4" Plywood Sheathing	Dead	3	
6" Rigid Insulation	Dead	9	
Vapor & Air Barrier	Dead	0	
3/4" Plywood Sheathing	Dead	3	
3N18 Roof Deck	Dead	4	
Superimposed DL	Dead	15	
TOTAL DEAD		**35**	**PSF**
Snow	Live	36	
Roof Live	Live	12*	
**Minimum Roof Live Load per ASCE7-10 4.8.2*			
TOTAL LIVE		**48**	**PSF**
TOTAL LOAD		**83**	**PSF**

Table 12: Roof Loads for Acoustical Deck Design

The 3N18 acoustical roof deck was assumed to be a three plus span condition and at 12'-0" spacing the deck can carry total load (85 psf > 83 psf) and live load (96 psf>48 psf) which is designed for deflection criterion of span/240 which was conservative.

Diagonals web member geometry was chosen so that all web members would be in tension to allow for more efficient use of the material and eliminate buckling considerations. Wide flanges were selected instead of double angles due to cost considerations.

HPR Integrated Design decided on a curved roof profile to create a stronger, more prominent look along with the recognition of this space as the main functional space within the facility. The arched profile of the top chord would create induced lateral thrust forces that would be handled by diagonal ties. The top chord with diagonal web members would act as a large, deep member in compression and the diagonal and horizontal ties would need to carry the majority of the tension forces in the geometry. Figure 69 shows the final geometry of the tied arch long span truss.

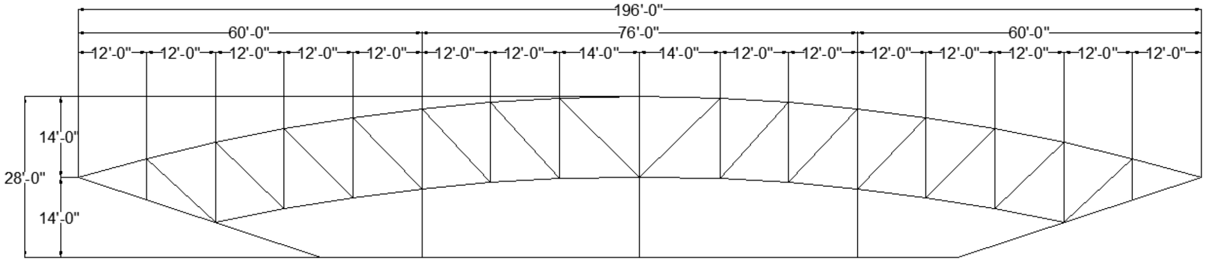


Figure 69: Long Span Truss Geometry

Long Span Truss Analysis & Design

After the geometry of the truss had been refined to a point where design could commence, the truss was placed into the structural design program SAP 2000 for frame analysis. The frame analysis shown in figure xx below was done for the worst case truss scenario, at the ends of the high roof systems and locations where the scoreboard would be hung from the trusses along column lines X8 and X9.

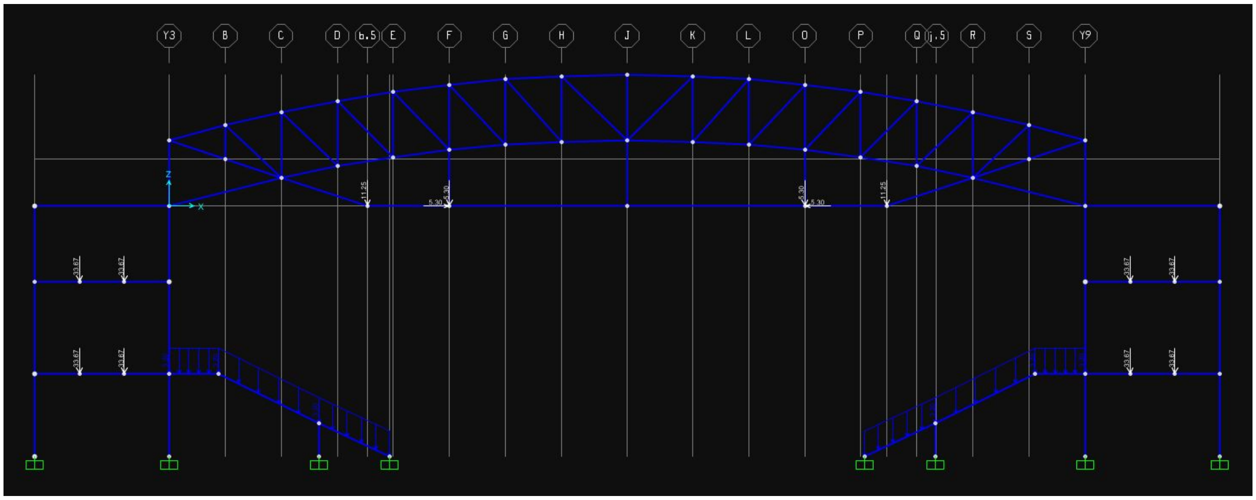


Figure 70: SAP 2000 Frame Analysis

Table 13 shows the gravity loads used in this frame analysis followed by the wind loads derived from ASCE 7-10 Chapter 26 – Method 2 Wind Analysis for High-Rise Buildings in Table 14. Additional wind load analysis can be found in Appendix G.

Dead & Live Loads – Frame Analysis

Load	Level	Space	Load (psf)
Dead	Main Concourse	Corridor/Rackers	90
Live	Main Concourse	Corridor/Rackers	100
Dead	Club	Corridor	90
Live	Club	Corridor	100
Dead	Low Roof	Roof	40
Live	Low Roof	Roof	12
Dead	High Roof	Roof	40
Live	Low Roof	Roof	12
Dead	All	Façade – Brick	58

Table 13: Dead & Live Loads - Frame Analysis

Windward Wall Pressures

		P (psf) with	
Surface	**z (ft)**	**GCpi**	**-GCpi**
Windward Wall	0-15	12.82	**26.50**
	20	13.98	**27.65**
	25	14.90	**28.58**
	30	15.83	**29.50**
	40	17.22	**30.89**
	50	18.37	**32.05**
	60	19.30	**32.97**
	70	20.32	**33.99**
	80	21.09	**34.77**
	81.52	21.20	**34.88**

Table 14: Windward Wall Wind Pressures

Wind Pressures - Remaining Walls & Roof			
Surface	z(ft)	P (psf) with	
		Gcpi	-GCpi
Side Wall	All	-31.37	-17.7
Leeward - Normal to L Face	All	-24.36	-10.69
Leeward - Normal to B Face	All	-21.36	-7.68
Roof - Normal to L Face	0-40.76	-38.38	-24.71
	81.52	-38.38	-24.71
	163.04	-24.36	-10.69
	252	-17.35	-3.68
Roof Normal to B Face	0-40.76	-38.38	-24.71
	81.52	-38.38	-24.71
	163.04	-24.36	-10.69
	252	-17.35	-3.68

Table 15: Side Wall, Leeward Wall, & Roof Wind Pressures

Snow loads were derived following the procedure outlined in Chapter 7 of ASCE 7-10 and using information from S0-1 of the contract drawings for exceptions for ground snow load values in State College. Based on factors from the tables in Chapter 7, the flat roof snow load was taken as 36 psf. Due to the high roof and low roof being at different elevations, drift was considered at locations where the high roof and low roof met. A summary of the snow and wind drift calculations can be found in Appendix G.

Additionally, rigging loads were considered in the loading of this typical frame. From research on case studies that were similar in size and arena function, the trusses were determined to be able to handle 30,000 lbs per truss with three rigging points at each panel point on the lower horizontal tie. Trusses along column lines X8 and X9 were designed to be able to hold the 30,000 lb. central hanging scoreboard using a four point rigging layout with 15,000 lbs capacity for each truss.

Some special rigging considerations were also considered based on research on the Agganis Arena in Boston. The horizontal tie member was designed to hold a typical end stage curtain rigging system which consists of a single, electrically operated 80' end stage rear curtain masking batten with the capacity to lift and sustain 2,000 lbs. Additionally, for events that want to cover the mezzanine level during smaller performances, the trusses were designed to hold a flexible/portable truss and motor system that consist of a box truss with 11 rigstar, 2,000 lb motors with a control system for velour curtains.

The frame analysis included the moment frames that run east-west on the building at all three levels. Worst case wind loads were considered in the east-west direction where the building slopes down and is exposed down to the event level. The frame analysis was run and the output from the program revealed that load combination 1.2D + 1.6S + 0.5W was the controlling load combination from

Chapter 2 of ASCE 7-10. The structural designer used the axial loads, major axis (bending 3-3) moments and maximum deflection values from the respective load case to design the members individually by hand. Figure 71 shows a screenshot of the long span truss in the frame analysis within the SAP2000 analytical program with axial loads displayed.

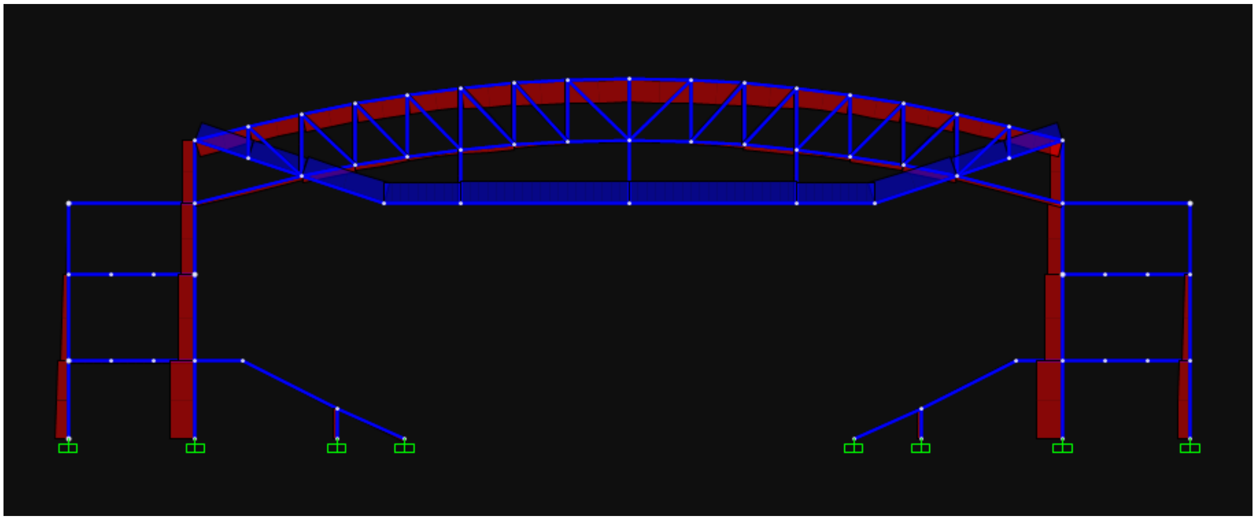
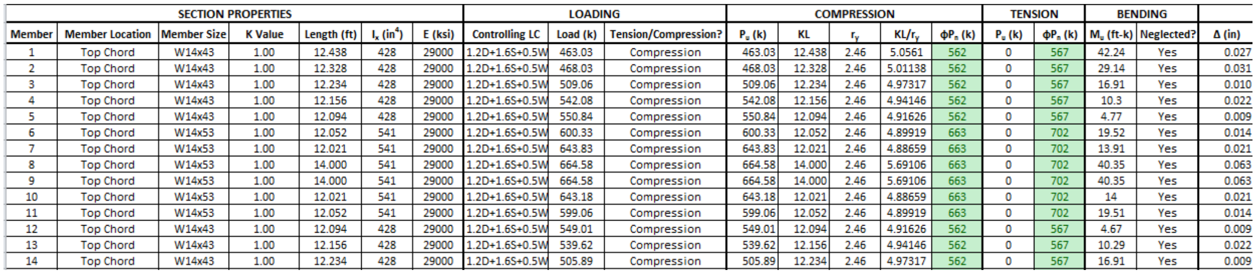


Figure 71: Axial Load Output - SAP2000 Frame Analysis

From the data output from the analytical software, the structural designer performed hand calculations to design the individual members within the truss. All members were designed per the AISC Steel Manual – 13th edition as either pure compression members (per Table 4-1), pure tension members (per Table 5-1) or as combined loading members per Table 6-1. All values extracted from SAP2000 output were accumulated into a spreadsheet as partially shown due to size in Table 16. Complete hand calculation spreadsheets for the member sizing of the long truss steel members can be found in Appendix G.

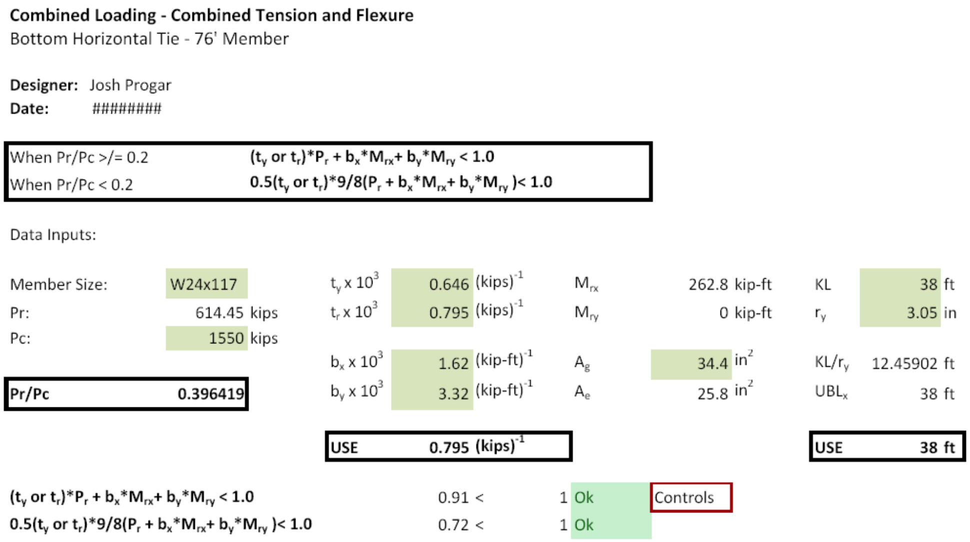


SECTION PROPERTIES							LOADING			COMPRESSION					TENSION		BENDING		
Member	Member Location	Member Size	K Value	Length (ft)	I_x (in^4)	E (ksi)	Controlling LC	Load (k)	Tension/Compression?	P_u (k)	KL	r_y	KL/r_y	ϕP_n (k)	P_u (k)	ϕP_n (k)	M_u (ft-k)	Neglected?	Δ (in)
1	Top Chord	W14x43	1.00	12.438	428	29000	1.2D+1.6S+0.5W	463.03	Compression	463.03	12.438	2.46	5.0561	562	0	567	42.24	Yes	0.027
2	Top Chord	W14x43	1.00	12.328	428	29000	1.2D+1.6S+0.5W	468.03	Compression	468.03	12.328	2.46	5.01138	562	0	567	29.14	Yes	0.031
3	Top Chord	W14x43	1.00	12.234	428	29000	1.2D+1.6S+0.5W	509.06	Compression	509.06	12.234	2.46	4.97317	562	0	567	16.91	Yes	0.010
4	Top Chord	W14x43	1.00	12.156	428	29000	1.2D+1.6S+0.5W	542.08	Compression	542.08	12.156	2.46	4.94146	562	0	567	10.3	Yes	0.022
5	Top Chord	W14x43	1.00	12.094	428	29000	1.2D+1.6S+0.5W	550.84	Compression	550.84	12.094	2.46	4.91626	562	0	567	4.77	Yes	0.009
6	Top Chord	W14x53	1.00	12.052	541	29000	1.2D+1.6S+0.5W	600.33	Compression	600.33	12.052	2.46	4.89919	663	0	702	19.52	Yes	0.014
7	Top Chord	W14x53	1.00	12.021	541	29000	1.2D+1.6S+0.5W	643.83	Compression	643.83	12.021	2.46	4.88659	663	0	702	13.91	Yes	0.021
8	Top Chord	W14x53	1.00	14.000	541	29000	1.2D+1.6S+0.5W	664.58	Compression	664.58	14.000	2.46	5.69106	663	0	702	40.35	Yes	0.063
9	Top Chord	W14x53	1.00	14.000	541	29000	1.2D+1.6S+0.5W	664.58	Compression	664.58	14.000	2.46	5.69106	663	0	702	40.35	Yes	0.063
10	Top Chord	W14x53	1.00	12.021	541	29000	1.2D+1.6S+0.5W	643.18	Compression	643.18	12.021	2.46	4.88659	663	0	702	14	Yes	0.021
11	Top Chord	W14x53	1.00	12.052	541	29000	1.2D+1.6S+0.5W	599.06	Compression	599.06	12.052	2.46	4.89919	663	0	702	19.51	Yes	0.014
12	Top Chord	W14x43	1.00	12.094	428	29000	1.2D+1.6S+0.5W	549.01	Compression	549.01	12.094	2.46	4.91626	562	0	567	4.67	Yes	0.009
13	Top Chord	W14x43	1.00	12.156	428	29000	1.2D+1.6S+0.5W	539.62	Compression	539.62	12.156	2.46	4.94146	562	0	567	10.29	Yes	0.022
14	Top Chord	W14x43	1.00	12.234	428	29000	1.2D+1.6S+0.5W	505.89	Compression	505.89	12.234	2.46	4.97317	562	0	567	16.91	Yes	0.009

Table 16: Partial Hand Calculations for Member Sizing

Per the definition of a combined loading member, every truss member has some axial force & moment that classifies them as combined loading members. For simplicity, the structural designer neglected the bending moments that were calculated to be less than 10% of the axial force as it would not affect the design of the member. These members were considered to only carry pure axial tension or compression.

The structural designer did check the diagonal and horizontal ties as combined loading members since their moments exceeded their axial forces. Table 17 below shows a sample hand calculation to check the capacity of the horizontal tie.



Combined Loading - Combined Tension and Flexure
Bottom Horizontal Tie - 76' Member

Designer: Josh Progar
Date: ########

When Pr/Pc >/= 0.2 **$(t_y \text{ or } t_r)*P_r + b_x*M_{rx} + b_y*M_{ry} < 1.0$**
When Pr/Pc < 0.2 **$0.5(t_y \text{ or } t_r)*9/8(P_r + b_x*M_{rx} + b_y*M_{ry}) < 1.0$**

Data Inputs:

Member Size:	W24x117		t_y x 10^3	0.646	$(\text{kips})^{-1}$	M_{rx}	262.8	kip-ft	KL	38	ft
Pr:	614.45	kips	t_r x 10^3	0.795	$(\text{kips})^{-1}$	M_{ry}	0	kip-ft	r_y	3.05	in
Pc:	1550	kips									
			b_x x 10^3	1.62	$(\text{kip-ft})^{-1}$	A_g	34.4	in^2	KL/r_y	12.45902	ft
Pr/Pc	**0.396419**		b_y x 10^3	3.32	$(\text{kip-ft})^{-1}$	A_e	25.8	in^2	UBL_x	38	ft
			USE	**0.795**	**$(\text{kips})^{-1}$**				**USE**	**38**	**ft**

$(t_y \text{ or } t_r)*P_r + b_x*M_{rx} + b_y*M_{ry} < 1.0$	0.91 <	1	Ok	Controls
$0.5(t_y \text{ or } t_r)*9/8(P_r + b_x*M_{rx} + b_y*M_{ry}) < 1.0$	0.72 <	1	Ok	

Table 17: Sample Hand Calculations - Combined Loading Members

Deflections criterion was also checked for every member in the truss. Deflections did not control the design of any of the members. The structural designer deflection criterion of span/180 for both live load and total load deflections per the IBC 2009 Table 1604.3. The deflection criterion exceeds code for total load and was used to prevent ponding issues on the roof.

After the truss members were designed by hand, member sizes were entered back into the SAP2000 structural program and check using the programs "Steel Design/Check of the Structure" application. Figure 72 shows a screenshot of a SAP2000 member check along with a legend.

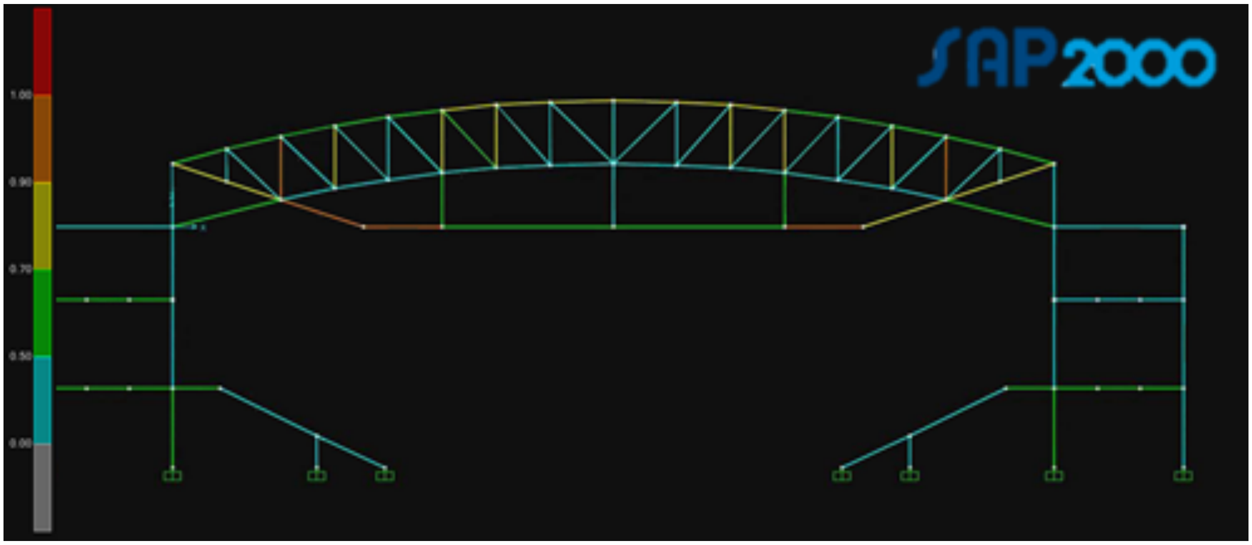
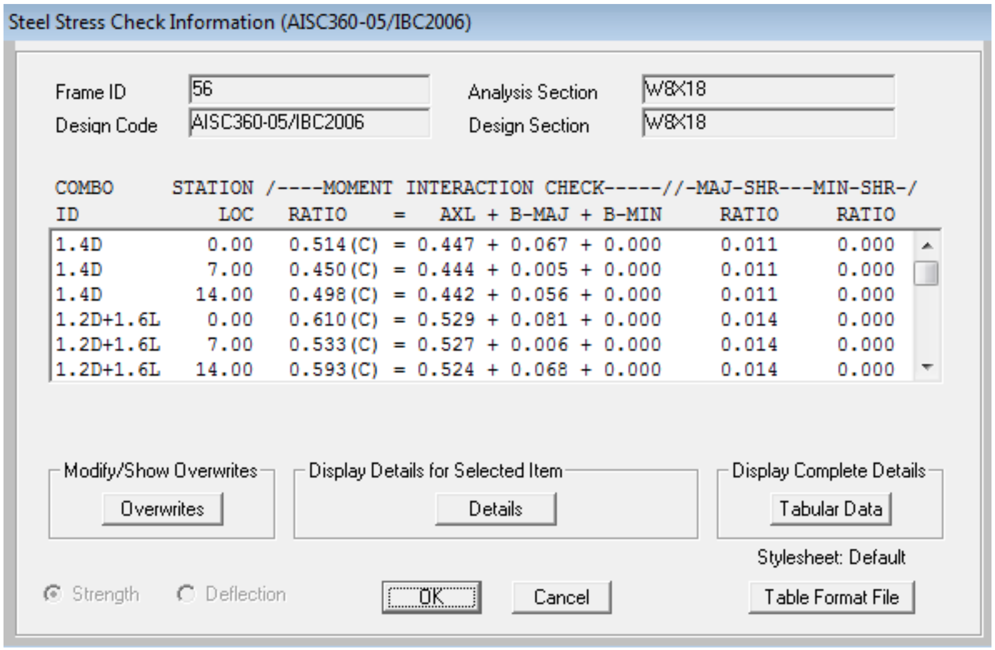


Figure 72: SAP2000 Member Check & Legend


Steel Stress Check Information (AISC360-05/IBC2006)

Frame ID: 56
Design Code: AISC360-05/IBC2006
Analysis Section: W8X18
Design Section: W8X18

```
COMBO      STATION /----MOMENT INTERACTION CHECK-----//-MAJ-SHR---MIN-SHR-/
ID             LOC  RATIO    =   AXL + B-MAJ + B-MIN     RATIO     RATIO
1.4D          0.00  0.514(C) = 0.447 + 0.067 + 0.000     0.011     0.000
1.4D          7.00  0.450(C) = 0.444 + 0.005 + 0.000     0.011     0.000
1.4D         14.00  0.498(C) = 0.442 + 0.056 + 0.000     0.011     0.000
1.2D+1.6L     0.00  0.610(C) = 0.529 + 0.081 + 0.000     0.014     0.000
1.2D+1.6L     7.00  0.533(C) = 0.527 + 0.006 + 0.000     0.014     0.000
1.2D+1.6L    14.00  0.593(C) = 0.524 + 0.068 + 0.000     0.014     0.000
```

Stylesheet: Default

● Strength ○ Deflection

Figure 73: SAP2000 Steel Check per AISC360-05/IBC2006

In this check, combined loading is taken into account, which allowed the structural designer to confirm that all members worked per hand calculations. Upon completion of the SAP2000 checks, the structural designer modeled the long span trusses and the rest of the structural system in SAP2000 for seismic analysis. Seismic lateral forces did not control the design of the lateral system, which is a seismic category A building.

Seismic Considerations & Analysis

Seismic design considerations were considered but no focused on during the duration of this thesis. The derivation of seismic design loads and analysis for code compliance was completed for code compliance using ASCE 7-10, Chapters 11 & 12 using the Equivalent Lateral Force method.

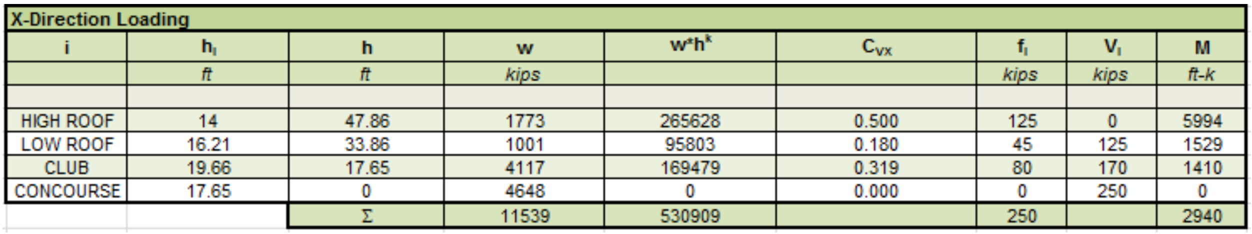
The structural designer obtained information from the USGS "Seismic Design Maps" information for site specific calculated spectral response accelerations for short and one second responses. These reports derive values and other seismic design criteria per the 2010 Minimum Design Loads for Buildings and Other Structures, ASCE 7-10 and the 2012 IBC. A detailed report of the USGS seismic design values can be found in Appendix G.

Following the Equivalent Lateral Force procedure in Chapter 11 of ASCE 7-10, the seismic loads were calculated. The approximate fundamental period for the structure was estimated using section 12.8.2.1 and the "All other Structural Systems" category. Additionally, the structural designer calculated the weight of the building at each level to obtain a base shear of 250.30 kips. The base shear for the building had not been included in the structural drawings so it was assumed to be within reason for this project. A summary of the seismic design criteria for the Penn State Ice Arena can be found in Table 18 on the following page.

Seismic Design Criteria per ASCE 7-10			
Seismic Design Criteria			**ASCE 7-10 Provision**
Soil Classification		C	Table 20.3-1
Occupancy		III	Table 1-1
Importance Factor	I_e	1.25	Table 1.5-2
Structural System		Ordinary Steel Moments Frames	Table 12.2-1
Spectral Response Acceleration, Short	S_s	0.116	USGS
Spectral Response Accelerations, 1 s	S_1	0.05	USGS
Site Coefficient	F_a	1.2	Table 11.4-1
Site Coefficient	F_v	1.7	Table 11.4-2
MCE Spectral Response Acceleration, Short	S_{MS}	0.1392	Eq. 11.4-1
MCE Spectral Response Acceleration, 1 S	S_{M1}	0.085	Eq. 11.4-2
Design Spectral Acceleration, Short	S_{DS}	0.093	Eq. 11.4-3
Design Spectral Acceleration, 1 s	S_{D1}	0.057	Eq. 11.4-4
Seismic Design Category	S_{DC}	A	Table 11.6-1
Response Modification Coefficient	R	8	Table 12.2-1
Deflection Amplification Factor	C_d	3	Table 12.2-1
Approximate Period Parameter	C_t	0.028	Table 12.8-2
Building Height	h_n	49.87	Above Grade
Approximate Period Parameter	x	0.8	Table 12.8-2
Calculated Period Upper Limit Coefficient	C_u	1.7	Table 12.8-1
Approximate Fundamental Period	T_a	0.64	Eq. 12.8-7
Fundamental Period	T	1.09	Sec 12.8.2
Long Period Transition Period	T_L	6	Fig. 22-15
Seismic Response Coefficient	C_s	0.0217	Eq. 12.8-2
Structural Period Exponent	k	1.29	Sec. 12.8.3
Redundancy Factor	p	1	Sec. 12.3.4.1
Building Weight	W	11539	
Base Shear	V	250.30	

Table 18: Seismic Design Criterion per ASCE 7-10

The structural designer derived story equivalent lateral loads as shown in Table 19 using the Equivalent Lateral Force procedure. At this point, computer modeling of the entire structure was completed using SAP 2000.



X-Direction Loading

i	h_i	h	w	$w*h^k$	C_{VX}	f_i	V_i	M
	ft	ft	kips			kips	kips	ft-k
HIGH ROOF	14	47.86	1773	265628	0.500	125	0	5994
LOW ROOF	16.21	33.86	1001	95803	0.180	45	125	1529
CLUB	19.66	17.65	4117	169479	0.319	80	170	1410
CONCOURSE	17.65	0	4648	0	0.000	0	250	0
		Σ	11539	530909		250		2940

Table 19: X-Direction Seismic Loading - Equivalent Lateral Force Method

For simplicity, since the Penn State Ice Arena falls into Seismic Design Category A and a detailed lateral analysis was not included in the accepted proposal for this thesis, several key assumptions were made. The computer model did include both gravity and lateral members, which was done primarily to complete the modeling process for additional uses. This modeling assumption should have make no significant changes to the outcome of the lateral load analysis. The model did not include floor diaphragms or a sloped diaphragm for the club and main concourse level sloped stadia seating.

The modeling process allowed the structural engineer to use knowledge gained in AE 597A, a MAE required course, to allow for more accurate results. Moments were released in all members where moment connections were not called for in design. It is important to note, for a quick check of the lateral system, center of mass and center of rigidity were quickly calculated by hand since the SAP2000 analytical program does not calculate these values automatically. The simplified computer model of the Penn State Ice Arena can be found below in Figure 74.

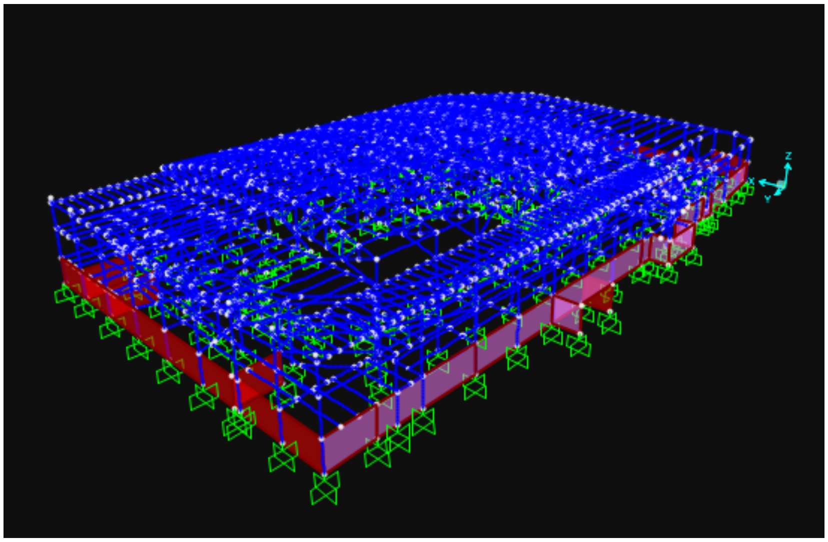
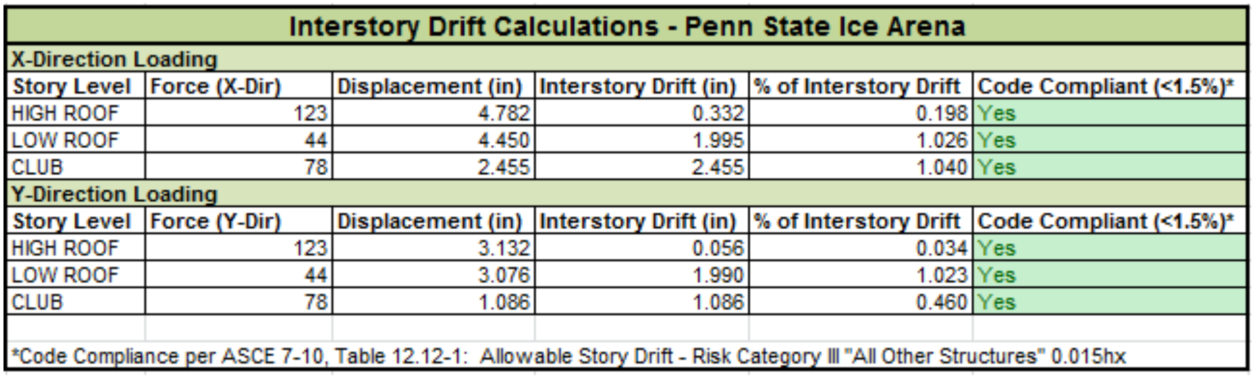


Figure 74: SAP2000 Simplified Lateral Analytical Model

Since the Penn State Ice Arena falls under Seismic Design Category A, torsional irregularities are not investigated as a part of this report. Using the simplified model, interstory drift was check against code compliance per ASCE 7-10 Table 12.12-1: Allowable Story Drift. Under section 12.12.1 the arena falls under "All Other Structures" category, which allows for a 1.5% interstory drift limit for risk category III facilities. With the assumption that the main concourse was on grade, the computer model was analyzed for seismic drift and loading. Table 20 below shows that interstory drifts for the arena all are acceptable per ASCE 7-10 12.12.1. This completed the simplified seismic analysis of the facility.



Interstory Drift Calculations - Penn State Ice Arena

X-Direction Loading					
Story Level	Force (X-Dir)	Displacement (in)	Interstory Drift (in)	% of Interstory Drift	Code Compliant (<1.5%)*
HIGH ROOF	123	4.782	0.332	0.198	Yes
LOW ROOF	44	4.450	1.995	1.026	Yes
CLUB	78	2.455	2.455	1.040	Yes
Y-Direction Loading					
Story Level	Force (Y-Dir)	Displacement (in)	Interstory Drift (in)	% of Interstory Drift	Code Compliant (<1.5%)*
HIGH ROOF	123	3.132	0.056	0.034	Yes
LOW ROOF	44	3.076	1.990	1.023	Yes
CLUB	78	1.086	1.086	0.460	Yes

*Code Compliance per ASCE 7-10, Table 12.12-1: Allowable Story Drift - Risk Category III "All Other Structures" 0.015hx

Table 20: Interstory Drift Calculations per ASCE 7-10

<u>Long Span Truss Final Design Overview</u>

Upon confirmation that the long span truss design was acceptable per seismic code provisions, the structural designer finalized design of all members and geometries. At this time, HPR Integrated Design finalized all high roof system MEP system locations and ran clash detection with the long span trusses to confirm a full coordinated, clean roof design. Once the high roof systems were coordinated the structural designer considered the design of the long span trusses completed. Figure 75 shows the final design of the long span trusses with member's sizes.

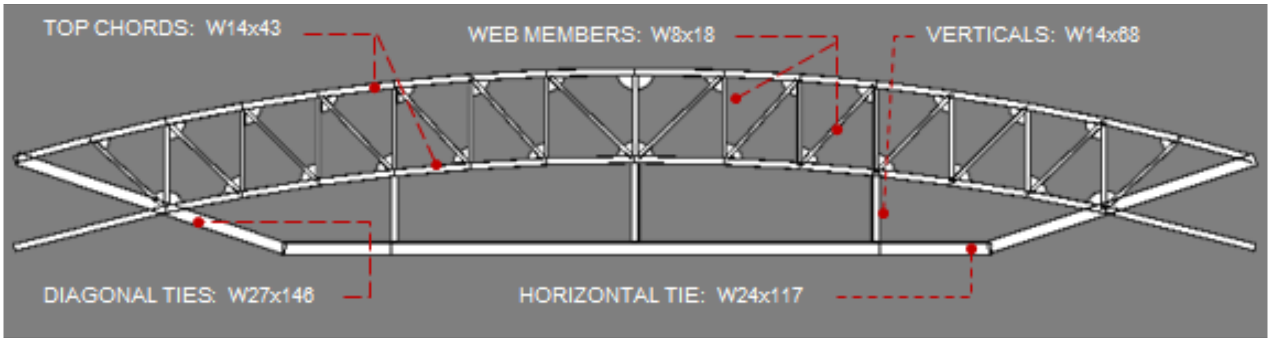


Figure 75: Long Span Truss Member Sizes

The structural designer used a combination of W14x43 and W14x53 wide flange shapes in the top and bottom chords of the top portion of the truss. Web members were W8x18 wide flange shapes that were picked over double angles due to economy. A tied arch framing system relies on the diagonal ties to carry the induced thrust forces of the arch geometry and therefore resulted in large diagonal ties and a large horizontal tie which are W27x146 and W24x117 respectively.

The W24x117 horizontal tie member is designed to keep the truss tied together and also carry rigging loads that are designed for loading at panel points where vertical W14x68 members connect the top portion of the truss, which is in compression to the bottom ties. Connection design of the members within the long span truss was not conducted as a part of this thesis.

Geometry of the truss remained 28'-0" in overall depth and the 196' span was not changed from the original design. As stated earlier, the bottom portion of the truss is deep to allow for catwalks and large mechanical supply ducts to penetrate through the trusses and allowed for adequate headroom for maintenance of these systems.

Additional Structural Considerations

To complete the high roof framing design, the structural designer completed the design of the supplementary framing system and also performed interior column checks for capacity in combined loading conditions per the new long span trusses. The supplementary framing included bridging trusses that run perpendicular to the long span trusses. These trusses were also 14'-0" deep and frame into the W14 wide flange top and bottom chords of the top portion of the long span truss. Interior web members of these bridging trusses were 2L5x3 1/2x3/8x3/8 LLB double angles welded together. Figure 76 shows these bridging trusses running perpendicular to the long span trusses in a section of the high roof framing system.

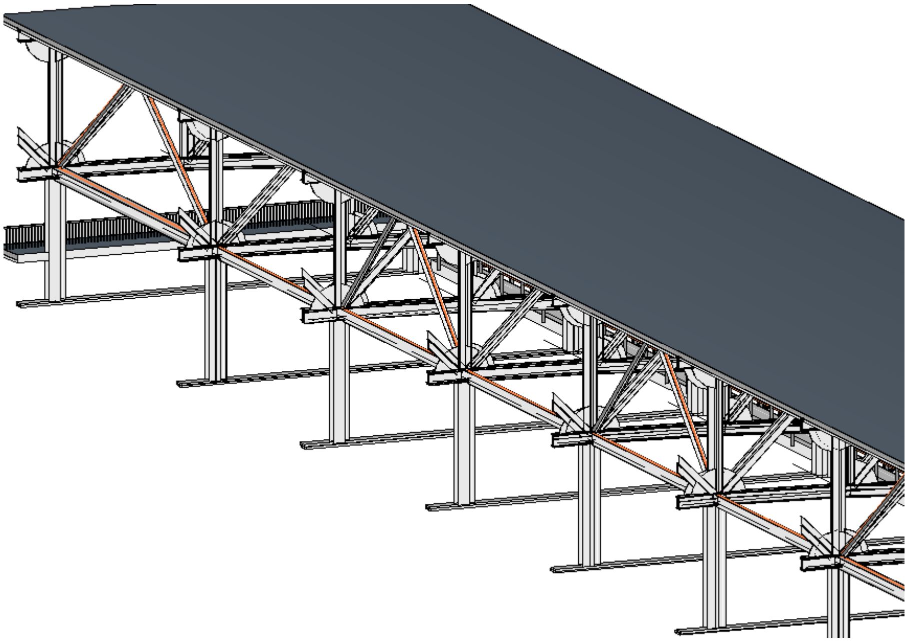


Figure 76: Bridging Trusses in High Roof Framing Section

Purlins in the high roof framing system were designed by hand assuming a simply supported beam configuration and limiting deflection criterion per IBC 2009 Table 1604.3. The supplementary framing members were then modeled in SAP2000 and check against critical gravity load combinations for capacity and serviceability criterion. The structural designer changed the spacing of these purlins from 13'-0" in the existing design to 12'-0" in the new high roof framing system which was reflected in downsized members and cost savings in detailed estimates.

Much like the long span trusses, SAP2000 was used to confirm that hand calculations were correct in sizing the high framing members. Figure 77 shows the high roof framing model check that was completed by the structural designer.

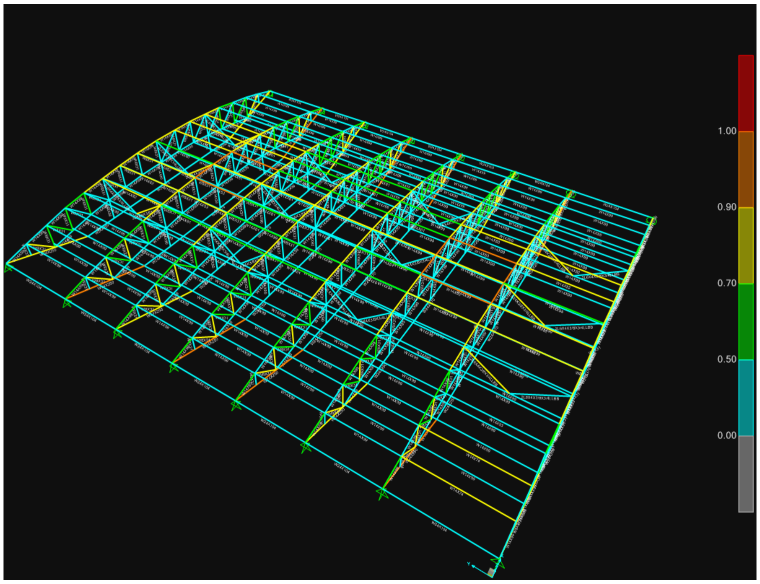
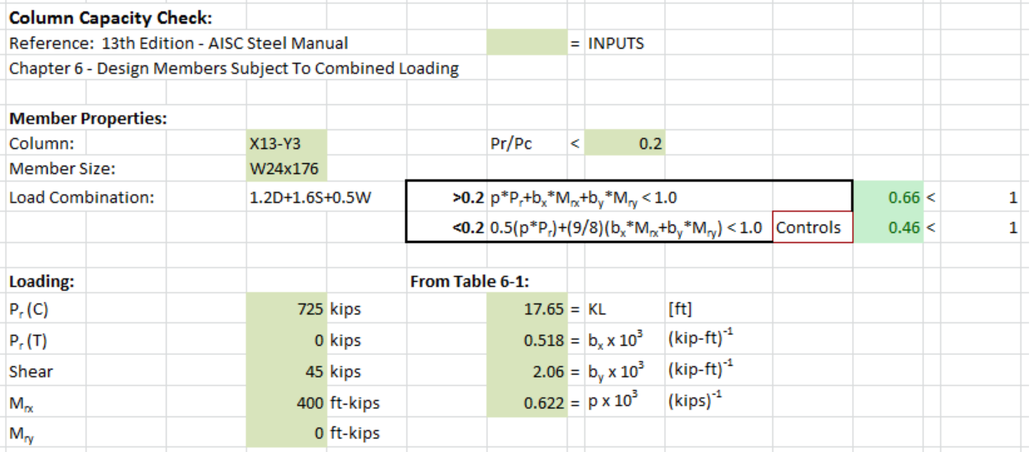


Figure 77: SAP2000 Supplementary Framing Checks

Additionally, the structural designer performed column capacity check using loads from SAP2000 frame analysis. Interior columns were checked as combined loading members for capacity due to the new long span trusses being approximately 3.5% heavier than the existing trusses. A sample calculation of these column checks can be seen in Table 21.

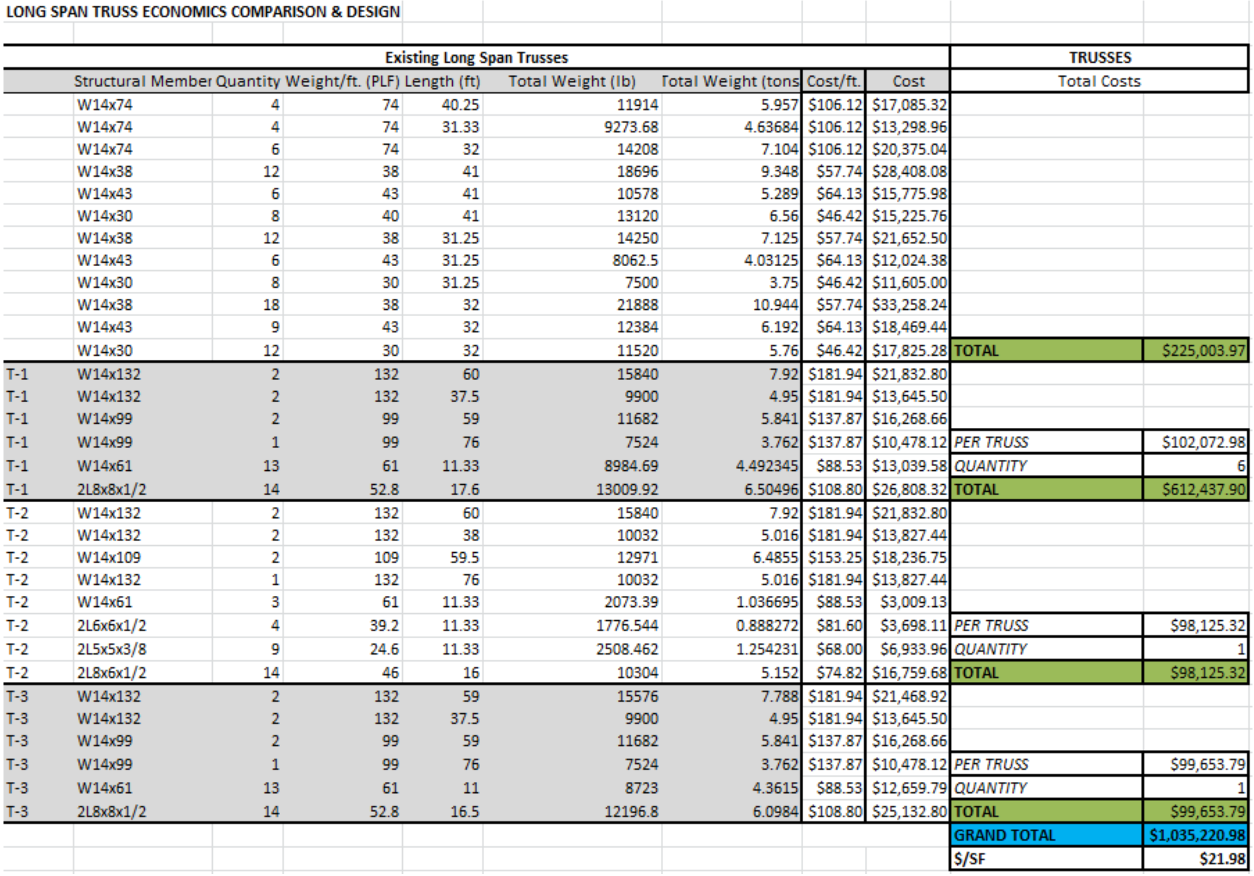


Column Capacity Check:										
Reference: 13th Edition - AISC Steel Manual					=	INPUTS				
Chapter 6 - Design Members Subject To Combined Loading										
Member Properties:										
Column:	X13-Y3			Pr/Pc	<	0.2				
Member Size:	W24x176									
Load Combination:	1.2D+1.6S+0.5W		**>0.2**	$p*P_r+b_x*M_{rx}+b_y*M_{ry} < 1.0$				0.66	<	1
			<0.2	$0.5(p*P_r)+(9/8)(b_x*M_{rx}+b_y*M_{ry}) < 1.0$			Controls	0.46	<	1
Loading:			**From Table 6-1:**							
P_r (C)	725	kips		17.65	=	KL	[ft]			
P_r (T)	0	kips		0.518	=	$b_x \times 10^3$	$(\text{kip-ft})^{-1}$			
Shear	45	kips		2.06	=	$b_y \times 10^3$	$(\text{kip-ft})^{-1}$			
M_{rx}	400	ft-kips		0.622	=	$p \times 10^3$	$(\text{kips})^{-1}$			
M_{ry}	0	ft-kips								

Table 21: Sample Calculation - Column Capacity Checks

Detailed Cost Estimates

Case studies mentioned earlier in the report were utilized for cost analysis throughout the design of the new high framing system for the Penn State Ice Arena. Prior to design the structural designer obtained drawings from these selected case studies with the help of industry practitioners. Takeoffs and detailed cost estimates were performed on these facilities using cost data from the RMS Cost Works estimating platform. The detailed estimates, shown partially in Table 22, were done on the steel members only. Roof deck and roofing assemblies were not considered in this cost estimate. Cost data reflects the cost of steel per linear foot with overhead and profit figured into the estimates.



LONG SPAN TRUSS ECONOMICS COMPARISON & DESIGN

				Existing Long Span Trusses					TRUSSES	
	Structural Member	Quantity	Weight/ft. (PLF)	Length (ft)	Total Weight (lb)	Total Weight (tons	Cost/ft.	Cost	Total Costs	
	W14x74	4	74	40.25	11914	5.957	$106.12	$17,085.32		
	W14x74	4	74	31.33	9273.68	4.63684	$106.12	$13,298.96		
	W14x74	6	74	32	14208	7.104	$106.12	$20,375.04		
	W14x38	12	38	41	18696	9.348	$57.74	$28,408.08		
	W14x43	6	43	41	10578	5.289	$64.13	$15,775.98		
	W14x30	8	40	41	13120	6.56	$46.42	$15,225.76		
	W14x38	12	38	31.25	14250	7.125	$57.74	$21,652.50		
	W14x43	6	43	31.25	8062.5	4.03125	$64.13	$12,024.38		
	W14x30	8	30	31.25	7500	3.75	$46.42	$11,605.00		
	W14x38	18	38	32	21888	10.944	$57.74	$33,258.24		
	W14x43	9	43	32	12384	6.192	$64.13	$18,469.44		
	W14x30	12	30	32	11520	5.76	$46.42	$17,825.28	TOTAL	$225,003.97
T-1	W14x132	2	132	60	15840	7.92	$181.94	$21,832.80		
T-1	W14x132	2	132	37.5	9900	4.95	$181.94	$13,645.50		
T-1	W14x99	2	99	59	11682	5.841	$137.87	$16,268.66		
T-1	W14x99	1	99	76	7524	3.762	$137.87	$10,478.12	*PER TRUSS*	$102,072.98
T-1	W14x61	13	61	11.33	8984.69	4.492345	$88.53	$13,039.58	*QUANTITY*	6
T-1	2L8x8x1/2	14	52.8	17.6	13009.92	6.50496	$108.80	$26,808.32	TOTAL	$612,437.90
T-2	W14x132	2	132	60	15840	7.92	$181.94	$21,832.80		
T-2	W14x132	2	132	38	10032	5.016	$181.94	$13,827.44		
T-2	W14x109	2	109	59.5	12971	6.4855	$153.25	$18,236.75		
T-2	W14x132	1	132	76	10032	5.016	$181.94	$13,827.44		
T-2	W14x61	3	61	11.33	2073.39	1.036695	$88.53	$3,009.13		
T-2	2L6x6x1/2	4	39.2	11.33	1776.544	0.888272	$81.60	$3,698.11	*PER TRUSS*	$98,125.32
T-2	2L5x5x3/8	9	24.6	11.33	2508.462	1.254231	$68.00	$6,933.96	*QUANTITY*	1
T-2	2L8x6x1/2	14	46	16	10304	5.152	$74.82	$16,759.68	TOTAL	$98,125.32
T-3	W14x132	2	132	59	15576	7.788	$181.94	$21,468.92		
T-3	W14x132	2	132	37.5	9900	4.95	$181.94	$13,645.50		
T-3	W14x99	2	99	59	11682	5.841	$137.87	$16,268.66		
T-3	W14x99	1	99	76	7524	3.762	$137.87	$10,478.12	*PER TRUSS*	$99,653.79
T-3	W14x61	13	61	11	8723	4.3615	$88.53	$12,659.79	*QUANTITY*	1
T-3	2L8x8x1/2	14	52.8	16.5	12196.8	6.0984	$108.80	$25,132.80	TOTAL	$99,653.79
									GRAND TOTAL	$1,035,220.98
									$/SF	$21.98

Table 22: High Roof Framing Cost Estimated - Existing Design

Cost estimates were completed and then divided by the total square footage that the high roof framing systems covered to allow for a cost per square foot analysis to be conducted on all three of the case studies. The structural designer recognized the existing design for the Penn State Ice Arena for comparison on addition cost and to prove the low cost of the existing design due to resources being tied up in rock excavation.

The cost estimates also allowed for the structural designer to compare the overall weight of the different trusses. This valuable information was relayed to the construction manager on the BIM team to allow for constructability and crane analysis procedures to commence. These cost estimates allowed the structural designer to make educated decisions on the economics of the long span trusses and allowed the construction manager to check his detailed estimates against the structural designer's.

As stated earlier in the report, the goal of the larger long span trusses was to create a prominent roof profile. HPR Integrated Design wanted to use the money saved in the savings package to be reallocated into the new roof profile and high framing system. Real time tracking of the economics using detailed cost estimations was extremely helpful in the design of these trusses.

After completion of HPR Integrated Design's new long span truss design, a detailed cost estimate was completed by both the structural designer and construction manager. Figure 78 below shows the results of the detailed cost estimates of both the case studies and the new HPR Integrated Design alternative truss design economics.

Figure 78: Detailed Cost Estimate Summary

Figure 78 shows the utilitarian design of the existing Penn State Ice Arena roof system, which costs nearly 11% than the much smaller Compton Family Ice Arena at the University of Notre Dame.

As seen above, HPR Integrated Design's new high roof framing design costs roughly $5 more per square foot costing approximately $26.50/SF. HPR Integrated Design believes this new roof profile adds a more prominent roof profile to the facility, consistent with team goals.

The cost estimates also confirmed that the economics for the new high roof framing design of the Penn State Ice Arena is within similar cases studies. The economics of the arena fit perfectly between the larger Agganis Arena (Boston University) which is at $27.85/SF but more expensive than the smaller Compton Family Arena at $24.57/SF.

Mechanical System

The main arena will continue to be served by the current designs two 45,000 cfm AHU's. These AHU's have both an enthalpy wheels as well as a desiccant wheel. This means the unit is providing both the conditioning for the space as well as the dehumidification. When HPR Integrated design originally ran the load calculations of the main arena the total load was 80,723 cfm (50°F supply air). After the new roof profile had been decided on it was necessary for us to recalculate the load to make sure the new loads could be meet by the current system.

A Trane Trace model was created for the entire design as it was when we received the drawings. This was done entirely in Trace. In hind sight it could have been easier and a more efficient use of time to create a simplified Revit model that had the key areas of interest. I could have then applied both space and zone tags to the model and then exported the model via the gbxml format into a energy or load calculating software such as Trace, eQuest or Energy Plus. Although this was not done it could have been a good opportunity to test and see what type of progress BIM and especially Revit is making in the areas of MEP design and energy modeling.

The Trace Model that was created was very detailed had had to account for the Ice sheets in both the main arena and the auxiliary rink. This was modeled by setting the floor temperature to 20^{O}F as previously stated. It turned out that the ice sheets provided roughly 40 tons of cooling to the space. This is cooling that the HVAC system does not have to meet because of the presents of the Ice sheet. The 40 tons of cooling is then picked up by the ice generation equipment. This was not looked into in much detail for this thesis.

Design criteria

The main arena is to be maintained at 60^{O}F and 40% relative humidity. The colder temperature is to reduced the load in the ice generation equipment. It is also essential to have a low relative humidity to prevent fogging in the arena. Having a large sheet of ice in an indoor space creates many difficulties when designing the HVAC system.

Final Design

The final design requires a total of 88,188 CFM of 50^{O}F to be supplied to the main arena. This increased air volume in cause by the added volume the new roof profile created. The current designs two 45,000 CFM AHU's are more than enough to meet this load. The space has to main duct runs that are each 64" round ducts. The duct has diffusers on three of its sides. One directs air up towards the club level seats, the largest diffuser serves the seats in the lower bowl, while a third smaller diffuser provides the required ventilation are above the ice. As mentioned in the Savings package, the return for the main arena system is located in the event level plenum space. The supply air is supplied high in this system and returned low with 1/3 of the air being returned just below the club level seating and the other 2/3 returning trough return grilles built in to the lower bowl stadia. The Revit model was essential in coordinating these tight spaces. Figure 79 depicts the high supply low return as well at the diffuser locations

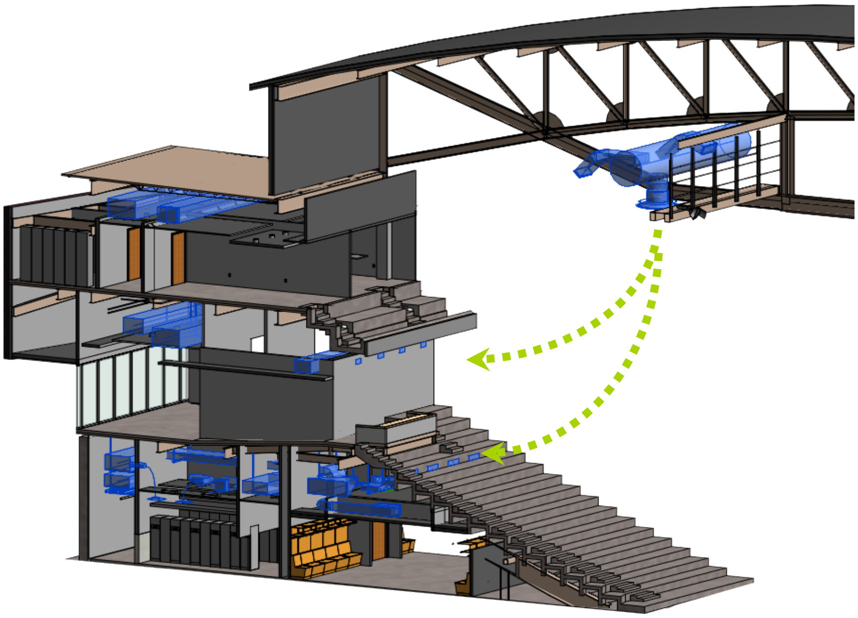


Figure 79: High Supply, Low Return, & Diffusers

In an additional effort to save energy the main arena's duct system is connected between AHU units. This means that if the load could be served by the capacity of one of the AHU the other can shut down and the one running has the ability to serve the whole space. If the ducts were not interconnected the one running AHU would not have the ability to evenly distribute the air. The controls for this system were not looked into is great detail.

The location of the duct work in this space was a combination of inputs. The optimum location for the distribution of air, the structural system, lighting system and catwalk location all played into the final location. The duct runs between the bottom cord and the tie of the tied arch structural joint. It is also running adjacent to the cat walk system on the opposite side on the lights. This allows for both the optimum lighting of the arena ice and for diffusers and duct work that can be easily maintained or adjusted.

Lighting System

The lighting in the main arena bowl is one of function. First and foremost is the lighting for the ice sheet and providing the necessary illumination and uniformity for the hockey players and spectators. Secondary to that is improving the customer experience for the spectators when they are not watching hockey being played. To do this light is provided at the perimeter of the arena seating bowl near the vomitories. Doing this creates a destination point for patrons leaving the lower bowl.

Design Criteria

The illumination design criteria for the main arena ice sheet are dictated by both the IES 10th edition Lighting Handbook and the NCAA Best Lighting Practice. The table below shows the strictest criteria between the two references.

Horizontal Illuminance	1500 lx @ Ice
Vertical Illuminance	400 lx @ 3'-5' AFF
Horizontal Uniformity	CV <= 0.13, Emax:Emin <= 1.7:1

The power density for the main arena bowl is dictated by AHSRAE Standard 90.1 section 9. The allowable power density for arena is 3.1 watt per square foot, while the power density for the seating area is 0.43 watts per square foot. The total allowable connected load for the arena bowl is 66752 Watts.

Although the emergency lighting system was not designed the implementation of LED floodlights mounted on the catwalk illuminating the seating area could be used to provide the required illumination for egress. The table below outlines the design criteria for the emergency system.

Horizontal Illuminance	75 lx min @ floor
Horizontal Uniformity	Eavg:Emin <= 2:1, Emax:Emin <= 10:1

Results

The lighting system for the main arena ice sheet is going to be mounted on a catwalk system contained within the high roof structure. The layout and location of the catwalk system needed to be determined early within the design of the building. A simple preliminary model of the arena was constructed to run quick calculations to determine the optimum catwalk location. Figure 80 shows the preliminary model.

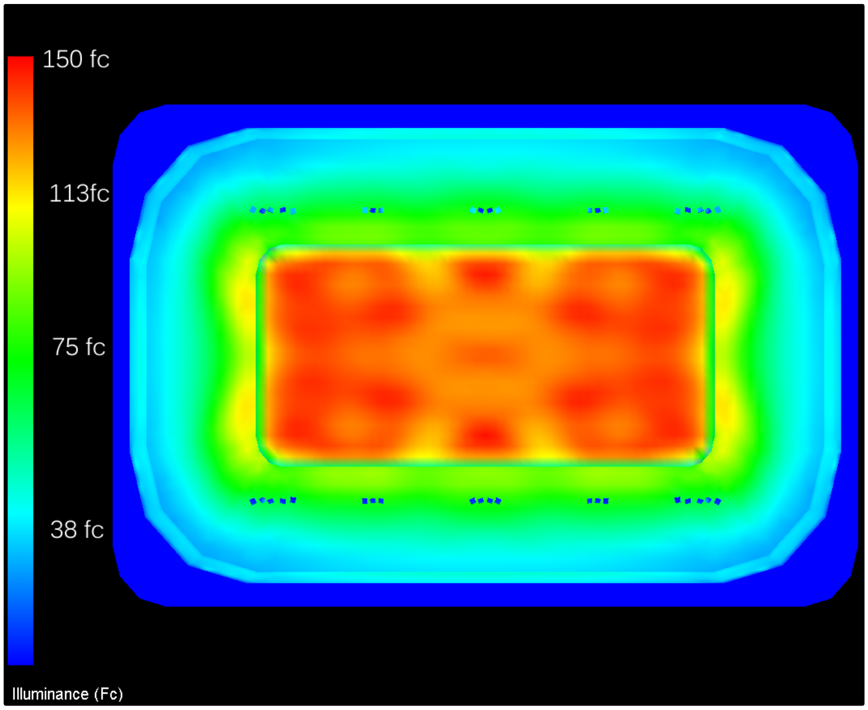


Figure 80: Preliminary Lighting Layout for Main Arena

After the preliminary locations of the luminaires were determined the information was relayed to the structural designer. When the structural designer was going through design integration of the high steel design the lighting design was being tweaked concurrently.

The lighting for the ice sheet utilizes 60 indoor sports lighting luminaires with black out shutters. Refer to Appendix G for cut sheet details of luminaires. An important consideration that makes the lighting in the arena more difficult is the need to use circuits across all three phases of power. Doing so reduces the strobe affect when video cameras are utilized for slow motion action shots. Therefore to negate this affect every third luminaire was circuited on the same phase.

Other important design considerations are the modeling of players on the ice. The uniformity of the illumination plays into this as well as using luminaires from various locations to illuminate the same point on the ice. The final layout can be seen in Figure 81 and Figure 82.

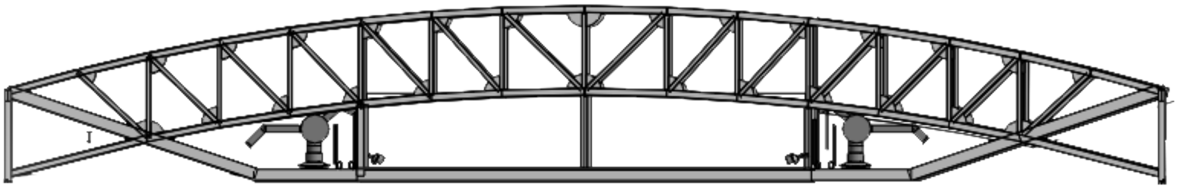


Figure 81: High Steel with Coordinated MEP System

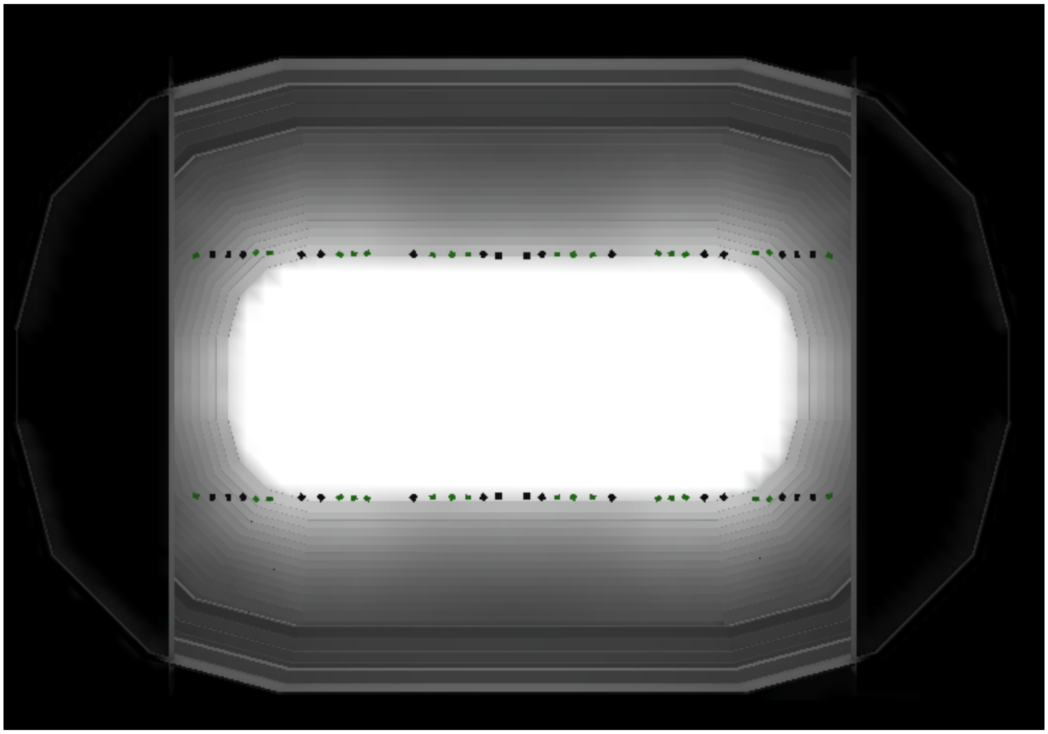


Figure 82: Finalized Lighting Layout

The results of the lighting system with the configuration that HPR proposes are compared to the design criteria in the following table. Figures 83, 84, and 85 show AGI renderings of the arena model. With the system implemented by HPR the total connected wattage is 65000 watts. Which is a savings of 1752 watts over the allowable.

	Design Criteria	Designed
Horizontal Illuminance	1500 lx @ Ice	1714 lx
Vertical Illuminance	400 lx @ 3'-5' AFF	1089 lx
Horizontal Uniformity	CV <= 0.13, Emax:Emin <= 1.7:1	Cv=0.1, max:min = 1.53

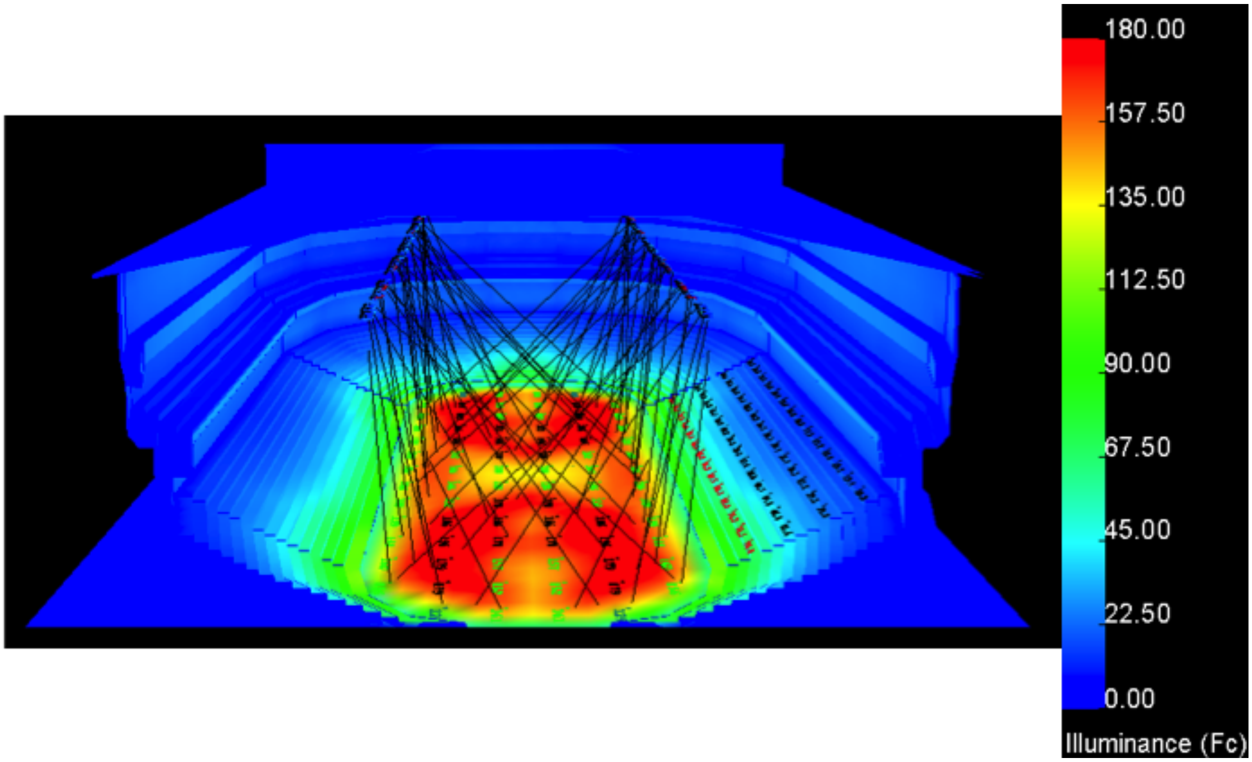


Figure 83: Pseudo Color Rendering of Main Arena

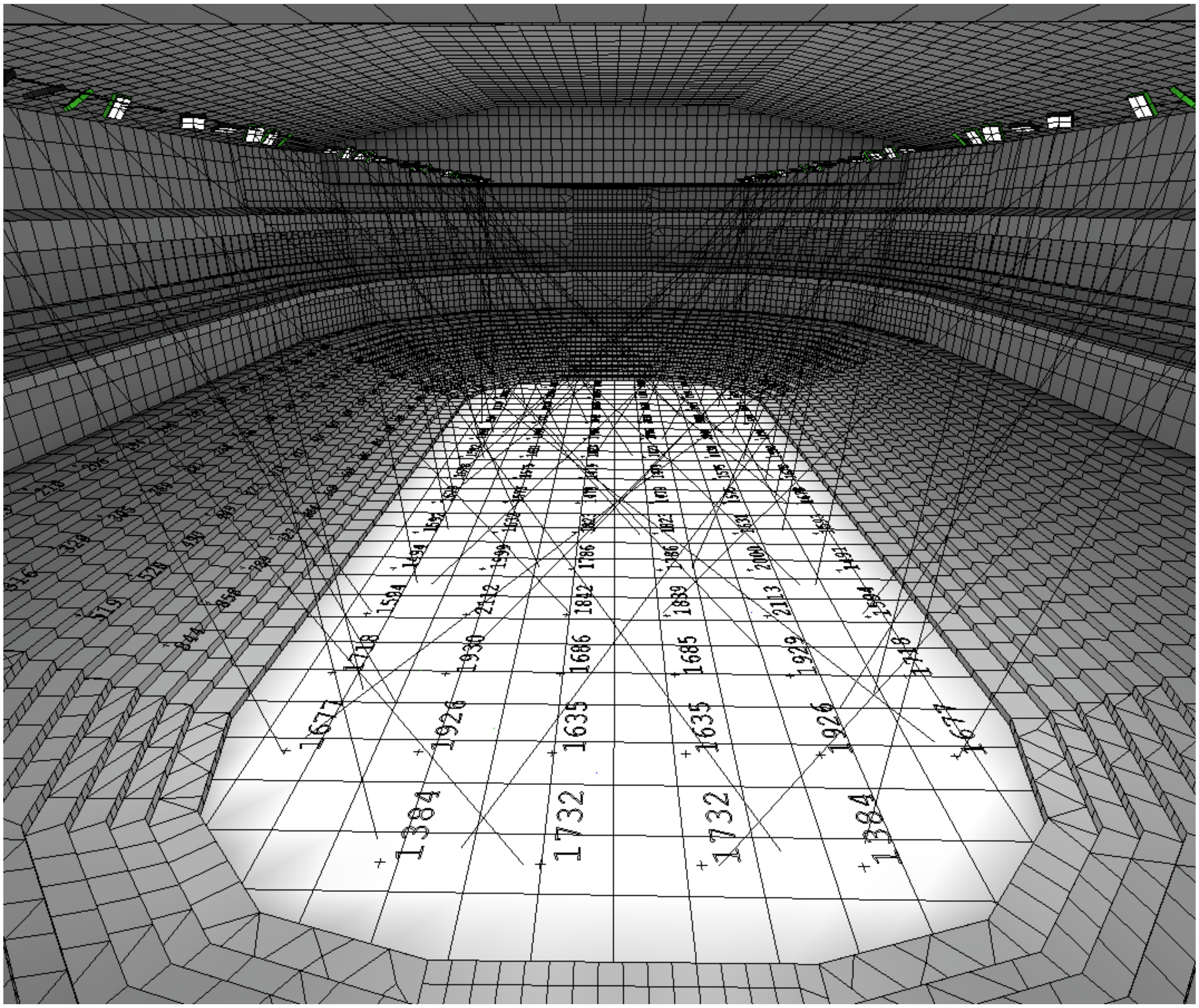


Figure 84: AGI Rendering Showing Arena Illumination & Model Overlay

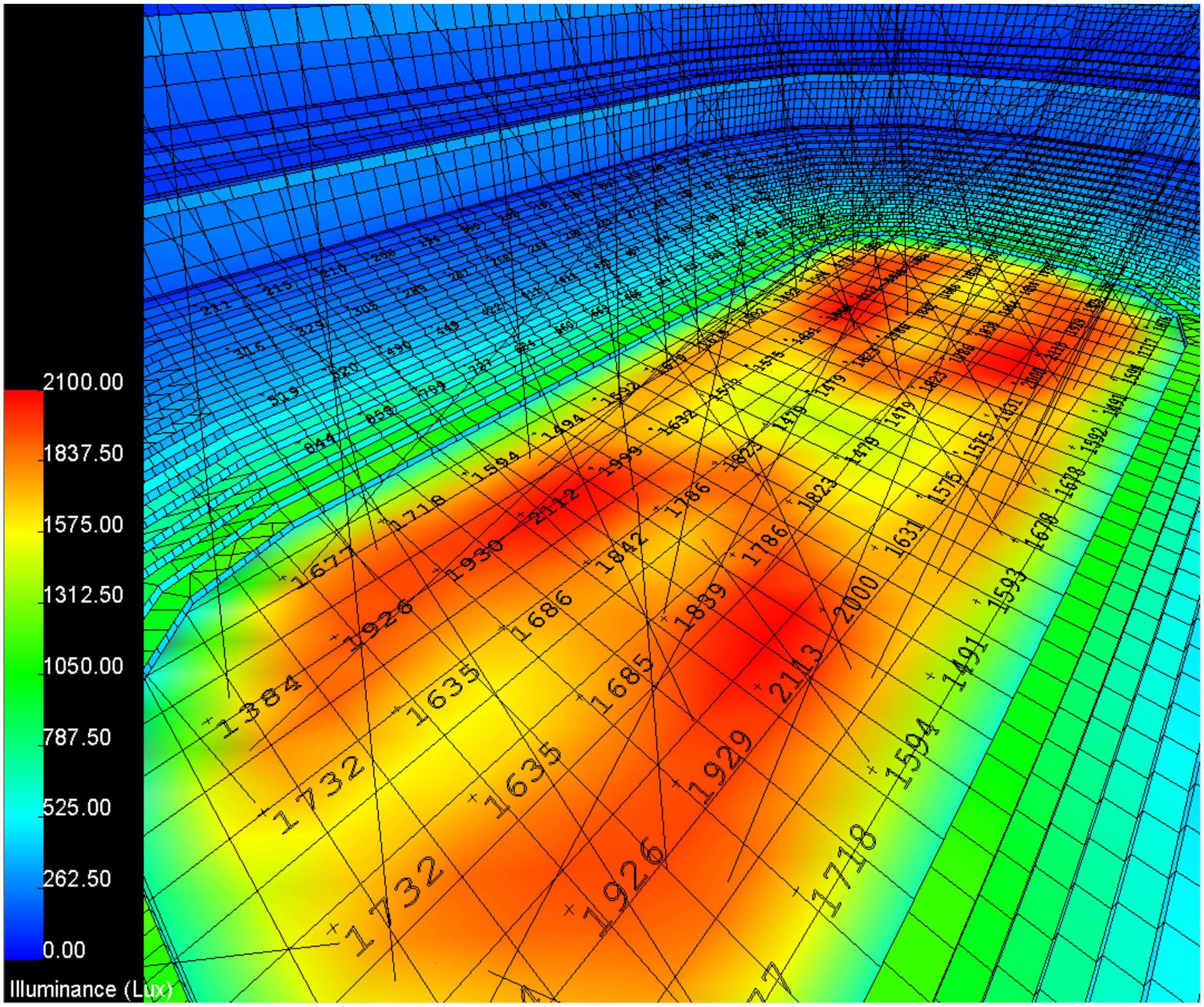


Figure 85: AGI Rendering Showing Pseudo Color Illumination Values on Ice

Design Impacts

HPR Integrated Design made collaborative decisions early in the design process of this thesis to create a more prominent high roof framing system. By reallocating the cost savings from raising the event level in the Savings package, the design team was able to reinvest construction funds into the high roof framing systems that made more a more recognizable roof profile. Benefits of this new arched roof profile could be realized architecturally through a facility that mimics the feasibility renderings that HPR deemed essential to deliver upon.

Engineering design impacts for the new systems were significant as well as the new architectural aesthetic that has been created in the facility. The most noticeable impact is the transformation in size of the arena. Figure 86 below shows a comparison of a section through the existing design and HPR Integrated Design's new proposed design.

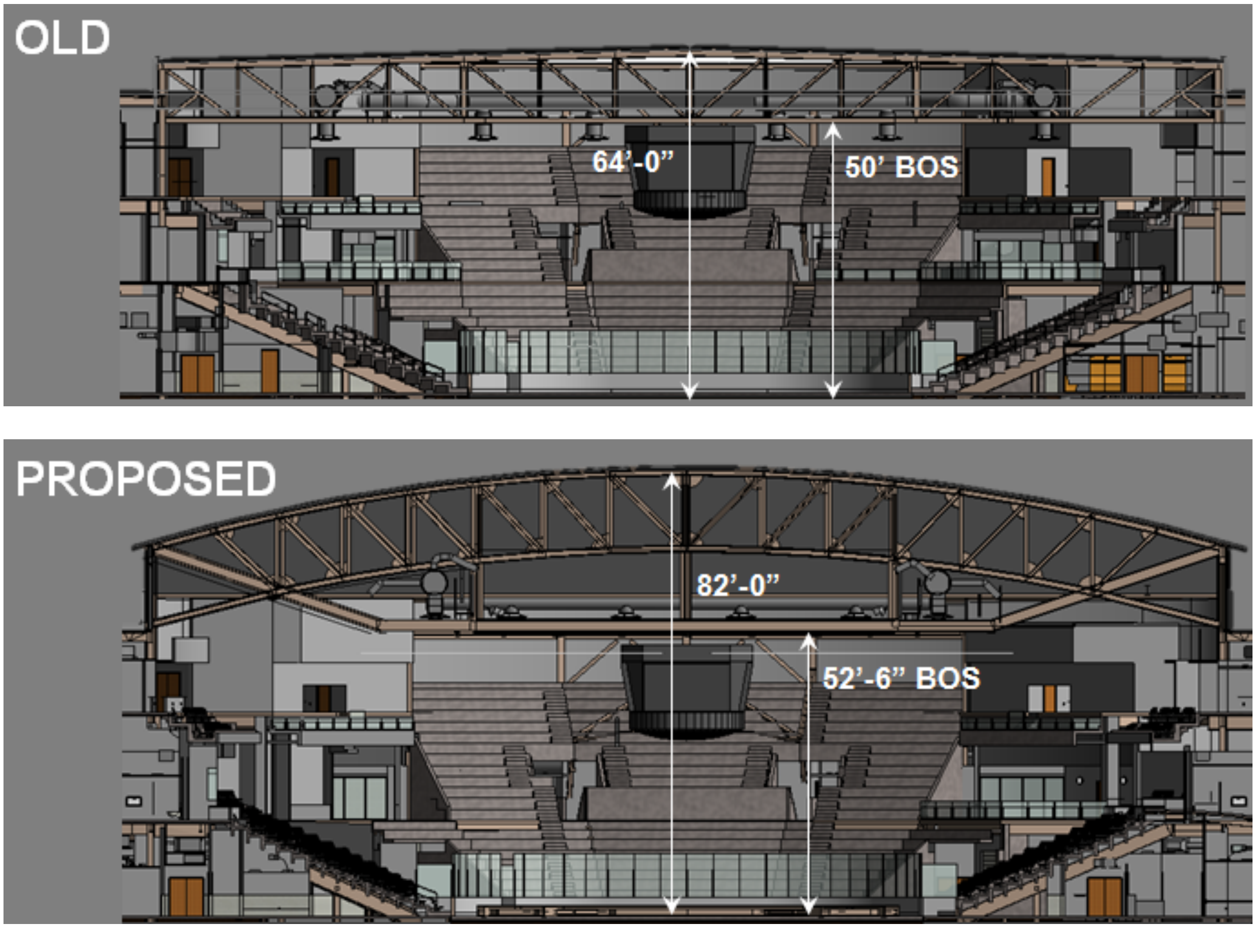


Figure 86: Comparison of Transverse Section through the Arena

HPR Integrated Design's proposed design increases the overall height of the arena 18 feet from the existing 64'-0" to 82'-0", still compliant with the 90 foot height restriction per the University Planned District section 1240.b.5 requirements. The proposed design adds about an additional 800,000 cubic feet of air as described previously in mechanical considerations. As stated prior, the mechanical designer analyzed the additional volume and the effect on the capacity of the two 45,000 CFM air handlers supplying the space early in the design.

HPR Integrated Design's long span trusses are much deeper than the existing design. The proposed trusses are 28'-0" in total depth compared to the 12'-6" maximum depth as stated earlier in this report. A comparison of the existing and proposed trusses is shown in Figure 87 below. Although truss design was driven by constructability and compatibility of the high roof MEP framing systems, team goals dictated that the proposed truss design increase in depth to create a prominent arched roof profile.

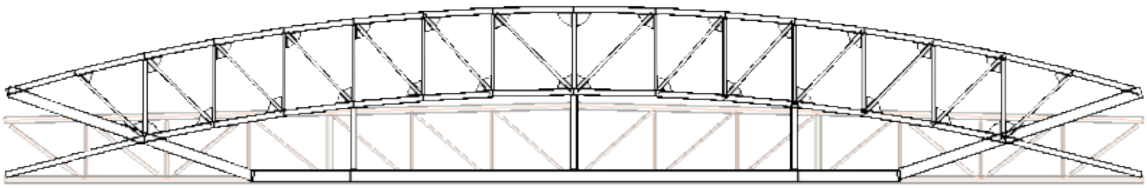


Figure 87: Comparison of Existing & Proposed Truss Designs

Delivery & Constructability

Delivery

Much like the current design, constructability of this size truss system is difficult and could be costly. The new roof system has a truss system that is deeper than that of the current design requiring heavier purlins to sustain the lateral and vertical forces. The new truss system has a weight of 538 tons, a 34.5% increase from that of the current design.

Due to the truss span, these new trusses will be prefabbed and delivered by flatbed trucks in three sections with the bottom chords and vertical members needing to be welded on-site. Figure 88 shows the breakdown of the truss sections to be delivered.

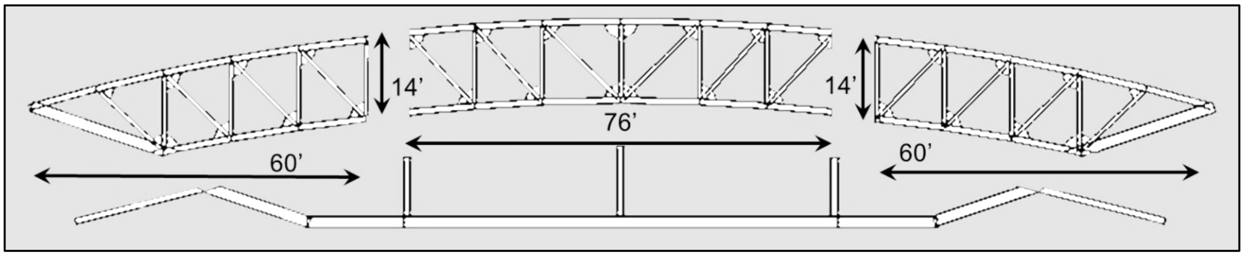


Figure 88: Deliverable Truss Sections

Current Project Design Sequencing & Constructability

The current project team's schedule shows the completion of all steel prior to the build-up and erection of the trusses. Figure 89 shows the sequence that the project team is using, starting in the south pink section circling east and back around to the blue section, followed by the east roof, northeast entrance canopy, and the auxiliary rink. The circled portion will have the steel erection completed, however the section will not have exterior wall enclosures or interiors completed complete until after all the trusses and stadia have been completely installed. The location lies between columns X9 to X10, and Y7 to Y10. This is to allow access for the 300 ton crane to drive in and out of the arena, and for precast stadia deliveries.

Originally, the project team opted for using shoring to support the trusses during erection. Through value engineering, they found it to be more cost effective to use two cranes rather than one large crane and shoring. This process requires the use of a 200 ton and a 300 ton hydraulic crane. To begin, the trusses are delivered by a flatbed truck in three sections to the north perimeter of the building where they are built up. The 300 ton crane is inside the building while the 200 ton crane is located on the outside of the building. Floor slabs and underdrains are not to be placed until after building enclosures are complete to avoid damage from the weight of the crane.

The trusses are to be erected in two picks for each truss. The first pick will be a 2/3 built-up section, and the second pick being the remaining 1/3. The first two trusses are to be installed prior to setting any purlins. As the trusses are being lifted into place, the precast stadia are also being installed. Using this sequence, the trusses have a final completion date of November 29, 2012.

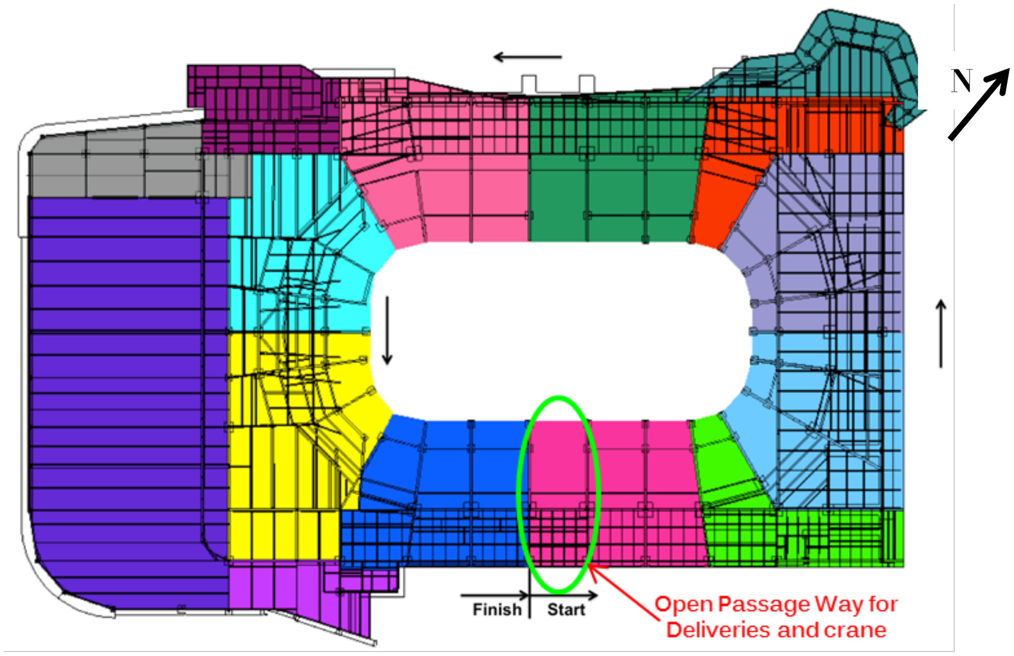


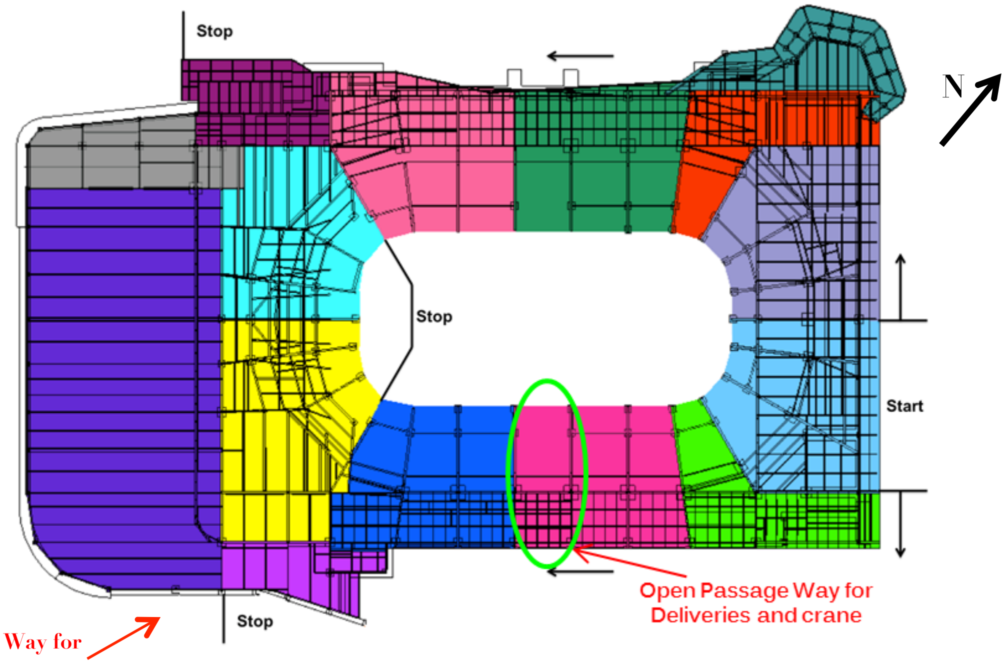
Figure 89: Current Design Erection Sequence

HPR's Erection Sequence

For HPR to use the same cranes and sequence as the current project team, the increased cost due to the increased weight would be $623,056 over budget with 18 workdays added to the schedule. HPR found this to be unacceptable. First thing the construction manager did was to create a site logistics plan to help devise a more cost effective sequence.

Based on the site logistics plan, HPR determined that building up and erecting the trusses from inside the building after the steel on the north, south, and east sides are erected could improve the schedule and cost. Foundations will begin in the eastern portion of the building. As foundations are completed, slab on grade underslab MEP utilities will be run, followed by concrete placement. It is important to note that placement of the underdrains and ice slabs will not be placed until steel erection, truss erection, and precast stadia installation has been completed. This is to avoid damage to the slab from the crane as it moves along the arena floor. Upon completion of slab on grade in each section, steel erection will begin.

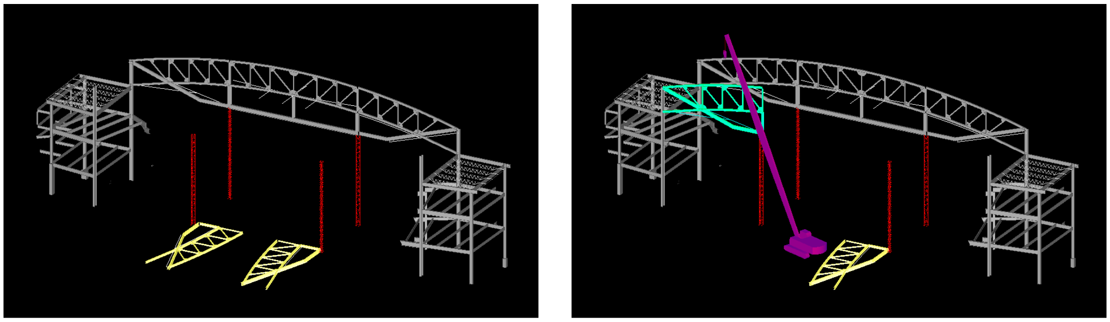
Figure 90 shows the steel erection sequence, beginning in the light blue section in the east, and then completing the north and south sides simultaneously utilizing one 150-ton crane for each side. Due to the increased weight of the truss system, it was important to stay on schedule as much as possible. The increased weight results in an increase work days in the schedule. Steel erection will halt for the time being once the north and south purple sections are completed. It is important to note at this time that the lower bowl stadia steel will not be installed yet. This is to allow the crane to maneuver and for shoring to be installed. In order for the crane to maneuver in and out of the arena, foundations in the south portion of the auxiliary rink, between columns X2 and X4, will not be completed until after the crane has finished erecting the west main arena steel.



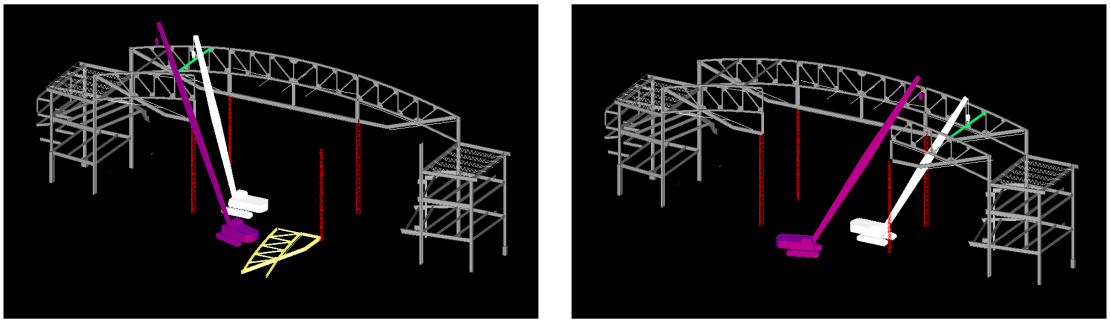
Open Passage Way for
Deliveries and Crane

Figure 90: HPR's Erection Sequence

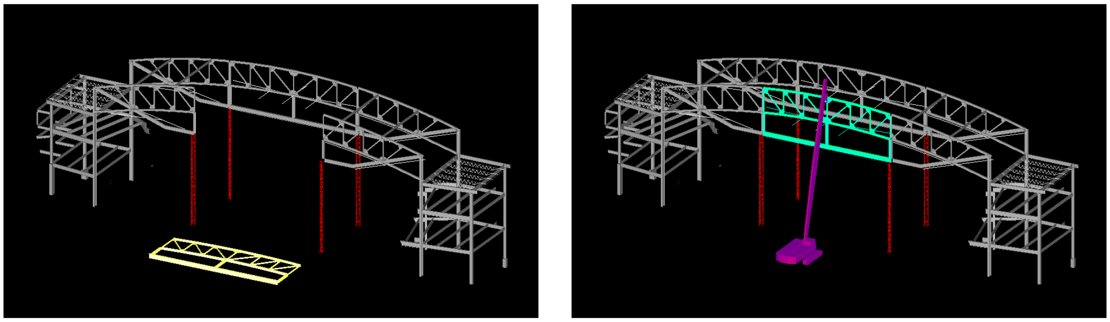
At this time, the sections of the trusses will be delivered by a flatbed truck to the inside of the building using the same auxiliary south rink opening. The trusses will be erected east to west. Due to the increased depth of trusses, each truss will need to be erected in a three-pick sequence. The process for build-up and erection of each truss will take three days. The outside sections will be delivered and built-up on day 1 and erected on day 2. On day 3, the mid section will be built-up in the morning and erected in the afternoon. Two 2 foot by 2 foot shoring towers will be installed per truss to sustain the vertical force prior to erection. The shoring towers have a capability of carrying 5 tons per leg. Each truss weighs 37 tons. To sustain the lateral forces as the trusses are being erected, a 40-ton crane will be used to installed two of the purlins for each of the outside sections while the 150 ton crane maintains the stability of the pick. The remaining purlins will be installed upon completion of the mid section erection. Figure 91 shows the 4D erection sequence for each truss.



Day 1 - Build-Up Outside Sections **Day 2 - Erect Outside Sections**



Day 2 - Erecting 2 Purlins 1st Pick **Day 2 - Erecting 2 Purlins 2nd Pick**



Day 3 Morning- Build-Up Mid Section **Day 3 Afternoon - Erect Mid Section**

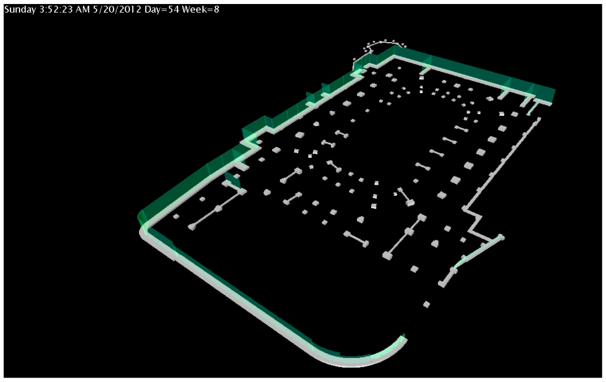
Figure 91: 4D Truss Erection Sequence

As mentioned, there will be two 150 ton cranes for steel erection. To stay on schedule, as the trusses are being erected, the second 150 ton crane used to complete the steel erection for the east roof, the northeast entrance canopy, northwest mechanical court, and west auxiliary rink steel. Once these sections are complete, the crane will be taken off-site.

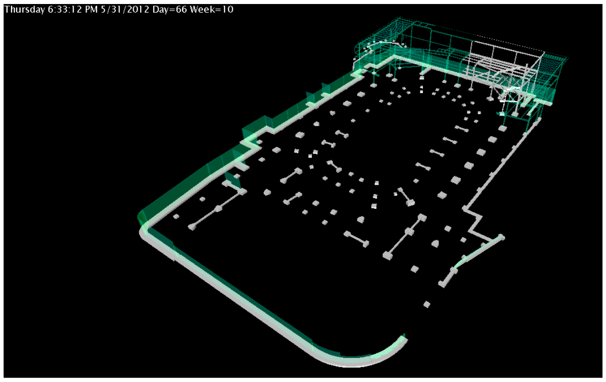
HPR will be renting shoring towers during of the truss erection, however, only 8 towers will be rented. At completion of the installation of the purlins between truss 3 and 4, the shoring tower for truss one will be taken down and erected for truss 5, and so on. Shoring towers for trusses 5 through 8 will remain in place until completion of installation of the purlins between truss 7 and 8.

Upon completion of installation of the purlins between truss 3 and 4, the arena bowl stadia steel will begin to be installed followed by the precast stadia installation. This will be completing using 10,000 lb telehandlers with a boom reach of 42 feet. With the boom reach and the height of the telehandler, the telehandler will be able to reach 55 feet. The telehandler will have a capability of lifting a maximum 6,000 pounds at the maximum reach.

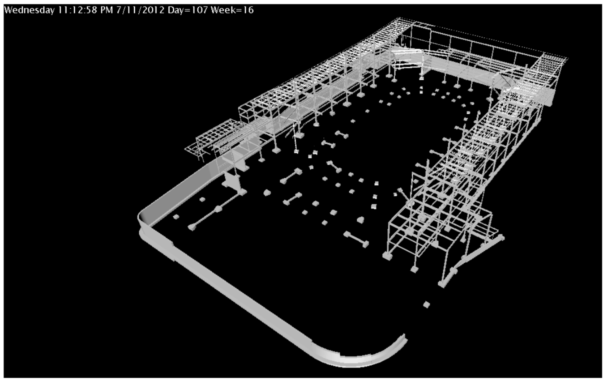
The west arena steel will be erected after the trusses are installed, followed by the auxiliary rink south foundations, steel, and roof. Once the trusses are complete, the smaller crane will be taken off-site. Figure 92 on the next page shows the 4D erection sequence for the steel and trusses. By using this sequence and reconsolidating the schedule, HPR found that the trusses could be completed by October 26, 2012. This is 26 working days ahead of the current design schedule at an added cost of $528,521 over budget.



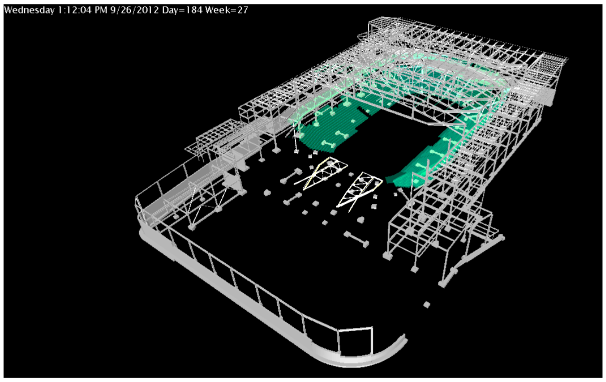
Arena Foundations



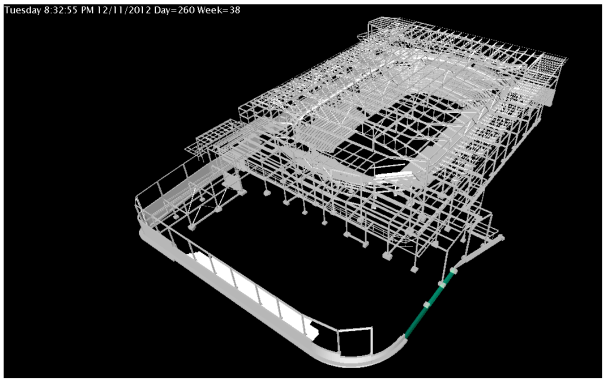
East Corner Steel Begins Erection



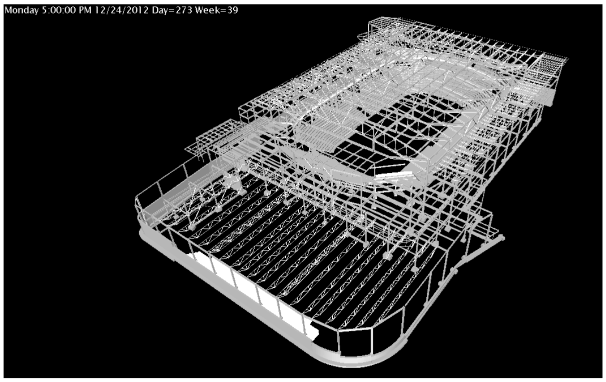
N & S Steel Complete, Begin Trusses



Stadia Installation Begins After 4th Truss



Auxiliary Rink South Foundations



Steel Completion - December 24, 2012

Figure 92: 4D Steel & Truss Erection Sequence

Site Logistics

By creating a site logistics plan, HPR was able to devise a cost effective method for steel and truss erection. The site sits along University Drive, which has a sloping grade. The main entrance is located on grade of the main concourse on the north elevation, however the north side of the event level is below grade. The event level has its own on grade entrances on the south side 20 feet 9 inches below the main grade. Since the event level only has the south side that is not hidden by soil, this is where the crane will have to enter and exit the arena.

Due to sizes of the trusses, the most cost effective way to erect the trusses is to erect the steel for the east, north, and south sides of the building, and then build-up and erect the trusses from with inside the arena. This will also improve the schedule. Figure 93 shows the site logistics plan developed by HPR's construction manager. Looking closer at the site, locations for steel laydown can be seen on the north and south sides of the building.

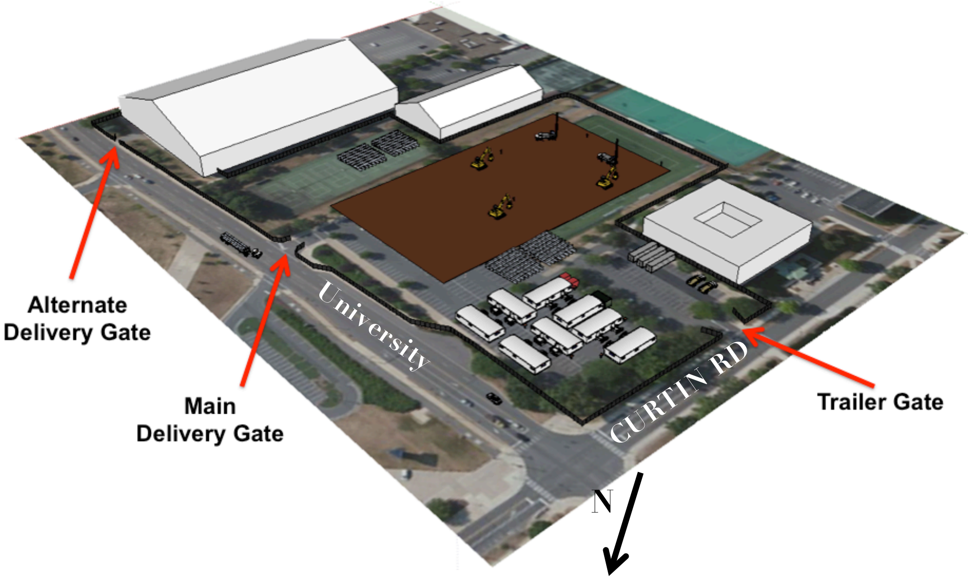


Figure 93: Site Logistics Plan

Figure 94: South Side Steel Laydown

Figure 95: North Side Steel Laydown

Figure 96 shows the truss delivery logistics. Flatbed truck deliveries will enter the site at the main gate on University Drive and be brought in along the south perimeter of the building. As the truck reaches the opening at the auxiliary rinks south opening, the truck will back into the arena to the laydown point. Once the truck has unloaded, it will exit the arena, head west, and continue its path around the north perimeter of the building and out onto University Drive.

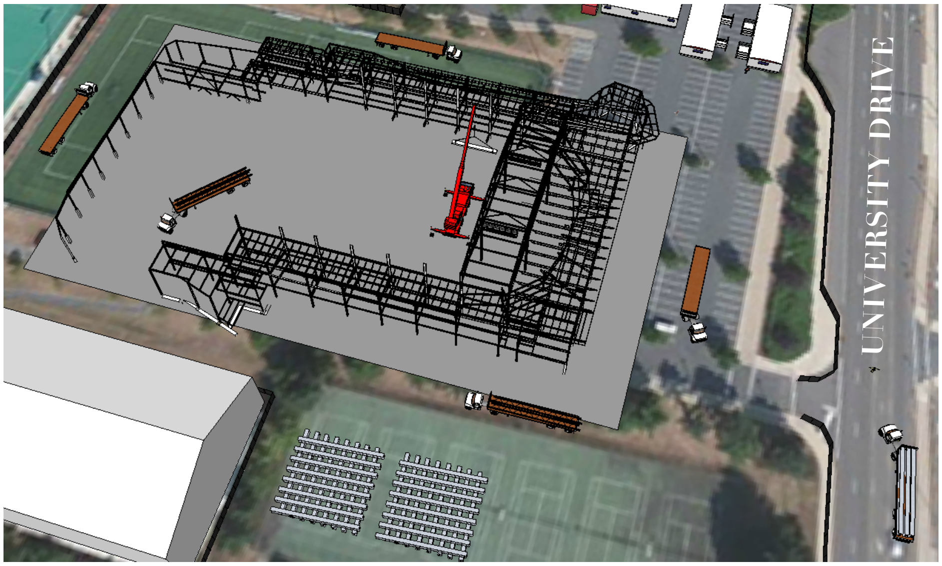


Figure 96: Truss Delivery Logistics

Figure 97 shows the building footprint excavation logistics. Excavation will begin on the west end of the arena and move towards the east. Dump trucks will the main gate on University Drive, turn right and follow around the north perimeter of the building. As the front loader loads the truck with soil and rock, the trucks with follow the south perimeter of the building and back out the University Drive gate.

Figure 97: Building Footprint Excavation Logistics

Crane Analysis

In determining the most cost effective method for steel and truss erection, the construction manager performed a crane analysis. First, an analysis was performed to determine the cost of using the current project team's erection sequence. The results were found to be $623,056 for the roof system alone, and $479,246 for the overall steel of the arena. See Appendix G for the breakdown of these costs.

In order to select the type crane needed, the load capacity of each truss, the height the truss needed to be raised, the radius in which the crane could swing, the length the boom needed to be extended, and any site constraints.

Truss Tons (Ave/Section)	37 (12-1/3)
Height (ft)	90
Radius (ft)	55
Boom Length (ft)	105

Once these numbers were determined, the construction manager referenced load charts found on Bigge Crane and Rigging Co.'s website. Based on the erection sequence and the load charts, it was determined that a 150 ton hydraulic crane would work for erecting the trusses, and a 40 ton hydraulic crane for installing the purlins. See Appendix G for cut sheets on each of the cranes.

By using these cranes and the designed sequencing method, HPR is able to reduce the costs to $528,521 for the roof system alone, and $306,381 for the overall steel of the arena. That is difference of $94,535 and $172,865, respectively. See Appendix G for the breakdown of these costs.

Cost & Schedule Impact

The newly designed roof system was designed with the intent to enhance and give prominence to the roof, and to reflect that of the adjacent arenas. After reviewing the initial feasibility study designs, it was important to design and deliver a high quality product that owner originally sought out.

Using Quantity Takeoff and costs found in *Craftsman's National Estimator*, the construction manager estimated the roofing materials, truss system, and catwalk system for the current project design and HPR's design. Figure 98 shows an image of the new truss system in Quantity Takeoff.

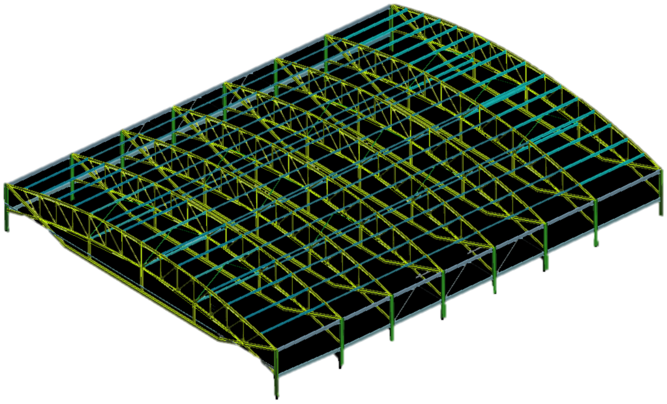


Figure 98: HPR's Proposed Truss System in Quantity Takeoff

The new truss system has a greater weight increasing the cost, however, some costs could be saved with the catwalk system. The following changes were made, with increased spending listed first, followed by additional savings.

Increased Spending

Truss System	**$377,479** (25.0%)
Shoring	**$7,707**
Roof Materials	**$197,831** (13.7%)

Additional Savings

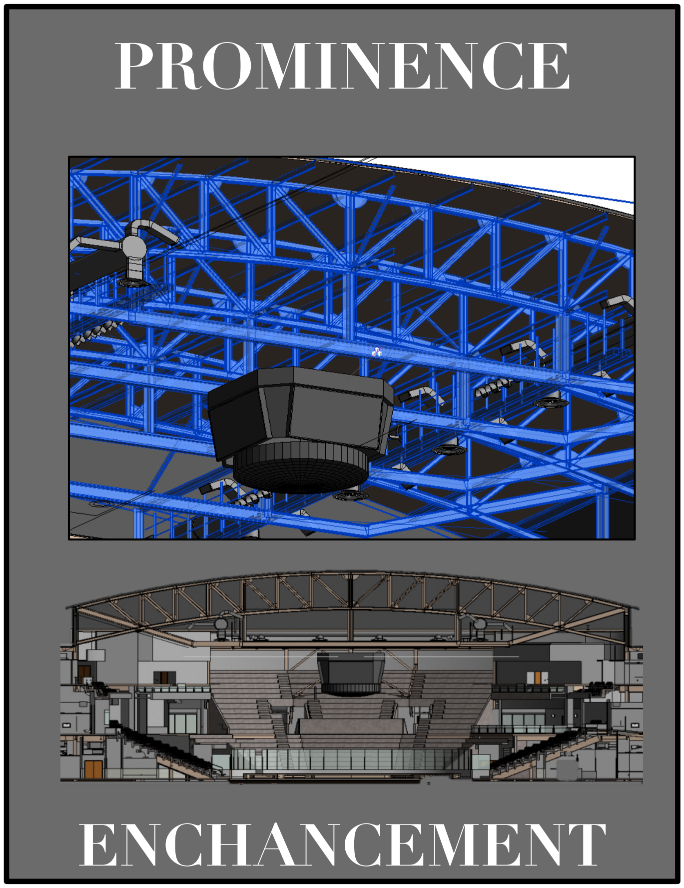
Catwalk	**$54,495** (19.2%)

By changing the erection sequence, the construction manager was able to improve the schedule by 26 working days, with a completion date of October 24, 2012. The new erection sequence also allowed for erection to be completed using smaller cranes reducing the equipment costs. The overall design of the new roof system increased the budget by $528,521. See Appendix G for complete breakdown of differences in cost for this design package.

Package Summary

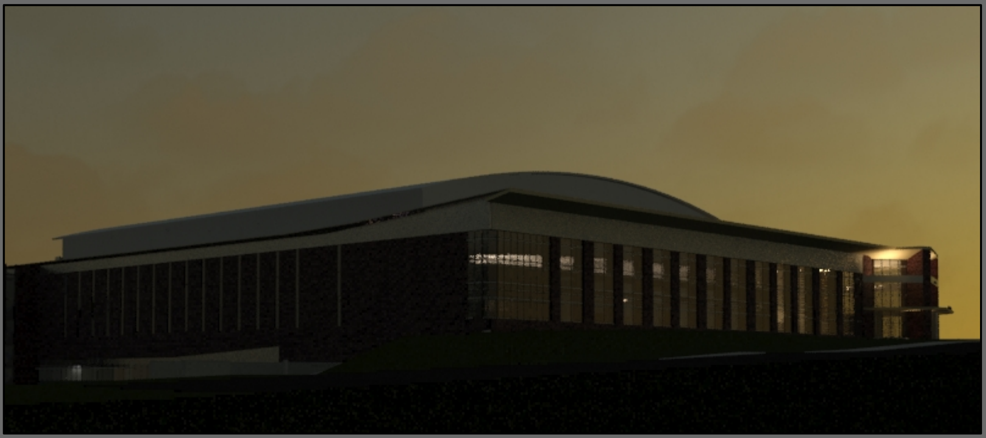
The main goal of the Prominence Package was to enhance the roof and give the owner a building that reflected that of the original feasibility study, a building with a grander appearance. Through coordination, HPR designed a high-roof arched truss system to help give the prominent look that the owner originally saw in the feasibility study.

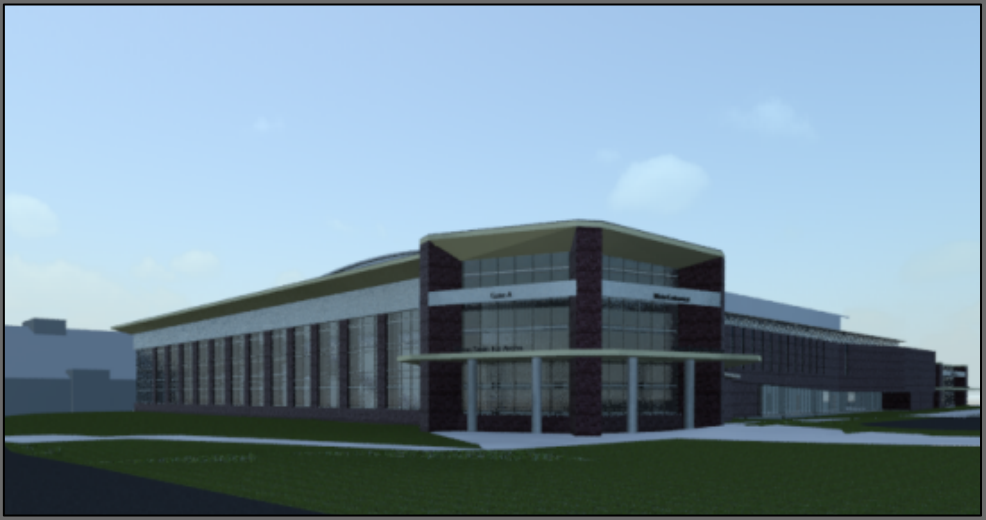
As the weight of the new truss system increased, so did the cost. Based on the crane analysis that was performed and the detailed erection sequence that was created, the construction manager is able to keep the cost to $528,521 over budget and complete truss erection 26 workdays ahead of schedule.



ENHANCEMENT PACKAGE: Function

FUNCTION





ENCHANCEMENT

Opportunity Statement

When HPR Integrated Design started to look at the existing plans for the Penn State Ice Arena, one area that was determined that could be improved upon was the façade design. This included the material choices as well as the size and appearances of the entrances. The east façade's current design consists of a full length curtain wall that scales from ground to roof. HPR Integrated Design believes that the intent of this design was to create and impressive view from University Drive as well as a view out to Mt. Nittany and the Bryce Jordan Center. A new design can improve on these original goals with the reduction of thermal loads on the building, cutting cost and potentially shortening the schedule.

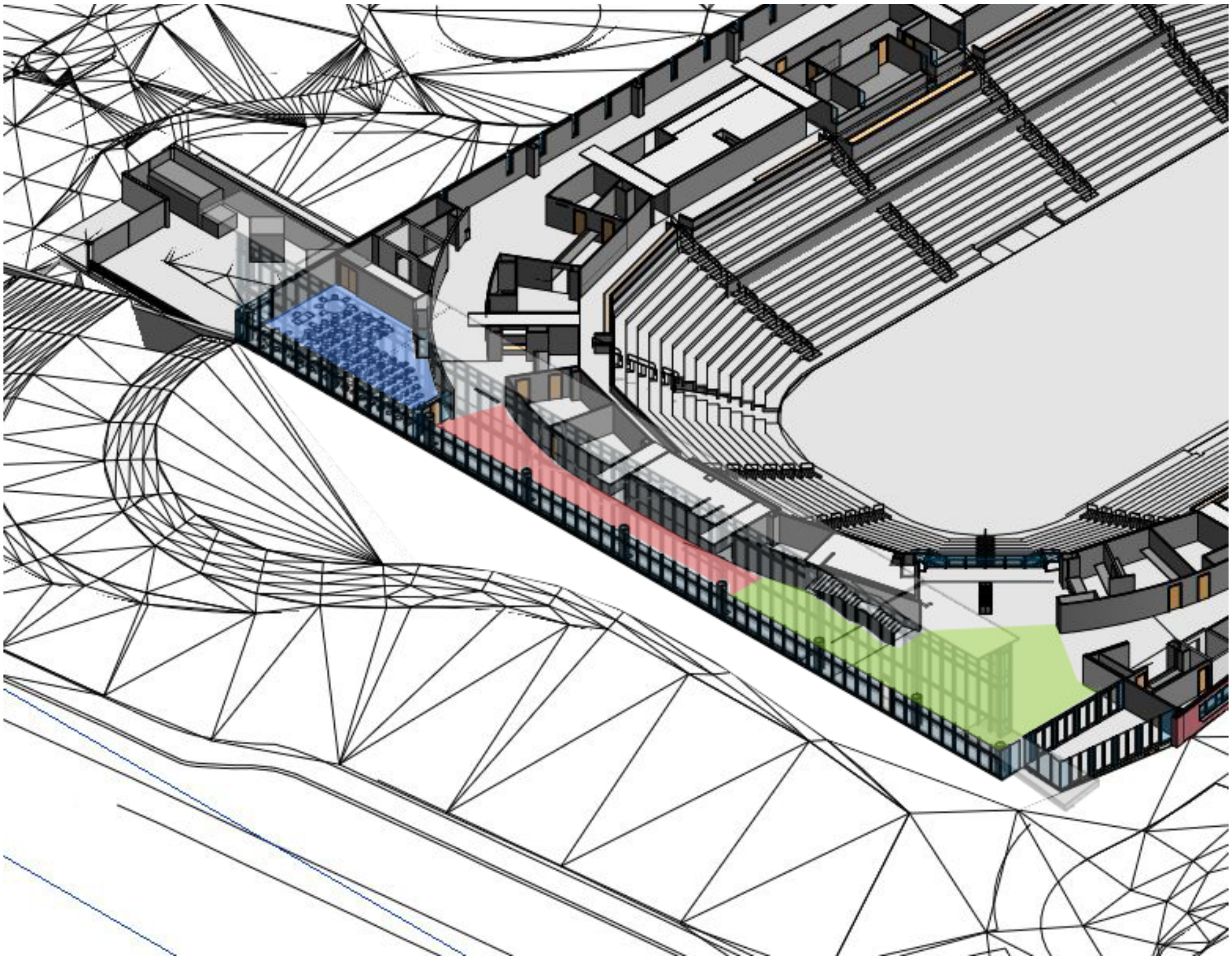
As part of the east façade, the main entrance will be altered. HPR Integrated Design will also aim to draw more attention to the student entrance. Although the student entrance is not the main entrance, it is still highly visible from the other sports fields and to the students on a daily basis.

Design Goals

Architectural

The main goal for the architectural redesign will be to provide a clear function for the form of the building . As mentioned in the problem statement the original architecture is transparent curtain wall intended to provide impressive views both out of the building and into the building. This original architectural intent will be kept with HPR Integrated Design's new redesigned façade and entrances with slight alterations to fit HPR's form follows function theme.

The spaces on the east façade of the building contain three distinct areas that respectively have a different occupancy levels and transparency needs. A two story atrium, general concourse space and lounge area all are located on the main concourse level on the east façade. On the club level the atrium continues as well as a general circulation space and a dining/lounge area. The atrium need a higher transparency both in and out of the building, the concourse need a high transparency out but a minimized view into the building due to the placement of restrooms and concessions in this area, and finally the lounge area on the southern part of the façade needed high transparency out to views of the surrounding landscape but minimal views in to increase privacy. This layout can be seen in Figure 97.



Green = Atrium, Red = Circulation, Blue = Lounge

Figure 99: East Facade Spaces

With the function of the spaces defined HPR designed the façade to contain brick piers encasing the structural columns. The spacing of the brick piers would relate to the adjacent spaces to reduce or increase the amount of glass on the façade. As seen in Figure 100, the piers were more closely spaced on the circulation zone and further in the atrium space, while the piers on the lounge zone were left spaced apart to increase view out.

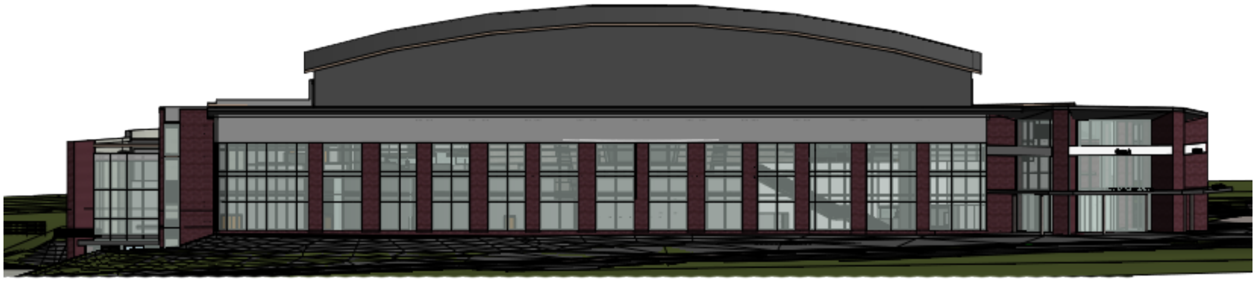


Figure 100: Proposed East Facade Elevation

Applying the form follows function theme to the entrances of the building posed a different architectural challenge to HPR. With both the student and main entrance HPR wanted to create "lanterns" that would guide patrons into the building. While doing this HPR wanted to create a connection between the academic core of the campus to the sports facilities on the northeastern portion of campus. A Rendering of the existing design by the design team can be seen in Figure 99.

Figure 101: Existing Facade

Taking a look at other collegiate arenas and stadium HPR came across Reser Stadium, the football stadium for Oklahoma State University. HPR thought that the entrance at Reser stadium, shown in Figure 102 did an excellent job of meeting our design criteria of form following function and transparency. After deciding to use Reser Stadium as inspiration we did preliminary modeling in Google SketchUp (shown in Figure 103) to work out geometries and dimensions. After doing so the final product was modeled in the teams linked federated Revit Architecture model. The proposed design for the main is shown in Figure 104.

Figure 102: Reser Stadium

Figure 103: Preliminary Modeling in Google SketchUp

Figure 104: Proposed Design for the Main Entrance Showing Lantern Effect

To address the precedence of hierarchy for the student entrance as part of an architectural link to the campus, the architectural forms used on the main entrance were scaled down to create an impressive student entrance. Shown in Figure 105.

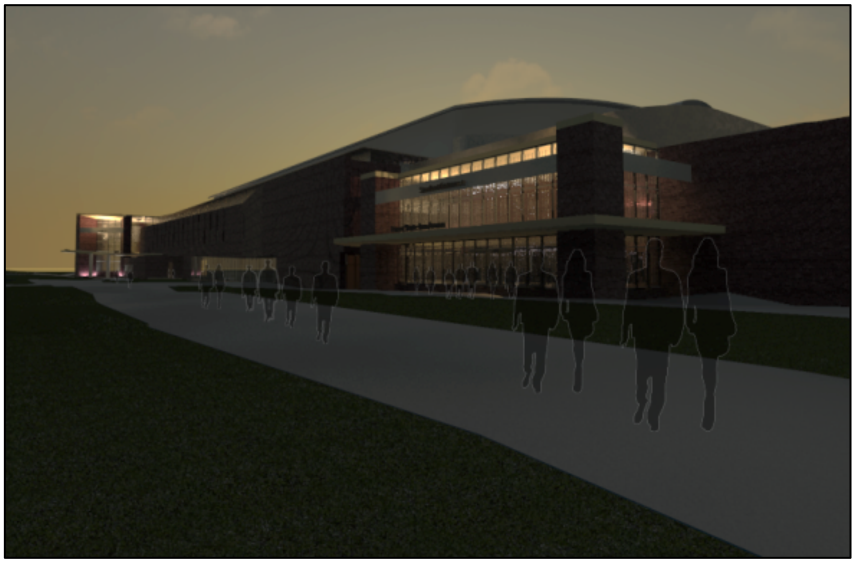


Figure 105: Proposed Design for the Student Entrance

Energy

HPR Integrated Design was interested in investigating the effects that the percent glass has on the energy consumption. Since the façade we are interesting in changing faces north east it is our assumption that the energy savings would be minimal and that the majority of the savings would come from the higher R-value of the wall in the place of existing glass.

We investigated the effects that the amount of glass has on energy. Once a decision was made regarding the amount of glass, keeping in mind both the energy use and the architectural vision, a separate analysis was done that investigated the effects of different curtain wall systems and of Wall construction type. Kawneer curtain walls were used for this comparison.

Effect of Glass

Five different percentages of glass were chosen for this study:100% (existing design), 70%, 50%, 30%, and 10%. An energy analysis was done using the Trane Trace model created for the loads. Schedules were changed to reflect the actual building occupancy and use schedules. The systems were also changed to reflect the AHU's of the actual design. The main changes included the addition of both the enthalpy and desiccant wheels in AHU-10,11, and 12, as well as the heat pipes in AHU-5,7,8,9. Fan power was also added for all of the air handling units.

The construction type for this analysis for this percent glass study used wall U-Value of 0.029 which was considered to be a good construction type will below the maximum allowed by ASHRAE 90.1 for climate zone 5A. The U-Value for the glass curtain wall system was set to 0.4. This is also below the maximum allowed for climate zone 5A.

In Table 23 you can see that the percent of glass does have an effect on the load on AHU-2,3, and 4 but that the reduction in load is not that drastic. This is because most of the spaces that these air handlers serve are not adjacent to the curtain wall in addition to the curtain wall facing northeast. It is HPR opinion that the orientation of this façade was chosen because of its limited impact on load.

	Load (MBTU/h)				
% Glass	AHU-2	AHU-3	AHU-4	Total	Percent Reduction
100	358.6	1041.2	1566.7	2966.5	0.0%
70	333.7	1029.7	1550.3	2913.7	1.8%
50	311.2	1016	1541.8	2869	3.3%
30	294.5	1001	1529.9	2825.4	4.8%
10	281.5	978	1517.9	2777.4	6.4%

Table 23: Percent Glass Effects on Spaces Adjacent to the Curtain Wall

Table 24 shows how this reduction in the percent of glass along the eastern façade affected the total energy consumption of the entire arena over the course of the year. Here the savings are even smaller when considered as a percent. With that said it sill shows a max of over $8,000 a year in total energy cost. A 30-year life cycle cost analysis was also done to see what effect this had on the life time cost of the building and the maximum amount of savings was roughly $250,000. This was determined using the Energy Price Indices and Discount Factors for Life Cycle Cost Analysis and can be seen in Table 25.

	Cost				
% Glass	Cooling/Electric	Heating	Total Building Energy Cost	Percent Reduction	30 Year Life Cycle
100	$335,150.00	$233,366.00	$568,516.00	0.0%	$16,521,128.24
70	$333,878.00	$232,560.00	$566,438.00	0.4%	$16,460,867.28
50	$332,857.00	$231,661.00	$564,518.00	0.7%	$16,404,774.76
30	$331,756.00	$230,837.00	$562,593.00	1.0%	$16,348,743.44
10	$330,471.00	$229,895.00	$560,366.00	1.4%	$16,283,951.96

Table 24: Percent Glass Effects on Total Energy for Building

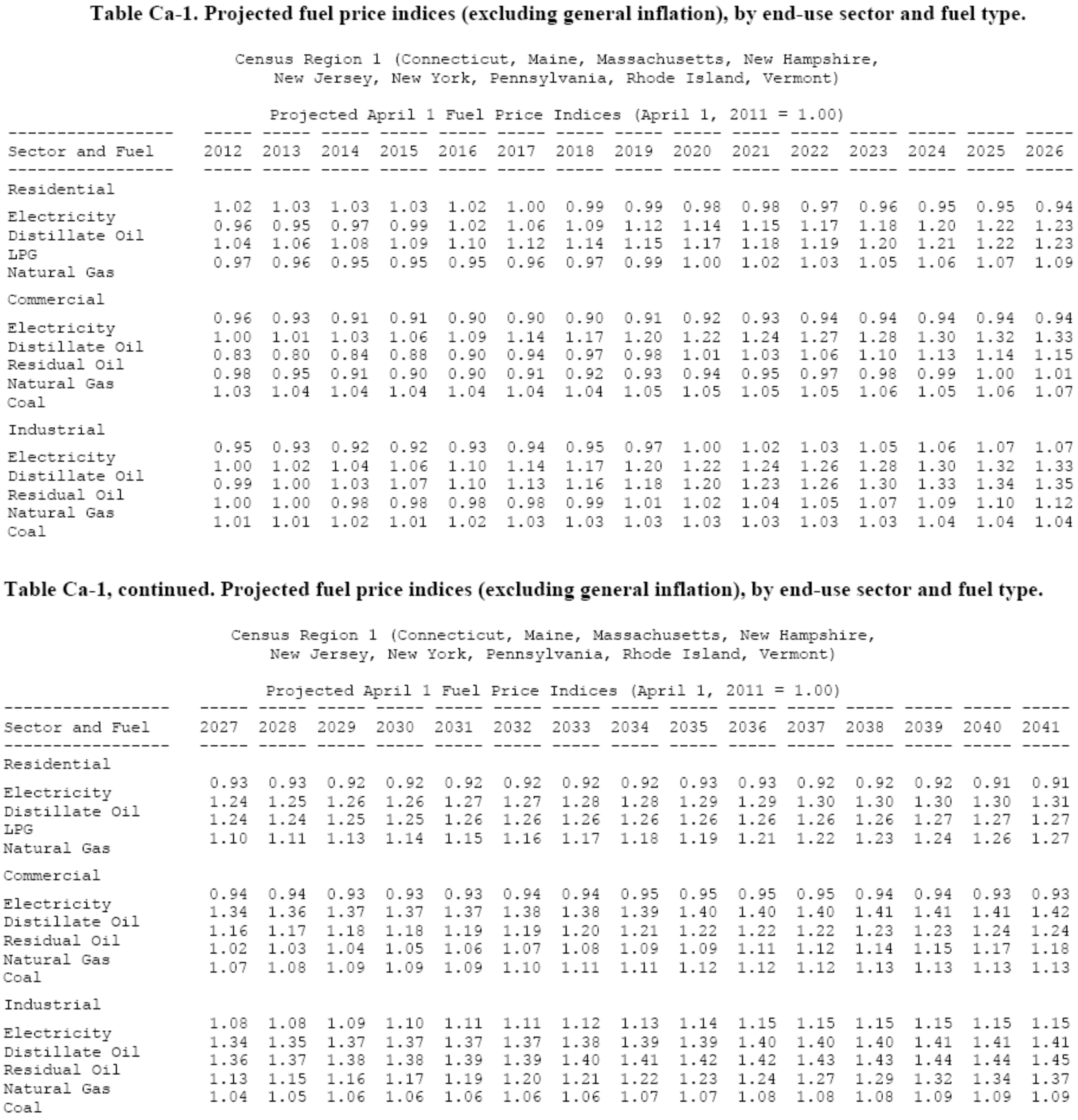


Table Ca-1. Projected fuel price indices (excluding general inflation), by end-use sector and fuel type.

Census Region 1 (Connecticut, Maine, Massachusetts, New Hampshire,
New Jersey, New York, Pennsylvania, Rhode Island, Vermont)

Projected April 1 Fuel Price Indices (April 1, 2011 = 1.00)

Sector and Fuel	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Residential															
Electricity	1.02	1.03	1.03	1.03	1.02	1.00	0.99	0.99	0.98	0.98	0.97	0.96	0.95	0.95	0.94
Distillate Oil	0.96	0.95	0.97	0.99	1.02	1.06	1.09	1.12	1.14	1.15	1.17	1.18	1.20	1.22	1.23
LPG	1.04	1.06	1.08	1.09	1.10	1.12	1.14	1.15	1.17	1.18	1.19	1.20	1.21	1.22	1.23
Natural Gas	0.97	0.96	0.95	0.95	0.95	0.96	0.97	0.99	1.00	1.02	1.03	1.05	1.06	1.07	1.09
Commercial															
Electricity	0.96	0.93	0.91	0.91	0.90	0.90	0.90	0.91	0.92	0.93	0.94	0.94	0.94	0.94	0.94
Distillate Oil	1.00	1.01	1.03	1.06	1.09	1.14	1.17	1.20	1.22	1.24	1.27	1.28	1.30	1.32	1.33
Residual Oil	0.83	0.80	0.84	0.88	0.90	0.94	0.97	0.98	1.01	1.03	1.06	1.10	1.13	1.14	1.15
Natural Gas	0.98	0.95	0.91	0.90	0.90	0.91	0.92	0.93	0.94	0.95	0.97	0.98	0.99	1.00	1.01
Coal	1.03	1.04	1.04	1.04	1.04	1.04	1.04	1.05	1.05	1.05	1.05	1.06	1.05	1.06	1.07
Industrial															
Electricity	0.95	0.93	0.92	0.92	0.93	0.94	0.95	0.97	1.00	1.02	1.03	1.05	1.06	1.07	1.07
Distillate Oil	1.00	1.02	1.04	1.06	1.10	1.14	1.17	1.20	1.22	1.24	1.26	1.28	1.30	1.32	1.33
Residual Oil	0.99	1.00	1.03	1.07	1.10	1.13	1.16	1.18	1.20	1.23	1.26	1.30	1.33	1.34	1.35
Natural Gas	1.00	1.00	0.98	0.98	0.98	0.98	0.99	1.01	1.02	1.04	1.05	1.07	1.09	1.10	1.12
Coal	1.01	1.01	1.02	1.01	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04	1.04

Table Ca-1, continued. Projected fuel price indices (excluding general inflation), by end-use sector and fuel type.

Census Region 1 (Connecticut, Maine, Massachusetts, New Hampshire,
New Jersey, New York, Pennsylvania, Rhode Island, Vermont)

Projected April 1 Fuel Price Indices (April 1, 2011 = 1.00)

Sector and Fuel	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
Residential															
Electricity	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.93	0.93	0.92	0.92	0.92	0.91	0.91
Distillate Oil	1.24	1.25	1.26	1.26	1.27	1.27	1.28	1.28	1.29	1.29	1.30	1.30	1.30	1.30	1.31
LPG	1.24	1.24	1.25	1.25	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.27	1.27	1.27
Natural Gas	1.10	1.11	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.21	1.22	1.23	1.24	1.26	1.27
Commercial															
Electricity	0.94	0.94	0.93	0.93	0.93	0.94	0.94	0.95	0.95	0.95	0.95	0.94	0.94	0.93	0.93
Distillate Oil	1.34	1.36	1.37	1.37	1.37	1.38	1.38	1.39	1.40	1.40	1.40	1.41	1.41	1.41	1.42
Residual Oil	1.16	1.17	1.18	1.18	1.19	1.19	1.20	1.21	1.22	1.22	1.22	1.23	1.23	1.24	1.24
Natural Gas	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.09	1.11	1.12	1.14	1.15	1.17	1.18
Coal	1.07	1.08	1.09	1.09	1.09	1.10	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.13
Industrial															
Electricity	1.08	1.08	1.09	1.10	1.11	1.11	1.12	1.13	1.14	1.15	1.15	1.15	1.15	1.15	1.15
Distillate Oil	1.34	1.35	1.37	1.37	1.37	1.37	1.38	1.39	1.39	1.40	1.40	1.40	1.41	1.41	1.41
Residual Oil	1.36	1.37	1.38	1.38	1.39	1.39	1.40	1.41	1.42	1.42	1.43	1.43	1.44	1.44	1.45
Natural Gas	1.13	1.15	1.16	1.17	1.19	1.20	1.21	1.22	1.23	1.24	1.27	1.29	1.32	1.34	1.37
Coal	1.04	1.05	1.06	1.06	1.06	1.06	1.06	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09

Table 25: Table Ca-1 of the Energy Price Indexes & Discount Factors

From these results HPR Integrated Design determined that an energy savings gained from a deduction of glass along the east would be taken as an added benefit to a change that would be driven by an architectural vision or goal.

As stated earlier the goal of the function package was to improve the function of the spaces through the façade, and to create a more distinct and attractive entrances. The portion of the façade that was adjacent to the concourse was to mimic the rhythmic vertical slit windows that line the concourse on the other two façades. Figure 106 shows the vertical slit windows along the concourse of the south façade.

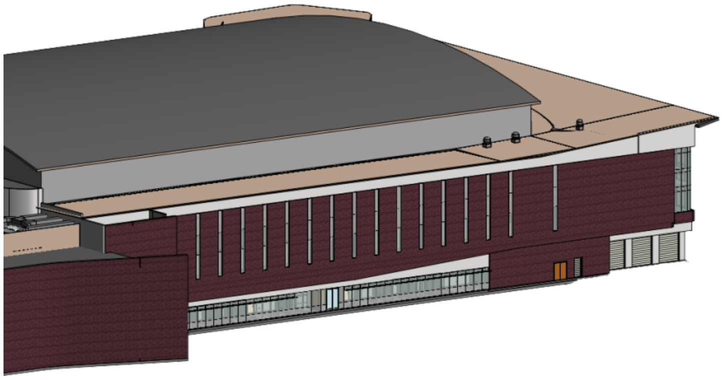


Figure 106: South Facade

It was HPR Integrated Design's goal to invert this trend on the east façade. Instead of a large brick wall with vertical slit windows, we were going to create a large glass façade with thin brick piers. We originally thought the design would level out around 70% glass but as the design progressed we quickly had a façade that meet out architectural goals and hade reduced the percent glass to 50%. This can be seen in Figure 107.

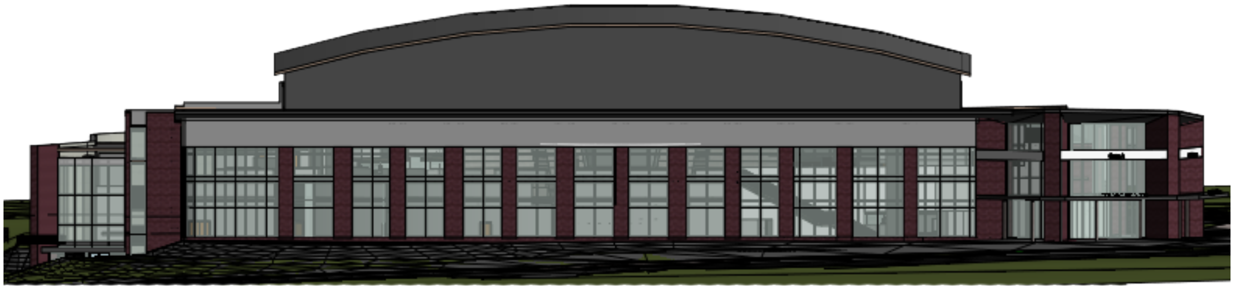


Figure 107: Proposed Design for East Facade

Effect of Wall Construction Type and Curtain Wall System

Once the percent glass and the final architectural design was decided open the curtain wall system had to be selected as well as the wall construction type. HPR Integrated Design decided to study two different wall construction types. The First was a standard wall construction type that original design used and that I had previous used in the percent class study. The U-Value (0.029) for this construction was confirmed by the structural designer using HAM Toolbox. The second was a block backed brick wall. This was chosen because of the possible reduction in material and labor cost. This U-Value (0.055) was also confirmed using the HAM Toolbox.

Brick Wall		Cost			
Construction	Total U-Value BTU/h-ft^2-F	Cooling/ Electric	Heating	Total Building Energy Cost	30 year life Cycle cost
CMU &Brick	0.055	$331,792.00	$232,465.00	$564,257.00	$16,399,631.92
Stud & Brick	0.029	$331,785.00	$231,613.00	$563,398.00	$16,373,330.92
CMU & Brick	0.055	$335,886.00	$231,368.00	$567,254.00	$16,480,488.08
Stud & Brick	0.029	$335,951.00	$230,487.00	$566,438.00	$16,455,311.64
CMU & Brick	0.055	$331,938.00	$231,484.00	$563,422.00	$16,373,656.24
Stud &Brick	0.029	$331,941.00	$230,412.00	$562,353.00	$16,340,894.04
CMU & Brick	0.055	$332,538.00	$231,085.00	$563,623.00	$16,378,206.88
Stud & Brick	0.029	$332,529.00	$230,238.00	$562,767.00	$16,352,003.16

Table 26: Wall Construction Type Study

Table 26 shows the results of the wall construction type study. The energy uses were fairly comparable between the to wall types. Once the costs of the two systems were actually compared it did not make sense to switch from the current designs stud and brick wall construction to the less efficient block backed brick wall.

The wall construction type determined it was than time to compare and select a curtain wall system. HPR Integrated Design decided to use Kawneer Wall Systems as our curtain wall provider. We choose Kawneer because we had access to one of there sales representatives in Andy Zubal. We would compare two different wall systems that Kawneer offers, the 1600 wall system and the 1600 UT wall System. The UT stands for Ultra Tremal and is on of the products that Kawneer is trying to push. With the standard wall system we compared the different mullion types you can install the system with. You will see there is a small impact on the systems U-value and shading coefficient.

The U-Values for the systems were found using the Kanween product data sheet using a center of glass U-value of 0.22. An example of the chart these data sheet provided can be seen in Table 27.

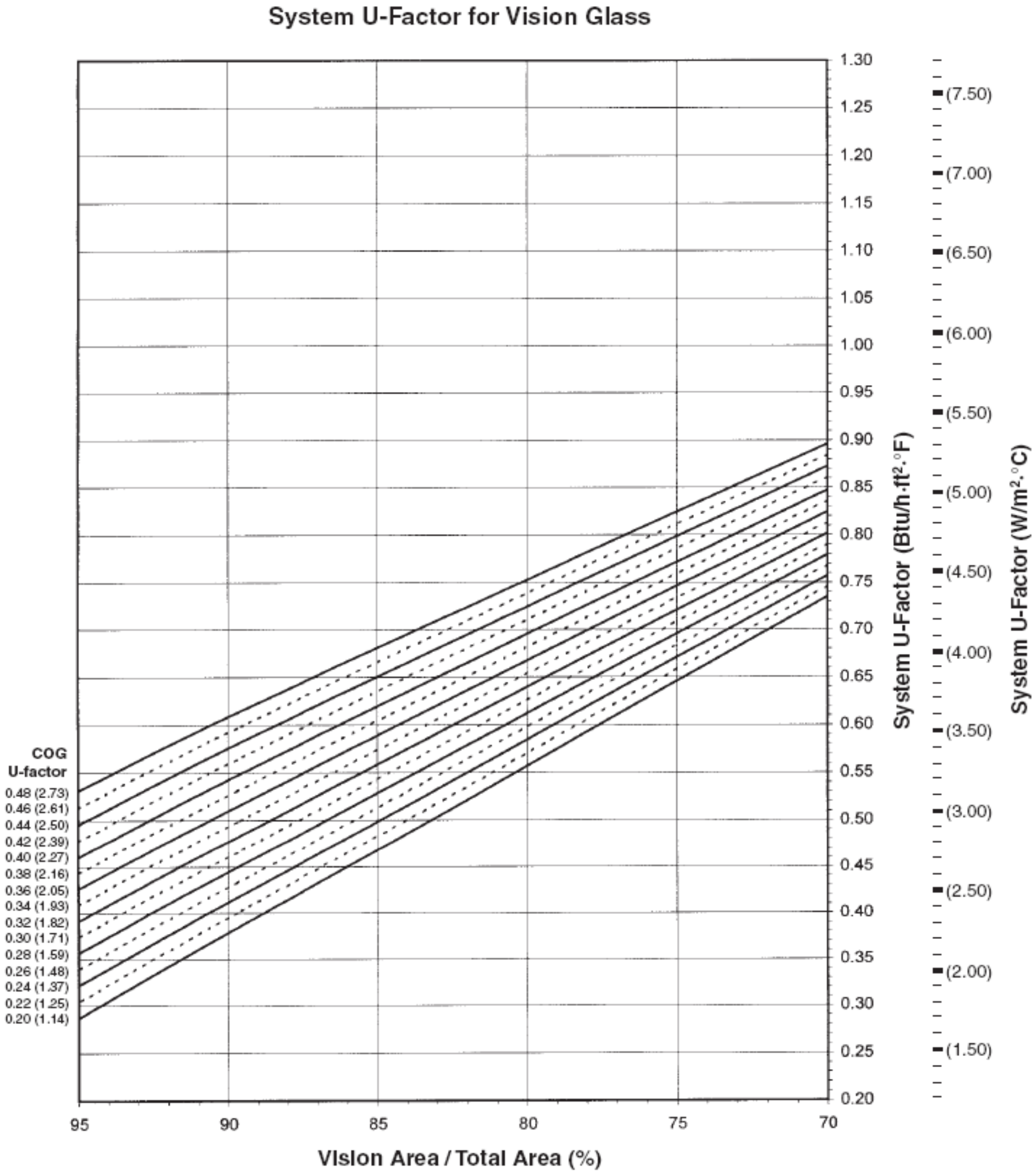


Table 27: U-Value Chart for the Kawneer 1601 Wall System

With a our Trace model now reflecting 50% glass and a wall U-Value of 0.029 the four different curtain wall assemblies were entered in separate alternatives. The results where run and can be seen in Table 28.

Curtain Wall				Cost				
Model	Total U-Value	SHGC	Cost Per SQFT	Cooling/ Electric	Heating	Total Building Energy Cost	30 year life Cycle cost	Curtain Wall Savings
1601	0.4	0.14	$ 63.00	$ 331,785.00	$ 231,613.00	$ 563,398.00	$ 16,373,330.92	0.2%
1602	0.34	0.21	$ 63.00	$ 335,951.00	$ 230,487.00	$ 566,438.00	$ 16,455,311.64	-0.3%
1603	0.34	0.14	$ 63.00	$ 331,941.00	$ 230,412.00	$ 562,353.00	$ 16,340,894.04	0.4%
1600 UT 1	0.33	15	$ 72.50	$ 332,529.00	$ 230,238.00	$ 562,767.00	$ 16,352,003.16	0.3%

Table 28: Curtain Wall Type Study Results

Cost was also a concern when selecting the two systems. The cost reflected in the fourth column of Table 28 contains the cost for the metal and the glass. It does not has labor included. The glass has a U-Value of 0.22. The costs are not dead nuts accurate but were deemed sufficient for HPR Integrated Designs comparison sake.

The Trace Model showed that the standard 1603 Wall system had the best energy performance although the savings where minimal. Because the cost for this system was the same as all the other standard 1600 wall systems and significantly cheaper than the Ulter Thermal alternative it was selected for our design.

The Ultra Thermal product was not beneficial for us because the double thermal break the product has only shows an affect when dealing with glazing with a super low u-value. HPR Integrated Design did not see any benefit in spending the extra money on either the metal or the improved glazing because, as show in the percent glass study, the load and energy savings by improving the walls total U-Value was minimal.

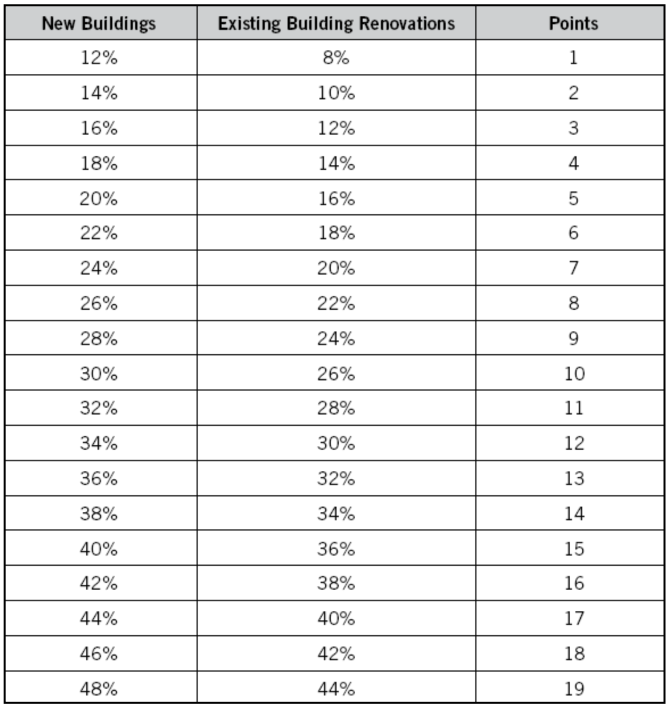
Once the wall system was selected the structural design performed the necessary structural checks to insure it could be used and the design was finalized.

LEED –Energy and Atmosphere

It Is HPR Integrated Design's goal to keep the building on track to earn a LEED Gold rating and part of this means conserving energy. According to the current projects LEED Score Card found in Appendix H, the current design is aiming for at least 5 points for the Energy and Atmosphere credit C.1. This credit is based on the comparison to a base line model created following the procedure laid out in Appendix G of ASHRAE Standard 90.1. The percent improvement is then found by using the blow equation.

$$\% \boldsymbol{Improvment} = 100 \times \frac{Baseline\ Building\ Performance - Proposed\ Builing\ Performance}{Baseline\ Building\ Performance}$$

Since tracking LEED point is a process that starts in design and continues to the building is occupied it is difficult for use to say with certainty what points we would actually be able to achieve. It is HPR Integrated Design's approach to assume the current design will achieve its goal of LEED gold and we will keep track of changes made that could affect the total number of point the arena earns. With this in mind HPR will not be creating a baseline model in accordance to ASHRAE 90.1. Instead we will use the model created for the original design and know that design earned 5 lead points we will be able to determine the energy the baseline model would use.



New Buildings	Existing Building Renovations	Points
12%	8%	1
14%	10%	2
16%	12%	3
18%	14%	4
20%	16%	5
22%	18%	6
24%	20%	7
26%	22%	8
28%	24%	9
30%	26%	10
32%	28%	11
34%	30%	12
36%	32%	13
38%	34%	14
40%	36%	15
42%	38%	16
44%	40%	17
46%	42%	18
48%	44%	19

Table 29: LEED Optimizing Energy Performance Credit

Including all the savings from the façade and the reduction in size of AHU-7 and AHU-8. HPR Integrated design is projected to use 3.9% less energy than the current design will use. This extrapolates out to put out design and 23% energy use than the ASHRAE 90.1 appendix G baseline model. This would give our design one addition LEED point over the current design. These calculations can been seen below.

$$Current\ Design\ Energy\ Use = \$585{,}299/yr$$

$$HPR\ Design's\ Energy\ Use = \$562{,}353/yr$$

$$\frac{\$585{,}299 - \$562{,}353}{\$585{,}299} = 3.9\%\ Reduction$$

$$\mathbf{20}\% = 100 \times \frac{Baseline\ Building\ Performance - Proposed\ Builing\ Performance}{Baseline\ Building\ Performance}$$

$$\mathbf{20}\% = 100 \times \frac{Baseline\ Building\ Performance - \$585{,}299}{Baseline\ Building\ Performance}$$

$$Baseline\ Building\ Permance = \$731{,}624$$

$$23.1\% = 100 \times \frac{\$731{,}624 - \$562{,}353}{\$731{,}624}$$

It is important to note that the current design was assumed to only be 20% better than the base line model. It the Current design was actually 21% better than the base line out new design could in fact earn 2 more LEED points than the current design.

Lighting

The lighting design for the facade redesign will reinforce the lantern theme of the redesign. To drive home the lantern theme the lighting in the atrium will be mostly an "indirect" delivery system developed by Zumtobel called Miros. This system does two things to achieve the fell HPR wanted; first it delivers a uniform lighting distribution on the atrium floor while providing efficient ambient light to have the entire atrium glowing with bounced light. A secondary use for the system is to hide the lighting delivery system from the exterior, by mounting the projectors on the brick piers and aiming them at the ceiling mounted mirrors located directly above obstructs the view of the lighting system from University Drive as well as the walkways leading up to the main entrance of the building.

The illuminance criteria outlined by the IES 10th edition lighting handbook are as follows:

Horizontal Illuminance	150 lx @ floor
Vertical Illuminance	75 lx @ 5' AFF
Uniformity	Emax:Emin <= 2:1

ASHRAE Standard 90.1 section 9 outlines the allowable lighting power density for the atrium space. Lobby spaces are allowed to have a power density of 0.73 watts per square foot. In the case of the atrium that gives a total connected wattage of 2580 watts. Figure 106 below shows a section through the atrium space detailing how the Miros system would be implemented in this space.

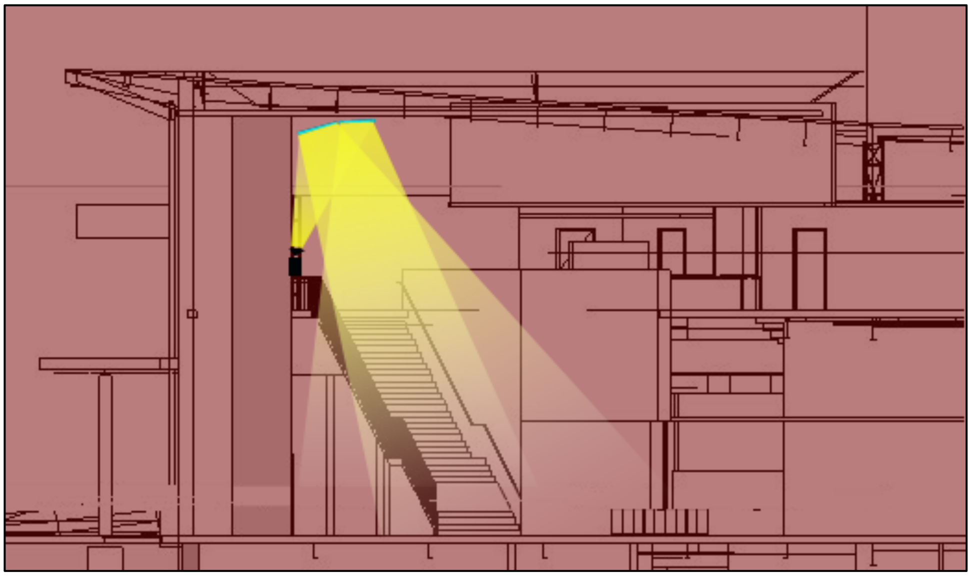


Figure 108: Diagrammatic Section through the Atrium

The Miros system chosen for the atrium is the semi-matte finish with a 30 degree spread. Choosing this option HPR was able to create a solution that was able to meet all of the design criteria. Figure 109 below shows the illuminance values on the surfaces within the atrium. It is important to note that the Miros system does create a hot spot on the system with the spill light that does not strike the mirror. However this is minimized by the distance between the projector and the mirror. In this solution the projector is mounted at 23' above the main concourse level and the mirror is mounted 2 feet below the ceiling plane of 35' above the main concourse level. Using these mounting heights the distance is reduced to 9' and the maximum illuminance on the ceiling is roughly 750 lux.

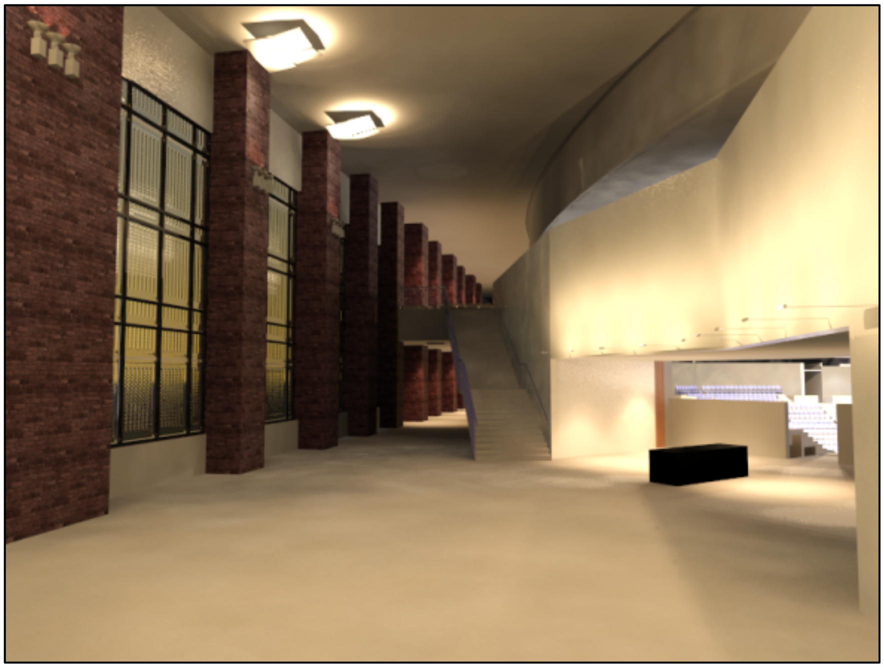


Figure 109: 3DS Rendering of Lighting Solution in Atrium

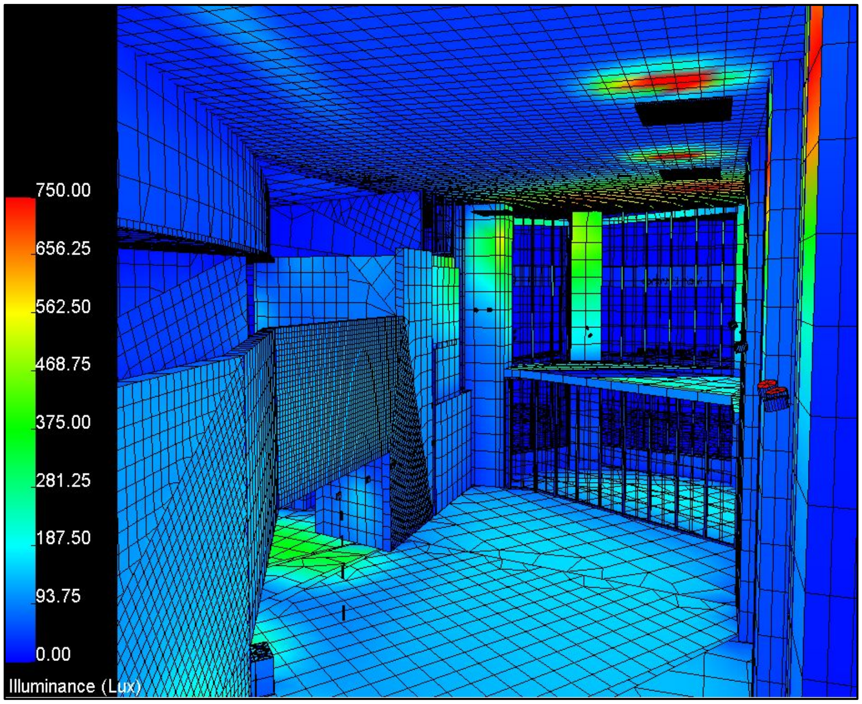


Figure 110: AGI Pseudo Color Rendering of Atrium

The Miros system provides the following illumination levels compared to the design criteria in the following table.

Horizontal Illuminance	150 lx @ floor	153 lx
Vertical Illuminance	75 lx @ 5' AFF	126 lx
Uniformity	Emax:Emin <= 2:1	xx lx

Another important lighting feature of the atrium is the illumination of the showcase wall. This wall is located opposite of the façade and the entrance. An important criteria for the showcase wall will be an illumination level that is 3 to 10 times higher than the ambient illumination in the atrium. To apply this technique to the atrium, HPR is implementing a cantilevered wall washing luminaire mounted at the bottom of the showcase wall. In Figure 109 it can be seen that the showcase wall is illuminated to around 375 lx, which is just over 3 times the ambient illumination provided on the floor.

The last lighting element within the atrium is the area directly above the vestibule space. Contained within the space HPR is proposing the use of hanging banners for another opportunity to showcase the new hockey program. The banners would be illuminated by track mounted fixtures on the piers of the main entrance. As it can be seen in Figure 111 the illumination of this area is 450 lux and above. The illumination of the banners can be seen in Figure 111.

Figure 111: 3DS Rendering Showing the Atrium Lighting Solution

The total connected wattage for the atrium is 3618 watts. This is over the code allowable by 1038 watts, however this space and the other spaces designed for this thesis are all categorized as tradable therefore looking at all three packages there is a net energy savings.

Structural

Structural considerations for the Function package we're limited in scope as the primary driver of this focus was energy, lighting conceptualization and architecture. The structural designer had significant input into the architectural design of both the East façade redesign and the new main and student entrances. This role of the structural designer in the function design package was to facilitate the needs of the mechanical and lighting/electrical designers in the redesign of the atrium and east façade spaces.

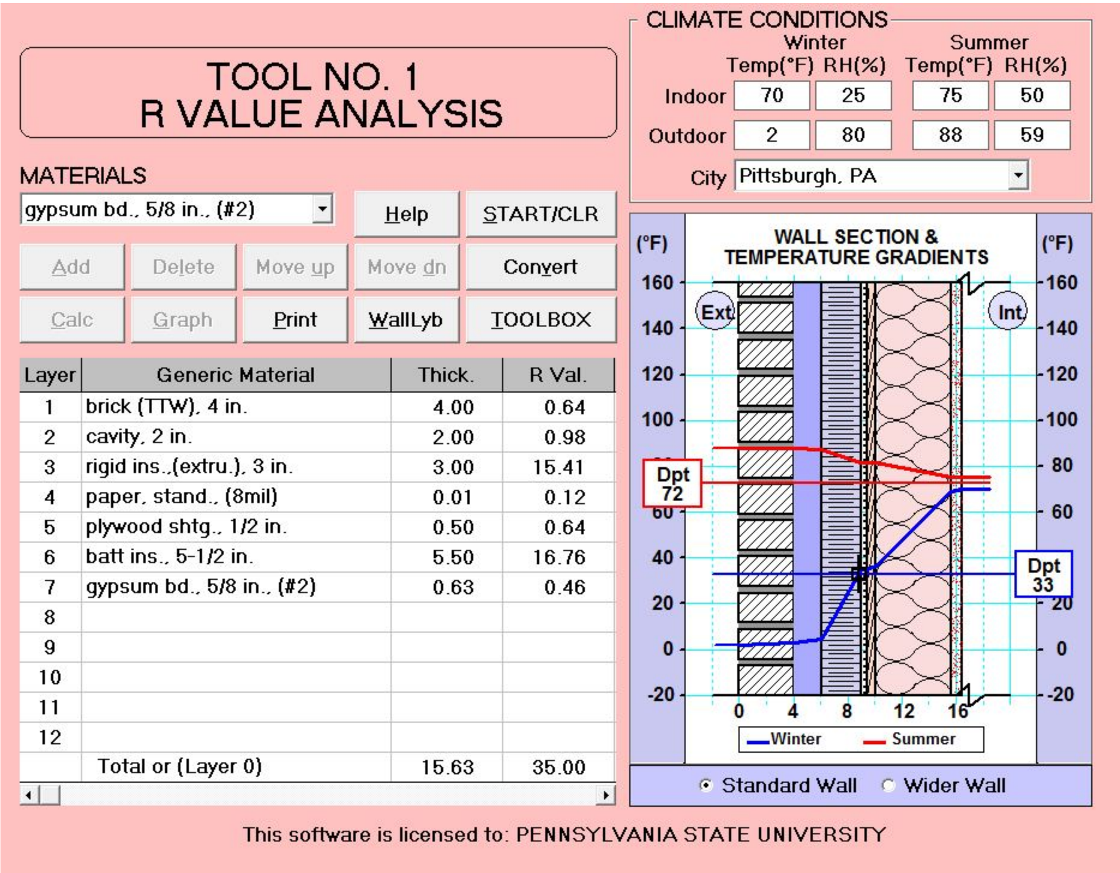
Master's coursework was used heavily throughout this enhancement package to assist in the confirmation of façade assemblies and curtain wall selection. Additionally, new main and student entrances were designed in SAP2000 to accommodate for the team's design alternative. The following section will go into more detail about these structural considerations and the role of the structural designer in this capacity.

East Façade Design Input

HPR Integrated Design's design concept for the east façade was to replace the curtain wall that encompasses the entire east face of the building with a more traditional brick pier system consistent with the adjacent walls of the facility. Switching from the lighter curtain wall system to a heavier brick cavity wall assembly required exterior column checks for capacity. Exterior columns were checked as combined loading members for both the axial load from the roof above and the wind loads derived from ASCE 7-10 wind criteria. Sample calculations for the exterior column checks can be found in Appendix H.

The structural designer worked closely with the mechanical designer to redesign the new east façade wall assembly and help in the selection of the new curtain wall system and layout. Through the use of H.A.M. Toolbox, a building enclosure analysis and design tool, the mechanical designer and structural designer confirmed the desired cavity wall assembly would have a desired U-value that would enhance the building's energy performance.

Multiple wall assemblies were investigated for their thermal efficiency including an study into using a block (CMU) back up instead of structural metal studs. Ultimately, the wall assembly matched the typical 1'-4" wide exterior cavity wall with a 6" metal stud backup. Using an u-value derived from HAM toolbox, the mechanical designer fan calculations using Trane Trace. An example of the R-Value Analysis completed by the structural designer can be seen in Figure 110 below. Additional H.A.M. toolbox analyses can be found in Appendix H.



TOOL NO. 1
R VALUE ANALYSIS

CLIMATE CONDITIONS

	Winter Temp(°F)	Winter RH(%)	Summer Temp(°F)	Summer RH(%)
Indoor	70	25	75	50
Outdoor	2	80	88	59

City: Pittsburgh, PA

MATERIALS: gypsum bd., 5/8 in., (#2)

Layer	Generic Material	Thick.	R Val.
1	brick (TTW), 4 in.	4.00	0.64
2	cavity, 2 in.	2.00	0.98
3	rigid ins.,(extru.), 3 in.	3.00	15.41
4	paper, stand., (8mil)	0.01	0.12
5	plywood shtg., 1/2 in.	0.50	0.64
6	batt ins., 5-1/2 in.	5.50	16.76
7	gypsum bd., 5/8 in., (#2)	0.63	0.46
8			
9			
10			
11			
12			
	Total or (Layer 0)	15.63	35.00

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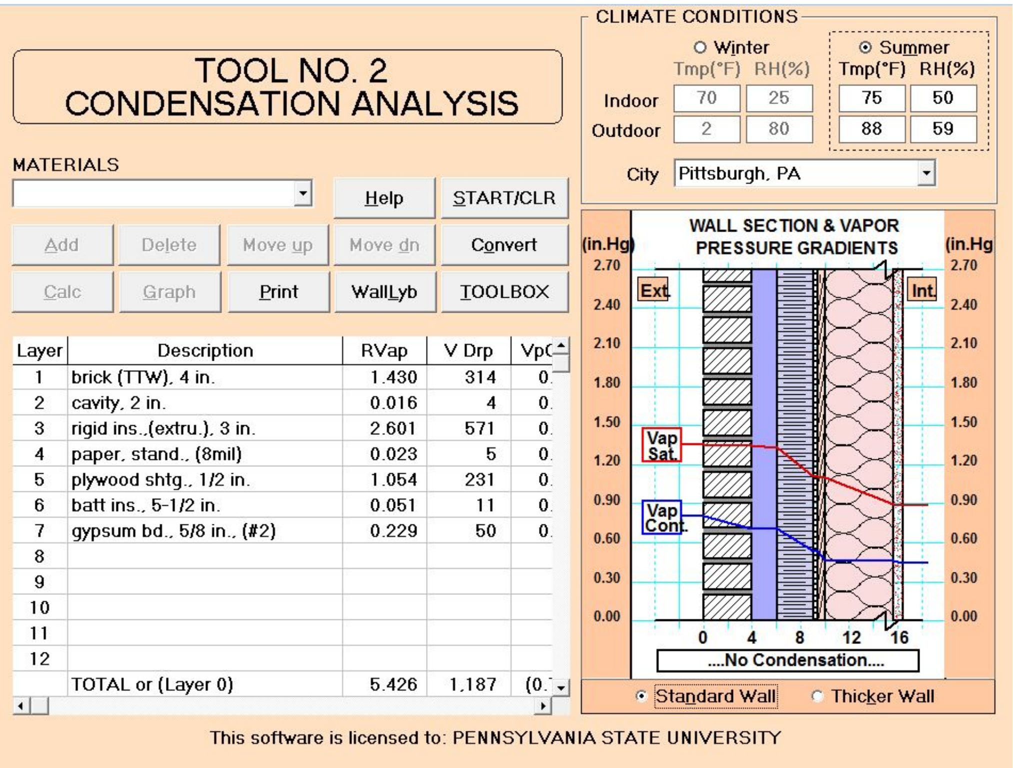
Figure 112: H.A.M. Toolbox R-Value Analysis - Exterior Cavity Wall Assembly

The R-value analysis also allowed the structural designer to verify that condensation issues would occur on the exterior side of the drainage plane. In addition to verification of the R-value, a condensation analysis was also performed using the chosen exterior cavity wall assembly. Figure 113 and 114 below show the condensation analysis for the summer and winter months assuming the location of the building is in Pittsburgh, PA , the closest city within the program.



TOOL NO. 2
CONDENSATION ANALYSIS

CLIMATE CONDITIONS

○ Winter: Indoor Tmp(°F) 70, RH(%) 25; Outdoor Tmp(°F) 2, RH(%) 80
● Summer: Indoor Tmp(°F) 75, RH(%) 50; Outdoor Tmp(°F) 88, RH(%) 59

City: Pittsburgh, PA

Layer	Description	RVap	V Drp	VpC
1	brick (TTW), 4 in.	1.430	314	0.
2	cavity, 2 in.	0.016	4	0.
3	rigid ins.,(extru.), 3 in.	2.601	571	0.
4	paper, stand., (8mil)	0.023	5	0.
5	plywood shtg., 1/2 in.	1.054	231	0.
6	batt ins., 5-1/2 in.	0.051	11	0.
7	gypsum bd., 5/8 in., (#2)	0.229	50	0.
8				
9				
10				
11				
12				
	TOTAL or (Layer 0)	5.426	1,187	(0.

....No Condensation....

● Standard Wall ○ Thicker Wall

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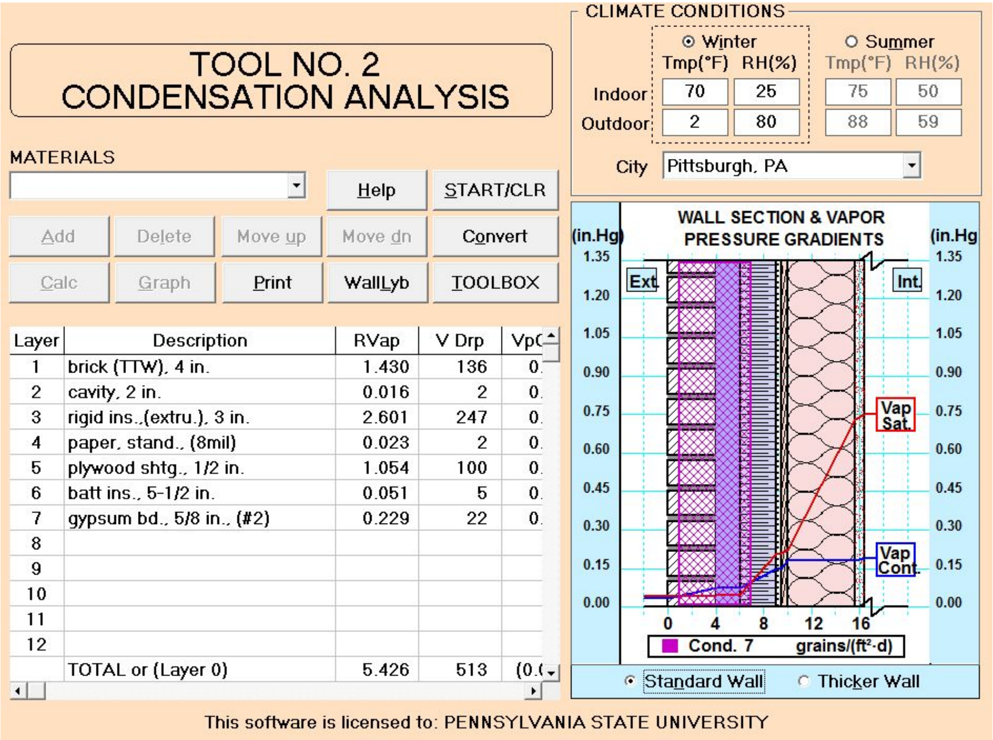
Figure 113: Summer - Condensation Analysis



TOOL NO. 2
CONDENSATION ANALYSIS

CLIMATE CONDITIONS

● Winter: Indoor Tmp(°F) 70, RH(%) 25; Outdoor Tmp(°F) 2, RH(%) 80
○ Summer: Indoor Tmp(°F) 75, RH(%) 50; Outdoor Tmp(°F) 88, RH(%) 59

City: Pittsburgh, PA

Layer	Description	RVap	V Drp	VpC
1	brick (TTW), 4 in.	1.430	136	0.
2	cavity, 2 in.	0.016	2	0.
3	rigid ins.,(extru.), 3 in.	2.601	247	0.
4	paper, stand., (8mil)	0.023	2	0.
5	plywood shtg., 1/2 in.	1.054	100	0.
6	batt ins., 5-1/2 in.	0.051	5	0.
7	gypsum bd., 5/8 in., (#2)	0.229	22	0.
8				
9				
10				
11				
12				
	TOTAL or (Layer 0)	5.426	513	(0.

🟪 Cond. 7 grains/(ft²·d)

● Standard Wall ○ Thicker Wall

This software is licensed to: PENNSYLVANIA STATE UNIVERSITY

Figure 114: Winter - Condensation Analysis

Condensation analysis for the exterior cavity wall assembly with structural stud backup allowed the structural designer to coordinate with the mechanical designer on required thickness of insulation, location of vapor and air barriers, etc. The analysis showed that the summer months would result in condensation issues as the saturated vapor pressure never is reached. In the winter however, condensation will occur in the wall cavity but on the exterior side of the drainage plane. Analysis on this wall showed that minimal condensation could occur between the exterior brick and mostly in the air space. If the exterior wall is wept correctly and blockages from masonry mortar are avoided in construction, this wall assembly should have no issues with condensation.

These analyses were part of master's level coursework for AE 542 – Building Enclosures Science & Design. Although the process was not purely structural in nature, the ability to verify the wall assemblies performance characteristics allowed HPR Integrated Design to move forward with design with the knowledge of an enhanced façade for energy performance. Additional condensation analysis was done in HAM toolbox for thoroughness in design choices and can be found as a part of Appendix H.

Continuing collaborative design with the mechanical and lighting/electrical designers, the curtain wall system was the next major structural consideration for the east façade design focus. After the mechanical designer had selected the Kawneer 1600 wall system, the mechanical designer and structural designer worked together to detail a typical curtain wall assembly. Figure 115 shows the final configuration of a typical curtain wall elevation, finalized through collaborative design.

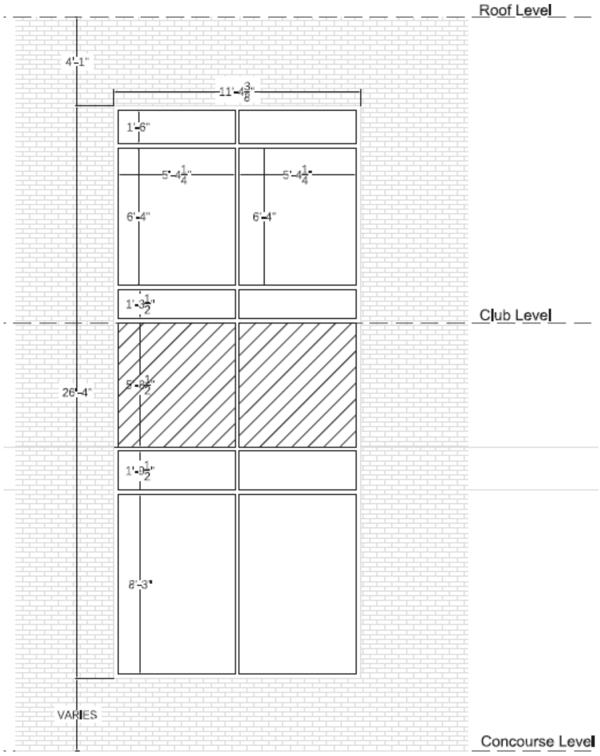


Figure 115: Typical Curtain Wall Elevation

Using the largest pane of glass in this elevation, which is a 8'-4" tall by 5'-4" wide pane at the bottom of the elevation, the structural designer performed analysis on the glazing. Two major analysis checks were conducted: wind strength design per ASTM E1300 and small missile impact analysis per ASTM E2025 for windborne debris considerations.

The analysis confirmed that the ¼" thick laminated glass insulated glass units (IGUs) meet both design criteria and could be used per the Kawneer specifications. Additionally, the structural designer completed design on the structural mullions with the assumption that the Kawneer system had continuous mullions as it was a shop fabricated unitized system. Analysis confirmed that T5 aluminum structural mullions had to be at least 7 mm or approximately 3/8" thick to satisfy both ASTM E1300 and ASTM E2025 design criteria. It is important to note that bearing criteria was not investigated and large missile impact was ignored. Hand calculations for the curtain wall glazing and mullion design can be seen in full in Appendix H.

New Entrance Structural Design

The overall team concept for the function enhancement package was to create spaces that revealed their function through the architecture. Part of the design focus was to increase the prominence of the main and student entrances. The structural designer performed a combination of hand calculations and computer modeling in SAP2000 to design the entrances for gravity forces only. To simplify the design, wind loads were not accounted for directly but the member sizes were conservative in the final design. Canopy framing was also considered purely for minimum live loads per code, conservative snow loads and dead loads. Figure 116 below shows the main entrance structural system and canopy framing.

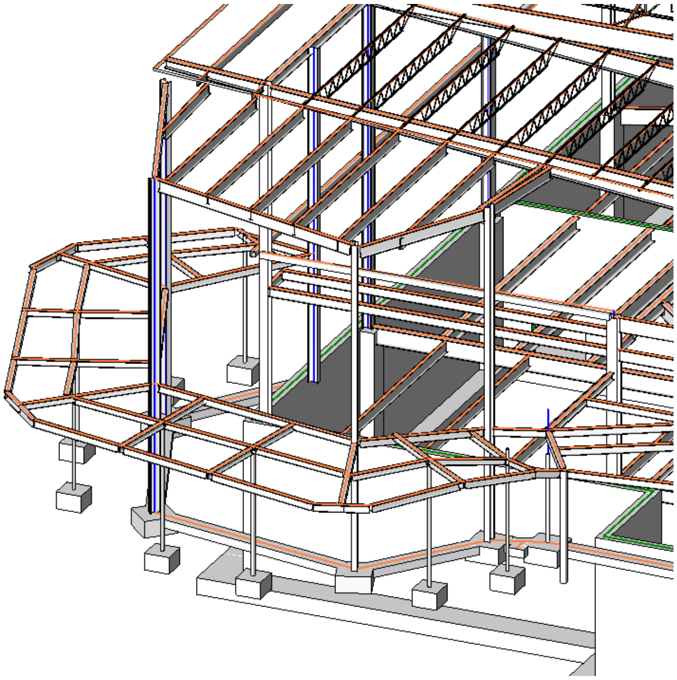


Figure 116: Main Entrance Canopy Framing

The main entrance consists of W10's for canopy framing members, W16's for more economic roof framing members and conservative W14x53 columns that tie into the existing structure system. Posts were added to the design for architectural and to support the canopy system. They consist of HSS6x6x3/8 members, which are conservative for the required capacities. Foundation design was not included as part of this quick design process but were modeled for design authoring purposes only.

Figure 117 shows a 3D view of the new student entrance framing design. The student entrance boost a two story atrium that is 50' wide and is a major architectural change from more modest existing design. Canopy framing for this entrance is again W10 wide flange shapes and W14 columns conservatively sized. Since the student entrance spans nearly 50', W24x94 girders were hand calculated by the structural engineer to take the applied loads of the structure. Foundation design was not taken into account at this location and was modeled solely for design authoring purposes. Sample hand calculations can be found in Appendix H for both the main and student entrances.

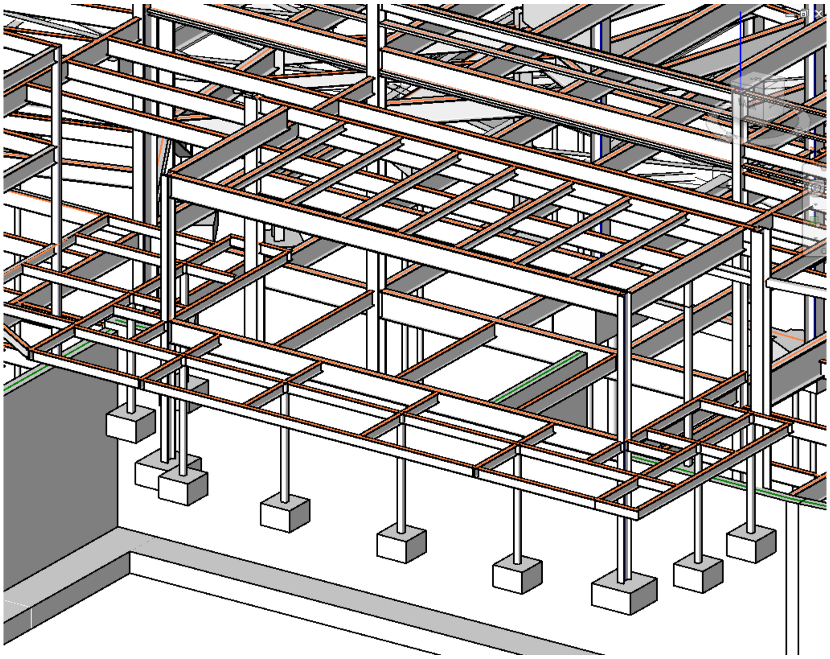


Figure 117: Student Entrance Framing Perspective

Cost & Schedule Impact

The newly designed roof system was designed with the intent to reduce energy consumption by reducing the square footage of glass on the east façade.

Using Quantity Takeoff and costs found in *Craftsman's National Estimator*, the construction manager estimated the façade for the current design and HPR's design. Figure 118 shows an image of the new east façade in Quantity Takeoff.

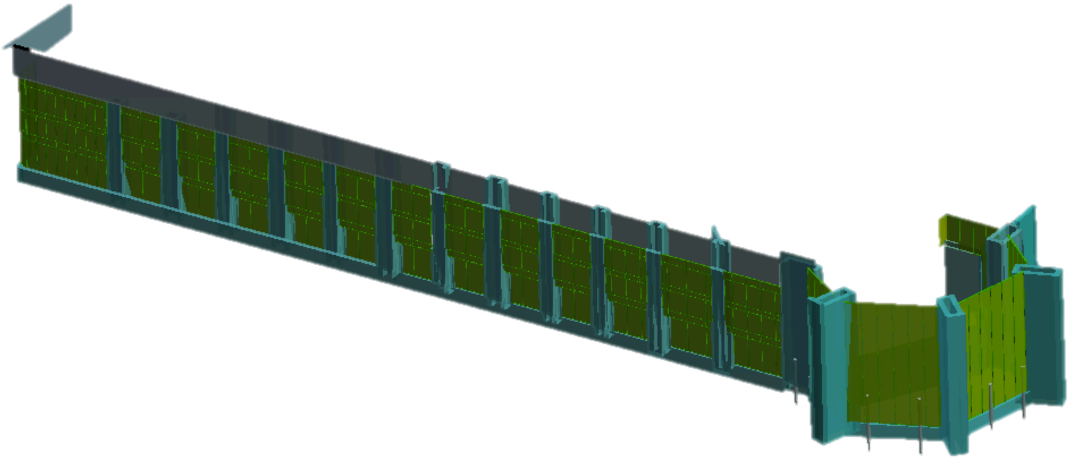


Figure 118: HPR's Proposed East Façade in Quantity Takeoff

The new façade design helps with energy savings, but increases the total construction cost by $77,575. This is due to the increase in the height of the main concourse walls and the added labor from the external walls. The following changes were made, with increased spending listed first, followed by additional savings.

Increased Spending	
Exterior Wall Material	**$115,256**
Additional Savings	
Glazing	**$37,680** (6.6%)

Along with redesigning the façade, HPR focused on enhancing the main and student entrances. The entrances are not very recognizable in the current design. It was important to deliver a more prominent and welcoming entrance for both locations. The following changes were made and estimated in Quantity Takeoff. Increased spending is listed first, followed by additional savings.

Increased Spending

Exterior Wall Material	**$115,969**

Additional Savings

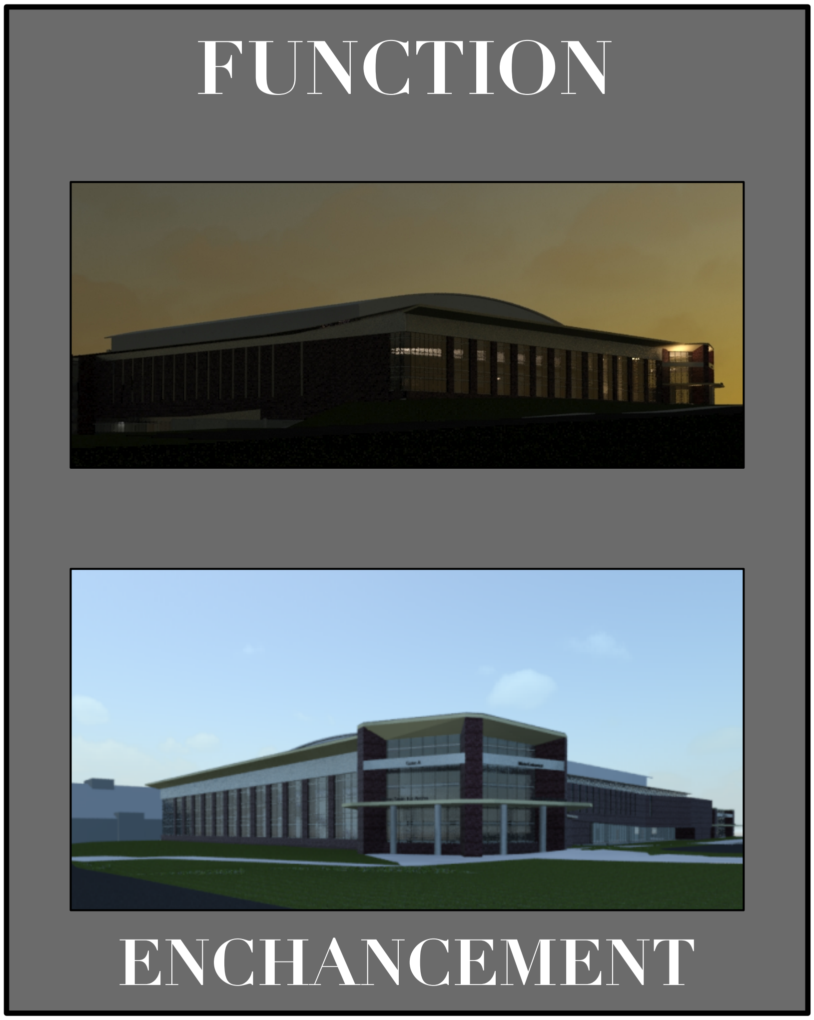
Glazing	**$97,602 (5758.3%)**

By enhancing the east façade and the entrances, the overall construction cost is increased by $95,942. See Appendix H for complete breakdown of differences in cost for this design package. The added material for the Function Package would result in 34 days passed the current project design schedule. The construction manager's new schedule created in the Prominence Package allows only an additional 8 days of construction for this design package.

Package Summary

The main goal of the Function Package was to reduce the building's energy consumption while striving to maintain code compliance. By reducing the square-footage of glass, HPR was able to reduce energy costs by 3.9% and earn one point more than that of the current design.

The secondary goal was to give the building a more grander and recognizable main and student entrances. Where the glass was reduced, brick was replaced. The total increased cost for this package is $95,542 with an added 8 workdays to the schedule. Design intent for this package was to design an energy efficient building.



HPR Redesign Cost & Schedule Summary

Summary of Packages

HPR Integrated Design has developed three packages that first saved costs, and then enhanced the building features. These packages will give the owner options to enhance the quality of their ice hockey arena. HPR has studied the feasibility study up through the preliminary design, as well case other case studies, while using value engineering to develop these packages. Shown below are the costs impacts of each of the packages. See Appendix F, G, and H for the breakdown of these packages.

Savings	$ (% Change)	Workdays
Savings Package	$330,406 (3.4%)	Save 15
Additional Cost		
Prominence Package	$528,521 (16.4%)	Save 26
Function Package	$95,942 (13.5%)	Add 8

When these packages are added together, a total of $294,056 is added to the overall budget. With the reconsolidation of the schedule, the project has a new completion date of August 13, 2013, 17 workdays ahead of schedule.

General Conditions

For this project, the construction manager used an overhead and profit markup of 24.8% of the overall $73 million budget. Based on *Craftsman's National Estimator*, a breakdown of this percentage is shown below.

Indirect Overhead	8.0%
Direct Overhead	7.3%
Contingency	2.0%
Profit	7.5%
Total	24.8%

HPR was able to complete the project 17 workdays ahead of schedule, or 22 calendar days. The result of this showed improved cost savings due to the reduction of indirect and direct overhead costs, a total general conditions savings of $394,411. The breakdown can be seen below.

	% of Budget	Current Design	Reduced Cost	Savings
Indirect Overhead	8	$5,840,000	$5,633,722	$206,228
Direct Overhead	7.3	$5,329,000	$5,140,817	$188,183
			Total	$394,411 (3.5%)

Final Savings

The overall savings to the owner for HPR's proposed design is $100,355, and 17 workdays.

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APPENDIX B: Measures for Success

Event Level Relocation

- Coordination amongst all of the disciplines throughout project design.
- Reduction in flooring system to allow for maximum plenum space while balancing optimum relocation of the entire event level.
- Reduction in cost for the redesign flooring system versus the existing flooring system.
- Reduce the cost of materials and resources needed for excavation.
- Reduce schedule by reducing amount of bedrock needing to be excavated.
- Optimize duct size balancing energy, cost, and space.
- Reduce the lighting power density of the level below ASHRAE Standard 90.1 Section 9.
- Reduce the cost of the electrical distribution system by optimizing the routing of conduit & wiring through the building.
- Ensure systems designed are achieving points necessary on LEED score card for Gold Certification.

Main Arena Roof System Design

- Coordination amongst all of the disciplines throughout project design.
- Along with the façade redesign, create an iconic roof system.
- Roof system design increases or maintains constructability.
- Reduce cost with reduction of long span truss member size.
- Structural design maintains performance of lateral system with new truss system.
- Structural design allows for efficient lighting and mechanical designs while fully integrated.
- Determine proper crane size and amount of cranes needed to install roof system.
- Create a site logistics plan that allows smooth flow of operations.
- Create a controllable system that can be turned down when arena is not occupied which leads to a reduction of energy use.
- Reduce the lighting power density of the space below ASHRAE Standard 90.1 Section 9.
- Meet or exceed the lighting design guidelines laid out by the NCAA.
- Create an electrical distribution system that is versatile and provides the space with functional & logical points of connection.
- Ensure systems designed are achieving points necessary on LEED score card for Gold Certification.

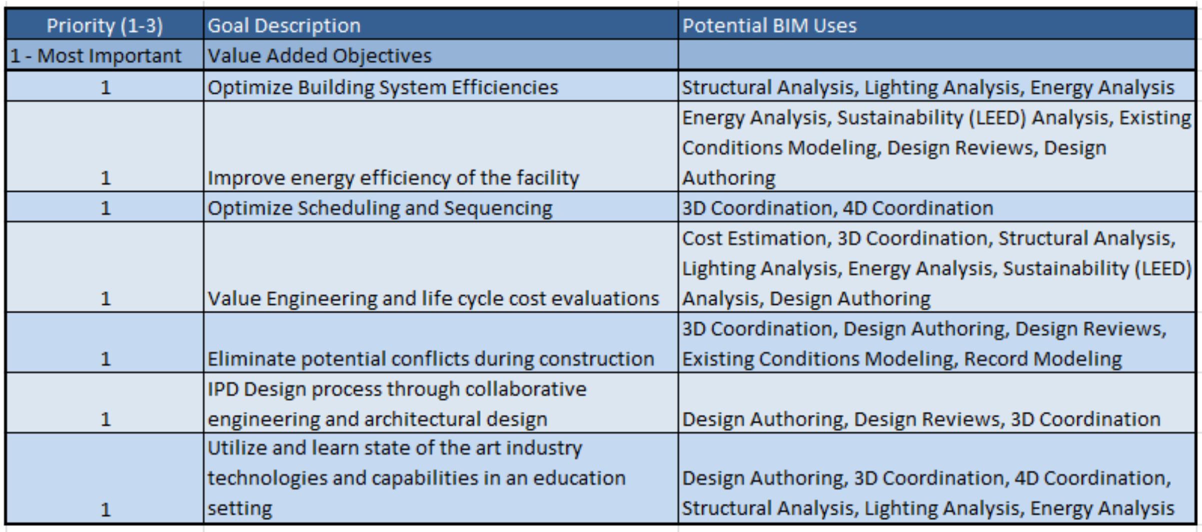
Façade Redesign

- Coordination amongst all of the disciplines throughout project design.
- Along with the main arena roof system design, create an iconic façade design.
- Reduction or maintain the exterior column sizes while accommodating new façade materials with appropriate connections.
- Reduce thermal load to spaces along the east façade.
- Create more efficient air distribution in the lobby and concourse.

- Reduce project cost and energy cost by selecting optimum glazing panels for architectural and energy performance.
- Reduce resources needed for installation by changing the system of the façade from glass curtain wall to brick and glazing.
- Improve schedule for installation of new design.
- Reduce the lighting power density of the spaces below ASHRAE Standard 90.1 Section 9.
- Create an iconic building facade that balances architecture and engineering.
- Ensure systems designed are achieving points necessary on LEED score card for Gold Certification.

APPENDIX C: BIM Execution Planning

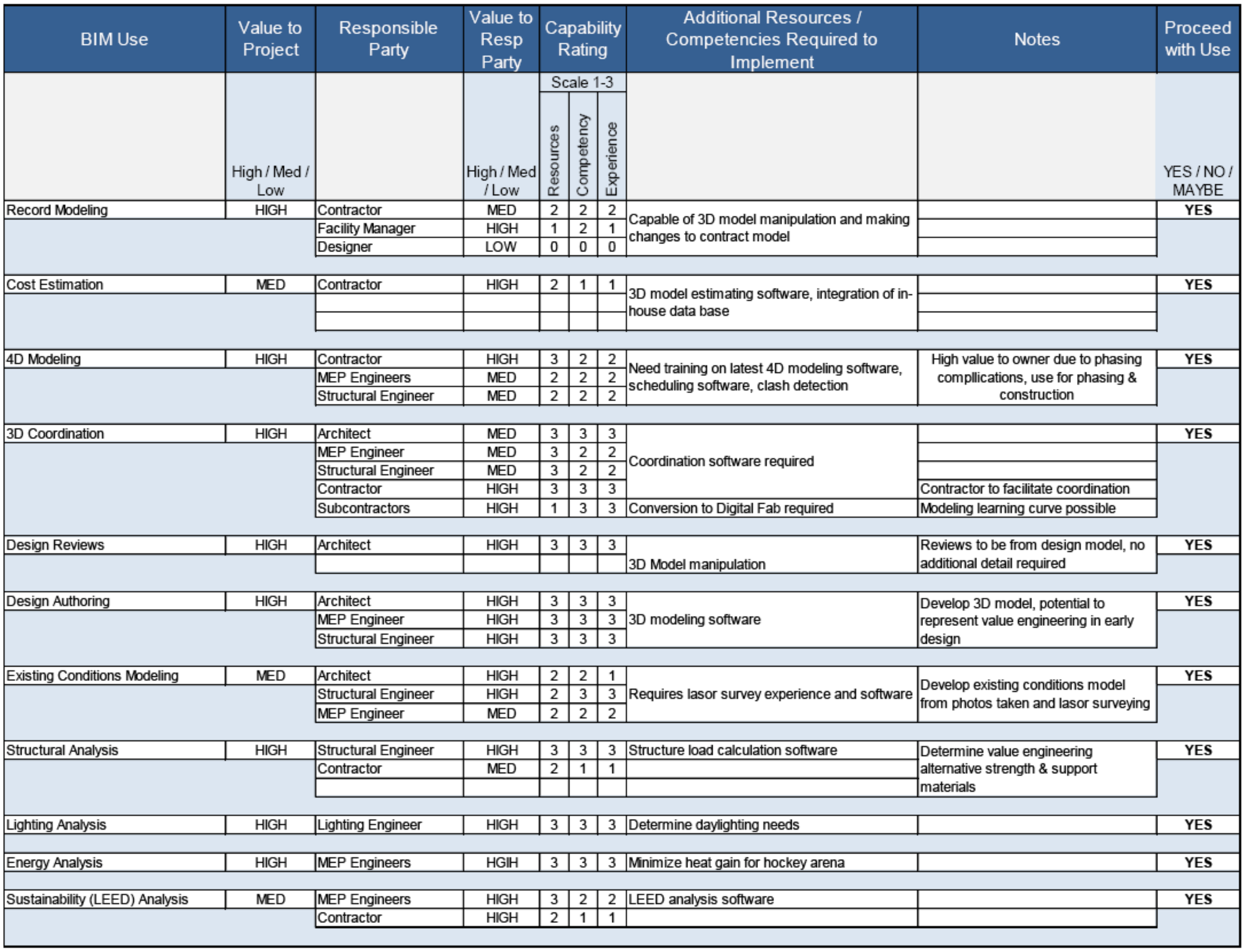
BIM Goals



Priority (1-3)	Goal Description	Potential BIM Uses
1 - Most Important	Value Added Objectives	
1	Optimize Building System Efficiencies	Structural Analysis, Lighting Analysis, Energy Analysis
1	Improve energy efficiency of the facility	Energy Analysis, Sustainability (LEED) Analysis, Existing Conditions Modeling, Design Reviews, Design Authoring
1	Optimize Scheduling and Sequencing	3D Coordination, 4D Coordination
1	Value Engineering and life cycle cost evaluations	Cost Estimation, 3D Coordination, Structural Analysis, Lighting Analysis, Energy Analysis, Sustainability (LEED) Analysis, Design Authoring
1	Eliminate potential conflicts during construction	3D Coordination, Design Authoring, Design Reviews, Existing Conditions Modeling, Record Modeling
1	IPD Design process through collaborative engineering and architectural design	Design Authoring, Design Reviews, 3D Coordination
1	Utilize and learn state of the art industry technologies and capabilities in an education setting	Design Authoring, 3D Coordination, 4D Coordination, Structural Analysis, Lighting Analysis, Energy Analysis

Table 30: BIM Goals

BIM Uses Worksheet



BIM Use	Value to Project	Responsible Party	Value to Resp Party	Capability Rating			Additional Resources / Competencies Required to Implement	Notes	Proceed with Use
				Scale 1-3					
	High / Med / Low		High / Med / Low	Resources	Competency	Experience			YES / NO / MAYBE
Record Modeling	HIGH	Contractor	MED	2	2	2	Capable of 3D model manipulation and making changes to contract model		**YES**
		Facility Manager	HIGH	1	2	1			
		Designer	LOW	0	0	0			
Cost Estimation	MED	Contractor	HIGH	2	1	1	3D model estimating software, integration of in-house data base		**YES**
4D Modeling	HIGH	Contractor	HIGH	3	2	2	Need training on latest 4D modeling software, scheduling software, clash detection	High value to owner due to phasing compllications, use for phasing & construction	**YES**
		MEP Engineers	MED	2	2	2			
		Structural Engineer	MED	2	2	2			
3D Coordination	HIGH	Architect	MED	3	3	3	Coordination software required		**YES**
		MEP Engineer	MED	3	2	2			
		Structural Engineer	MED	3	2	2			
		Contractor	HIGH	3	3	3		Contractor to facilitate coordination	
		Subcontractors	HIGH	1	3	3	Conversion to Digital Fab required	Modeling learning curve possible	
Design Reviews	HIGH	Architect	HIGH	3	3	3	3D Model manipulation	Reviews to be from design model, no additional detail required	**YES**
Design Authoring	HIGH	Architect	HIGH	3	3	3	3D modeling software	Develop 3D model, potential to represent value engineering in early design	**YES**
		MEP Engineer	HIGH	3	3	3			
		Structural Engineer	HIGH	3	3	3			
Existing Conditions Modeling	MED	Architect	HIGH	2	2	1	Requires lasor survey experience and software	Develop existing conditions model from photos taken and lasor surveying	**YES**
		Structural Engineer	HIGH	2	3	3			
		MEP Engineer	MED	2	2	2			
Structural Analysis	HIGH	Structural Engineer	HIGH	3	3	3	Structure load calculation software	Determine value engineering alternative strength & support materials	**YES**
		Contractor	MED	2	1	1			
Lighting Analysis	HIGH	Lighting Engineer	HIGH	3	3	3	Determine daylighting needs		**YES**
Energy Analysis	HIGH	MEP Engineers	HGIH	3	3	3	Minimize heat gain for hockey arena		**YES**
Sustainability (LEED) Analysis	MED	MEP Engineers	HIGH	3	2	2	LEED analysis software		**YES**
		Contractor	HIGH	2	1	1			

Table 31: BIM Uses Worksheet

APPENDIX D: MAE Thesis Requirements

Construction MAE

The construction management MAE requirements were satisfied through knowledge gained in the following courses:

- AE 597G – Building Information Modeling Execution Planning
- AE 598C – Sustainable Construction Project Management.
- AE 570 – Production Management in Construction

As the BIM Execution Plan Manager for HPR Integrated Design, along with my teammates, I was able to create and implement a successful BIM Execution Building Information Modeling (BIM) Execution Plan for this project. The plan described the process for how the flow of the project would progress, the BIM uses for the scope of the project, and the coordination efforts of the team.

Sustainable Construction Project Management skills were used to keep Green in mind and strive for LEED Gold Certification. While there was not enough time in the semester for the team members to focus on every category of the LEED scorecard, efforts were made in each design aspect to maintain or exceed the current design's score. It was important for the team to incorporate Value Engineering in every decision that was made in order to deliver the highest quality product for the budget allotted. Individual members of the team brainstormed on the first design package in trying to find a way to reduce wasted space in the plenum of the event level by raising portions of the event level. After much deliberation, I was able to formulate a way to reduce the excavation by suggesting the entire event level be raised while keeping the main concourse locked in place. While maintaining the architect's intent, we were able to reduce the excavation cost and reallocate those savings into our roof design package. By reducing the excavated material, my team was able to reduce excess hauling away of the material, reducing vehicle exhaust into the atmosphere.

Skills developed in the Production Management course were used to successfully create a short interval project schedule for the erection of steel, erection of the truss system, and installation of precast stadia. The new truss system increased in weight by 34.5%, requiring an additional 18 workdays passed the truss completion date. By reconsolidating the schedule and creating a new erection sequence, I was able to complete the truss erection 26 workdays sooner than that of the baseline schedule.

Mechanical MAE

The mechanical MAE requirements were satisfied by the completion of a CFD analysis on the Men's Locker Room. The goal of the study was to determine more accurately the required amount of ventilation the locker room would need. To perform this analysis the mechanical design drew on knowledge gain in his Indoor Air Quality class, AE 552, and his CFD modeling class, AE 559. Fundamental skills gained in AE 552 where used to calculate a ventilation rate that would allow for 80% of the room occupants to be satisfied with the rooms odor levels. This value turned out to be roughly 2.5 CFM/sf, five times greater than that required by code.

Because of this a CFD model was created an analysis run to determine what exactly the implications were to the two different ventilations rates. The room diffuser layout was designed, the diffusers selected (Titus). The model ran for 5000 iterations, used a K-E turbulence model and a hybrid differencing scheme. The results can be seen in both Appendix F and in the Savings Package under "Mechanical Design."

Structural MAE

The structural MAE requirements for the BIM Thesis were satisfied through using knowledge obtained from AE 542 – Building Enclosure Design & Science and AE 597A – Computer Modeling of Structures throughout the yearlong capstone thesis project. The use of knowledge gained from AE 597A was used heavily throughout the computer modeling process to obtain more accurate results and a deeper understanding of the numbers the computer analytical software was spitting out. The class allowed for more accurate design of members, obtaining critical loading information for long span truss design and design checks.

Coursework from AE 542 – Building Enclosure Science & Design was also very helpful throughout the thesis. HPR was able to perform H.A.M. Toolbox façade assembly condensation analysis and R-value checks for more accurate energy performance analysis. The structural design also was able to design & analyze the curtain wall system for strength considerations and resistance to wind borne debris. Finally, AE 537 – Building Failures was another class that was used in the thesis for input on best design practices against failures mostly in the façade redesign process.

APPENDIX E: Engineering Calculations

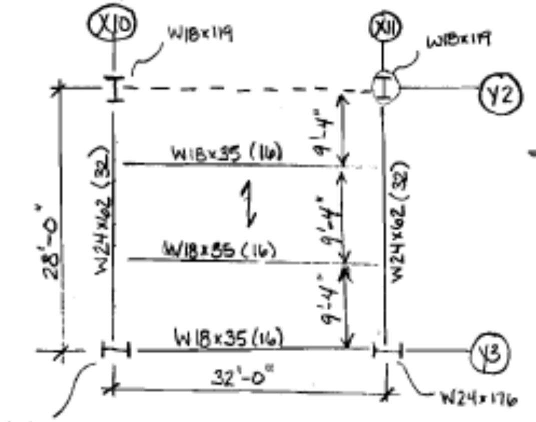
Structural Hand Calculations

Savings Package Hand Calculations

Alternative Flooring Study – NWC vs. LWC

VERIFICATION OF EXISTING COMPOSITE FLOOR SYSTEM

MAIN CONCOURSE LEVEL



ACTUAL DESIGN

ASSUMPTIONS:

- COMPOSITE DECK, 2 HR RATING (UNPROTECTED DECK)
- NORMAL WEIGHT CONCRETE
- UNSHORED CONSTRUCTION

⇒ FOR 2 HR. FIRE RATING WITH UNPROTECTED DECKS YOU CAN USE THE FOLLOWING:

→ 3¼" LW CONC. U.L. DES. D733# D826# D840# D902# D907# D913# D916# D918# D919#

⇒ 1.5VL, 1.5VLI, 2VLI, 3VLI

→ 4½" NWC UL DES. D902# D916# D918# D919#

⇒ 1.5VL, 1.5VLI, 2VLI, 3VLI

$\boxed{\text{* CM TO PERFORM COST ANALYSIS ON NWC VS LWC}}$

* NOTE: LIGHTWEIGHT CONCRETE WAS NOT USED ON ACTUAL PROJECT DUE TO AVAILIBILITY AND CRACKING PROBLEMS ASSOCIATED WITH CONC.

CHECK NWC DECK SYSTEMS: t = 4.5" TOPPING

- SPACING = 9'-4"
- 3+ SPAN → UNSHORED CONSTRUCTION

→ BASED ON SDI MAX UNSHORED REQUIREMENTS ONLY: (t = 4.50")

→ COULD NOT USE 1.5VL OR 1.5VLI DECK (1.5VLI 16 → 9'-1" MAX SDI SPAN)

→ COULD USE 2VLI 19 (SDI MAX SPAN = 10'-0" > 9'-4") ⇒ WILL NOT USE (SEE BELOW)

* NOTE: ACTUAL PROJECT DID NOT USE 2VLI DECK BECAUSE THERE ARE CLEAR SPANS OF 12'-6" IN OTHER BAYS AND SO THEY USED UNIFORM DECK.

→ COULD NOT USE 2VLI DECK (2VLI 16 → 11'-0" < 12'-0" MAX SDI SPAN)

→ $\boxed{\text{COULD USE 3VLI 18}}$ (SDI MAX SPAN = 13'-3" (3+ SPAN) > 12'-6")

↳ LIGHTEST GAUGE THAT COULD BE USED

* NOTE: 3VLI 18 DECK WAS THE ACTUAL DECK USED ON THE PROJECT ∴ OK ✓

CHECK LWC DECK SYSTEMS: (t = 3.25)

- MAX SPACING : 12'-6" (9'-4" IN OUR BAY)
- 3+ SPAN UNSHORED CONSTRUCTION

→ BASED ON SDI MAX UNSHORED REQUIREMENTS ONLY:

→ COULD NOT USE 1.5VL OR 1.5VLI DECK (1.5VLI 16 → 11'-0" < 12'-6") * COULD WORK FOR THIS BAY

→ COULD USE 2VLI DECK (2VLI 18 → 13'-3" > 12'-6")

↳ USE $\boxed{\text{2VLI 18 DECK}}$

CHECK BOTH DECKS FOR STRENGTH REQUIREMENTS:

LOADS: SUPERIMPOSED LIVE LOAD = UNFACTORED LL + SI DL

LIVE LOAD = 100 PSF (S0-1)
SI DL = 15 PSF (S0-1)
SI LL = 115 PSF

⇒ 3VLI 18 DECK w/ 4.5" NWC TOPPING ⇒ 12'-6" MAX SPACING: 168 PSF > 115 PSF ∴ OK✓

⇒ 2VLI 18 DECK w/ 3¼" LWC TOPPING ⇒ 12'-6" MAX SPACING: 121 PSF > 115 PSF ∴ OK✓

SUMMARY FOR CM COST ANALYSIS:

NWC: USE 3VLI18 DECK w/ 4½" NWC TOPPING (t=7.50")

THEORETICAL CONC. VOLUME: 1.85 $YD^3/100\ FT^2$ ($A = 32' \times 28' = 896\ FT^2$) ⇒ 16.576 YD^3
0.500 FT^3/FT^2 ⇒ 448 ft^3

RECOMMENDED REINF.: 6×6 = W2.1 × W2.1

LWC: USE 2VLI18 DECK w/ 3¼" LWC TOPPING (t = 5.25")

THEORETICAL CONC. VOLUME: 1.31 $YD^3/100\ FT^3$ ⇒ 11.71 YD^3
0.354 FT^3/FT^2 ⇒ 317.18 ft^3

RECOMMENDED REINF.: 6×6 = W1.4 × W1.4

NOTE LOADS OF TWO SYSTEMS:
3VLI18 w/ 4.5" NWC CONC. (t=7.50") ⇒ 75 PSF
2VLI18 w/ 3.25" LWC CONC. (t=5.25") ⇒ 42 PSF

VERIFY INTERIOR BEAMS USING NWC:

LOADS:

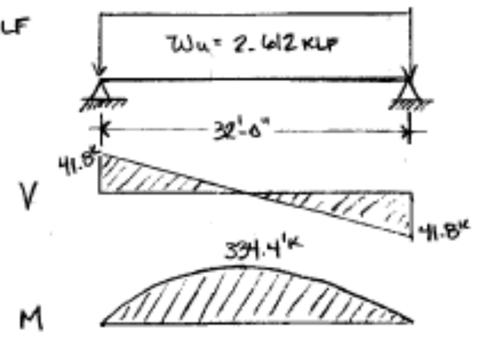
DEAD:
DECK + CONC. = 75 PSF (VULCRAFT MANUAL)
SI DEAD LOAD = 15 PSF
SW (FRAMING) = 10 PSF
100 PSF

LIVE:
LIVE LOAD = 100 PSF (NOT REDUCED EVEN THOUGH $K_{LL}A_T = 597.12\ ft^2 > 400\ ft^2$)
ACTUAL PROJECT

$$w_u = 1.2(100 \times 9.33) + 1.6(100 \times 9.33) = 2.612\ KLF$$

$$M_u = \frac{2.612(32')^2}{8} = 334.34'^K$$

(ASSUME SIMPLY SUPPORTED BEAM)



* ASSUME a = 1.00"

$$Y_2 = 7.5" - \frac{1.00"}{2} = 7.0"$$

⇒ W18x35 $\phi M_n = 382'^K$ ($Y_1 = 7$, $Y_2 = 7$)
$\Sigma Q_n = 129^K$

SHEAR STUD STRENGTH: * USE 3/4" ϕ SHEAR STUD

$$Q_n = \min \left| \begin{array}{l} 0.5 A_{sc} \sqrt{f'_c E_c} = 0.5\left(\pi \left(\frac{0.75}{2}\right)^2\right) \sqrt{4\ 145^{1.5} \sqrt{4}} = 26.1^K \\ R_g R_p A_{sc} F_u = 1.0(0.6)\left(\pi \left(\frac{0.75}{2}\right)^2\right)(65) = 17.2^K \end{array} \right.$$

$\leftarrow$ DECK PERPENDICULAR (CONTROLS)

\# OF SHEAR STUDS: $\frac{\Sigma Q_n}{Q_n} = \frac{129^K}{17.2^K} \times 2 =$ 16 SHEAR STUDS

$$b_{eff} = \min \left| \begin{array}{l} \frac{32' \times 12}{8} = 48'' \times 2 = 96'' \\ \frac{1}{2}(9.33 \times 12) = 56'' \times 2 = 112'' \end{array} \right.$$

$\leftarrow$ CONTROLS

$a = \frac{129}{0.85(4)(96)} = 0.395'' < 1.0'' \therefore a = 1''$ CONSERVATIVE ASSUMPTION

CHECK UNSHORED STRENGTH:

FOR W18x35: $w_u = 1.2(75 \times 9.33) + 1.2(35) + 1.6(20)(9.33) = 1.180$ KLF

$\phi_b M_p = 249'^K$

$M_u = 151.04'^K < \phi_b M_p \therefore$ OK FOR NO SHORING ✓

CHECK WET CONC. DEFLECTION:

$w_{wc} = 75(9.33) + 35 = 0.735$ KLF

$\Delta_{wc} = \frac{5(0.735)(32^4)(1728)}{384(29000)(510)} = 1.172''$

$\Delta_{wc,max} = 32(12)/240 = 1.60''$

$\Delta_{wc} < \Delta_{wc,max} \therefore$ OK ✓

CHECK LL DEFLECTION:

$w_{LL} = 100(9.33) = 0.933$ KLF

$I_{LB} = 1030\ \text{IN}^4$ (TABLE 3-20)

$\Delta_{LL} = \frac{5(0.933)(32^4)(1728)}{384(29000)(1030)} = 0.737''$

$\Delta_{LL,max} = 32(12)/360 = 1.07''$

$\Delta_{LL} < \Delta_{LL,max} \therefore$ OK ✓

EVALUATION OF ECONOMY. $35^{LB}/FT \times 32' + 16 \times 10 =$ 1280 LBS OF STEEL

$\Rightarrow \boxed{\text{W18x35 w/ 16 SHEAR STUDS CONFIRMED!}}$

REDESIGN COMPOSITE BEAMS W/ LWC

LOADS: **DEAD LOADS:** 2VLI18 DECK W/ 3¼" LWC TOPPING ($t = 5.25"$) = 42 PSF
SELF IMPOSED DEAD LOAD = 15 PSF
SW FRAMING = 10 PSF

TOTAL (UNFACTORED DL) = 67 PSF (9'-4") = 626 PLF = 0.626 KLF

LIVE LOADS: LL = 100 PSF (9'-4") = 934 PLF = 0.934 KLF

$w_u = 1.2(0.626) + 1.6(0.934) = 2.246$ KLF

$M_u = \frac{2.246(32^2)}{8} = \underline{287.44}^{'k}$

* ASSUME $a = 1.00$

$Y_2 = 5.25" - \frac{1.00"}{2} = 4.75"$ $(Y_1 = 4.5")$ $(Y_2 = 7)$

$\Rightarrow$ W18x35 $\phi M_n = 358^{'k} > 287.44^{'k}$

$\Sigma Q_n = 129^k$

CHECK SHEAR STRENGTH: * USE ¾" Ø SHEAR STUD

$Q_n = 17.2^k$ (DECK ⊥, 1 WEAK STUD/RIB, LWC - $f'_c = 4$ KSI

\# OF SHEAR STUDS = $\frac{129^k}{17.2^k} \times 2 = \underline{16 \text{ STUDS}}$

CHECK b_{eff} $b_{eff} = 96"$ CONTROLS

CHECK a: $a = 0.395" < 1.0 \therefore a$ = CONSERVATIVE (SAME AS NWC)

CHECK UNSHORED STRENGTH:

$\phi_b M_p = 249^{'k}$ $w_u = 1.2(42 \times 9.33) + 1.2(35) + 1.6(20 \times 9.33) = 0.811$ KLF

$M_u = 103.81^{'k} < 249^{'k} \therefore$ OK✓

CHECK WET CONC. DEFLECTION:

$w_{wt} = 42(9.33) + 35 = 0.427$ KLF $\Delta_{wc} = 0.681" < 1.60" \therefore$ OK✓

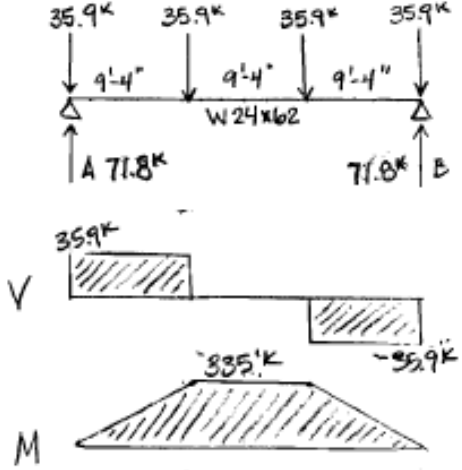
CHECK LL DEFLECTION: $\Delta_{LL} = 0.737" < \Delta_{LL\,max} = 1.07" \therefore$ OK✓

EVALUATION OF ECONOMY: 35 LB/FT × 32' + 10(16) = 1280 LBS OF STL.

LWC ⇒ W18x35 W/ 16 SHEAR STUDS
NWC ⇒ W18x35 W/ 16 SHEAR STUDS

REDESIGN COMPOSITE GIRDER w/ LWC

$\boxed{\$0.59/\text{LB OF STEEL}}$



$\circlearrowleft \Sigma M_A = 0 \quad -35.9(9.33) - 35.9(18.66) - 35.9(28) + 28B = 0$

$B = A = 71.8^K$

$P_D =$

$M_u = 334.9'^K$

* ASSUME $a = 1.00"$

$Y_2 = 4.75" \Rightarrow$ USE $4.5"$ (CONSERVATIVE)

$Y_1 = 7$

$\phi M_p = 810'^K > 335'^K \therefore$ OK✓

$\Sigma Q_n = 228^K$

SHEAR STRENGTH: $Q_n = 21.2^K$ CONTROLS

\# OF SHEAR STUDS: $\frac{228^K}{21.2^K} \times 2 = 22$ SHEAR STUDS

$$b_{eff} = \min \left| \begin{array}{l} \frac{28' \times 12}{8} = 42" \times 2 = 84" \leftarrow \text{CONTROLS} \\ \frac{1}{2}(32' \times 12) = 192" \times 2 = 384" \end{array} \right.$$

$a = \frac{228}{0.85(4)(84)} = 0.798" < 1.00" \therefore a =$ CONSERVATIVE

CHECK UNSHORED STRENGTH:

$P_u = 1.2(6.27) + 1.2(0.87) + 1.6(2.99) = 13.35^K$

$M_u = 13.35(9.33) = 124.56'^K < 574'^K \therefore$ OK✓

CHECK WET CONC. Δ

$P_{wt} = 6.27 + 0.87 = 7.14^K$

$\Delta_{WC} = \frac{7.14(28^3)(144)}{28(29000)(1550)} = 0.0179"$

$\Delta_{WC_{max}} = 1.4" > 0.0179" \therefore$ OK✓

CHECK Δ_{LL}

$P_{LL} = 14.9^K$

$\Delta_{LL} = \frac{14.9(28^3)(144)}{28(29000)(2530)} = 0.023"$

$\Delta_{LL_{max}} = 0.93" >> 0.023" \therefore$ OK✓

EVALUATION OF ECONOMY: $62 \times 28 + 22(10) = 1956$ LBS OF STEEL ($1,155)

LWC ⇒	USE	W24x62 w/ 22 SHEAR STUDS	($1,155)
NWC ⇒	USE	W24x62 w/ 24 SHEAR STUDS	($1,165)

COMPARISON OF ECONOMY FOR TYP. BAY   * ASSUMPTION: $0.59/LB OF STEEL

NWC ⇒ (3) W18x35 w/ 16 SHEAR STUDS = 3840 LBS = $ 2265.60
(2) W24x62 w/ 24 SHEAR STUDS = 3952 LBS = $ 2331.68
4000 PSI NWC ON 3VLI18 DECKING = $5117.07
$9,714.35

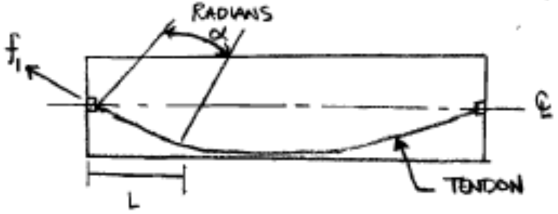
LWC ⇒ (3) W18x35 w/ 16 SHEAR STUDS = 3840 LBS. = $2265.60
(2) W24x62 W/ 22 SHEAR STUDS = 3912 LBS. = $ 2308.08
4000 PSI LWC ON 2VLI18 DECKING = $ 4694.76
$ 9268.44

SUMMARY:
⇒ COST SAVINGS = $445.91 ≈ 4.6%

Curved Tendon Research

NAWY, EDWARD G., "PRESTRESSED CONCRETE: A FUNDAMENTAL APPROACH", 5TH ED., 2010, PRENTICE HALL: UPPER SADDLE RIVER, NJ, P. 85-88.

LOSSES DUE TO FRICTION: CURVATURE EFFECT

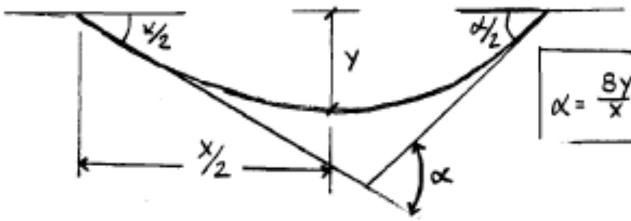


$$\boxed{\Delta f_{pF} = -f_1\left(\overbrace{\mu\alpha}^{\text{CURVATURE}} + \overbrace{KL}^{\text{WOBBLE}}\right)}$$

WHERE f_1 = STRESS OF JACKING FORCE
μ = FRICTION BETWEEN TENDON AND THE DUCT DUE TO CURVATURE
α = CURVATURE (IN RADIANS)
K = COEFFICIENT OF FRICTION BETWEEN TENDON & SURROUNDING CONCRETE
L = LENGTH OF TENDON

*APPLIES TO BOTH SECTION AND PLAN?

*ASSUMPTION: PRESTRESS FORCE BETWEEN THE START OF THE CURVED PORTION AND ITS END IS SMALL (≅15%)



$$\boxed{\alpha = \frac{8y}{x}\ \text{[RADIANS]}}$$

TABLE 3.7: WOBBLE AND CURVATURE FRICTION COEFFICIENTS

TYPE OF TENDON	WOBBLE COEFFICIENT K PER FOOT	CURVATURE COEFFICIENT μ
→ TENDONS IN FLEXIBLE METAL SHEATHING		
- WIRE TENDONS	0.0010 - 0.0015	0.15 - 0.25
- 7 WIRE STRANDS	0.0005 - 0.0020	0.15 - 0.25
- HIGH STRENGTH BARS	0.0001 - 0.0006	0.08 - 0.30
→ TENDONS IN RIGID METAL DUCT		
- 7-WIRE STRANDS	0.0002	0.15 - 0.25
→ MASTIC-COATED TENDONS - WIRE TENDONS AND 7 WIRE STRANDS	0.0010 - 0.0020	0.05 - 0.15
→ PREGREASED TENDONS - WIRE TENDONS AND 7 WIRE STRANDS	0.0003 - 0.0020	0.05 - 0.15

CONTINUOUS CURVED TENDON:

✗ * ASSUME TENDONS ENCASED IN FLEXIBLE METAL SHEATHING

$f_{pe} = f_1 = 159{,}000$ PSI

$S = r\theta \Rightarrow \theta = 91.5°$

$\alpha = 91.5°\left(\frac{\pi \text{ RAD}}{180°}\right) = 1.598$ RAD.

$\Delta f_{pF} = -159000\,(0.25\,(1.598)) = \boxed{-63{,}520 \text{ PSI}}$

$\mu = 0.25$ (7 WIRE STRANDS, WORST CASE)
$K = 0.002$

$\% \text{ LOST} = \frac{-63520}{159000} = \boxed{-40\%} \gg 15\%$

⇒ NOT ACCEPTABLE

✗ * ASSUME MASTIC-COATED TENDONS:

$f_{pe} = f_1 = 159{,}000$ PSI

$\Delta f_{pf} = -159000\,(0.15\,(1.598)) = \boxed{-38112 \text{ PSI}}$

$\alpha = 1.598$ RAD.
$\mu = 0.15$
$K = 0.002$

$\% \text{ LOST} = \frac{-38112}{159000} = -24.0\% > 15\%$

⇒ NOT ACCEPTABLE

SPLIT SLAB - CURVED TENDON:

✗ * ASSUME TENDONS ENCASED IN FLEXIBLE METAL SHEATHING

$f_{pe} = f_1 = 159{,}000$ PSI

$\theta = \frac{91.5°}{2}\left(\frac{\pi \text{ RAD}}{180°}\right) = 0.799$ RAD. $= \alpha$

$\mu = 0.25$
$K = 0.002$

$\Delta f_{pF} = -159000\,(0.25\,(0.799)) = \boxed{-31{,}760 \text{ PSI}}$

$\% \text{ LOST} = -\frac{31760}{159000} = \boxed{-20\%} > 15\%$

⇒ NOT ACCEPTABLE

✓ * ASSUME MASTIC-COATED TENDONS:

$f_{pe} = f_1 = 159{,}000$ PSI

$\Delta f_{pF} = -159000\,(0.15\,(0.799)) = \boxed{-19{,}050 \text{ PSI}}$

$\alpha = 0.799$ RAD.

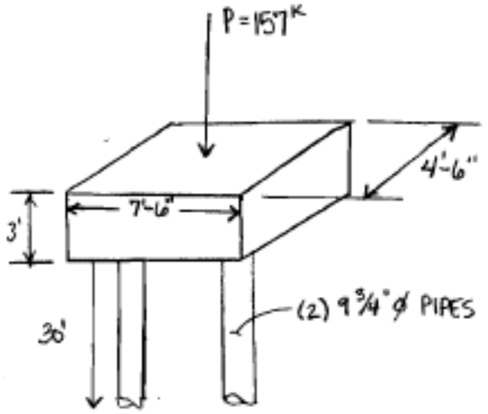
$\% \text{ LOST} = \frac{-19050}{159000} = \boxed{-12\%} < 15\%$

$\mu = 0.15$
$K = 0.002$

$\boxed{\Rightarrow \text{ACCEPTABLE}}$

Sample Calculation: Micropile Capacity Check

CAPACITY CHECK - MICRO PILE FOUNDATIONS



$f'_c = 4000$ PSI

REFERENCE:
DAS, B. "PRINCIPLES OF FOUNDATION ENGINEERING,"
7TH ED., CENGAGE LEARNING: STAMFORD,

STEEL PILES:

$Q_{ALL} = A_s f_s$

$A_s = 5.81 \text{ in}^2$ (10"ø OUTSIDE, t= 0.188 in)
$f_s = 0.33 - 0.5(35) =$
↑ (AISC MANUAL - TABLE 2-3)

TYPE OF PILE: 9

ESTIMATING PILE CAPACITY:

$Q_u = Q_p + Q_s$

$q_u = q_p = c' N_c^* + q N_q^* + \gamma' D N_\gamma^*$

$Q_p = A_p (c' N_c^* + q' N_q^*)$

$A_p = 5.81 \text{ in}^2$ (9¾"ø PIPE)

FROM GEOTECHNICAL REPORT:
→ BORING LOG No. B-22 (CLOSEST TO FOUNDATION)
↳ 2.5' OF FILL
↳ 15' OF BEDROCK → WEATHERED "DOLOMITE" (LIMESTONE)

$q_p = q_u (N_\phi + 1)$ → PILES RESTING ON BEDROCK

$N_\phi = \tan^2(45 + \phi'/2)$
$q_u = 15000$ PSI ← (LIMESTONE - CONSERVATIVE)
$\phi' = 30°$ ←

USE FULL VALUE SINCE $\phi < 1'$

$$Q_{pall} = \frac{[15000\,(3+1)]\,5.81 \text{ in}^2}{3} = 116.2\ ^K/\text{PILE} > 79\ ^K/\text{PILE} \therefore \text{OK}✓$$

$157^K/2 = 78.5^K$

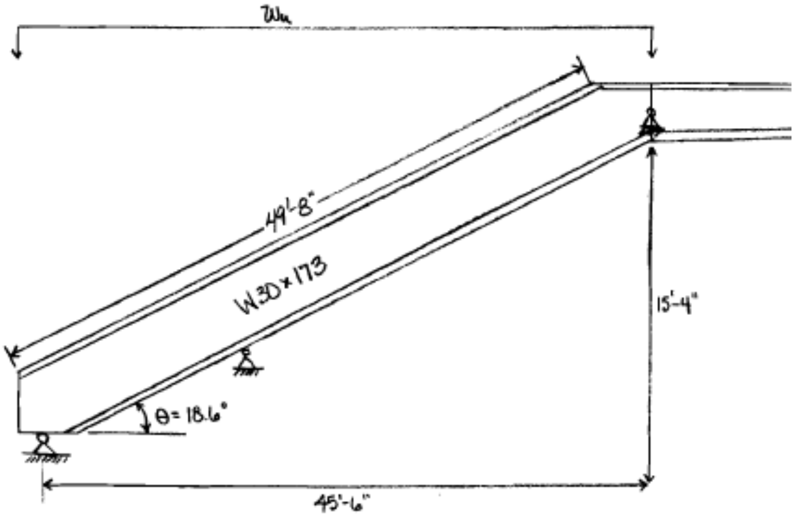
FROM GEOTECH REPORT:

→ CASING IS FILLED WITH NEAT CEMENT GROUT > 5000 PSI

→ MAX CAPACITY = 300^K/PILE
RECOMMENDED:
↳ IF P < 350^K:
→ 5½"ø PILES
- 120^K/PILE MAX. CAPACITY
- 12' MIN. EMBED.
- 20^K/PILE LAT. @ 15° FROM VERT.
↳ IF P > 900^K:
→ 7"→9¾"ø
- 300^K/PILE MAX. CAPACITY
- 20'→28' MIN. EMBED.
- 50^K/PILE LAT @ 15° FROM VERT.

Sample Calculations: Sloped Lower Bowl Steel Design & Analysis

Sloped Rackers Capacity Check – LFRD Analysis



LOADING: DEAD LOAD = 75 PSF (PRECAST STADIA)
5 PSF (SEATING)
173 PLF (BEAM SW)
LIVE LOAD = 100 PSF

SPACING: 32'-0"

LC: $1.2D + 1.6L = 1.2((75+5)(32)+173)+1.6(100(32)) = 8.40$ KLF

$w_u = \left(\frac{49.67}{45.5}\right)(8.40) = 9.17$ KLF

$M_u = 766'^{K}$ (FROM STADD) $< \phi M_n = 2280'^{K} \therefore$ OK✓

$V_u = 154^{K}$ (FROM STAAD) $< \phi V_n = 598^{K} \therefore$ OK✓

ALLOW. $\Delta_{LL} = \ell/240 = 33(12)/240 = 1.65"$

$$\Delta_{LL} = \frac{5(3.49)(33^4)(1728)}{384(29000)(8230)} = 0.39" < \Delta_{LL,ALLOW} \therefore \text{OK}✓$$

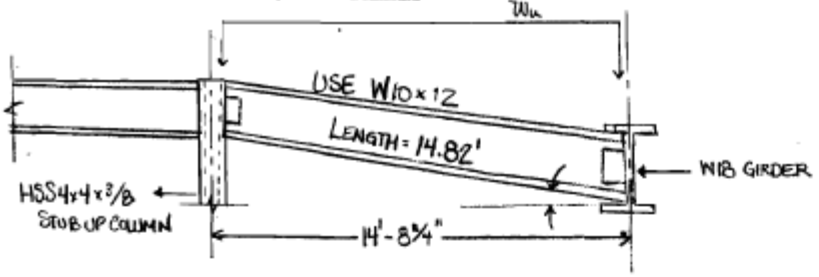
ALLOW. $\Delta_{TL} = \ell/360 = 33(12)/360 = 1.10"$

$$\Delta_{TL} = \frac{5(6.46)(33^4)(1728)}{384(29000)(8230)} = 0.72" < 1.10" = \Delta_{TL,ALLOW} \therefore \text{OK}✓$$

→ W30×173 SLOPED RACKERS WORK!

Sample Calculation: Sloped Vomitory Steel Design – Non-Composite Design – LFRD Design

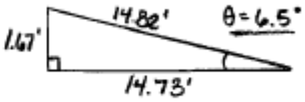
DESIGN SLOPED VOMITORY STEEL BEAM:



LOADS: DEAD LOAD = 90 PSF SPAN = 2'-4"
LIVE LOAD = 100 PSF

LC: $1.2D + 1.6L = 1.2(90) + 1.6(100) = 268$ PSF

→ USE 3VLI18 COMPOSITE DECK
↳ 400 PSF CAPACITY WORKS!



$w_u = 268(2.33) = 625 \text{ PLF} = 0.625 \text{ KLF}$

$w_u = \left(\frac{14.82}{14.73}\right) 625 \text{ PLF} \doteq 628 \text{ PLF} = 0.628 \text{ KLF}$

$$\left.\begin{array}{l} M_u = \dfrac{0.628(14.82^2)}{8} = 17.2'^{k} \\ V_u = \dfrac{0.628(14.82)}{2} = 4.65^{k} \end{array}\right\} \text{MINIMAL}$$

DEFLECTION CRITERION:

$\Delta_L \leq l/240 = 14.82(12)/240 = 0.741"$

$\Delta_T \leq l/360 = 14.82(12)/360 = 0.494"$

$\Delta_L = \dfrac{5(.233)(14.82^4)(1728)}{384(29000)I} = 0.741"$ $I_x \geq 11.8 \text{ in}^4$

$\Delta_T = \dfrac{5(0.210)(14.82^4)(1728)}{384(29000)I} = 0.494"$ $\underline{I_x \geq 15.9 \text{ in}^4}$ → CONTROLS

→ USE W10×12 FOR SLOPED VOMITORY STEEL BEAMS

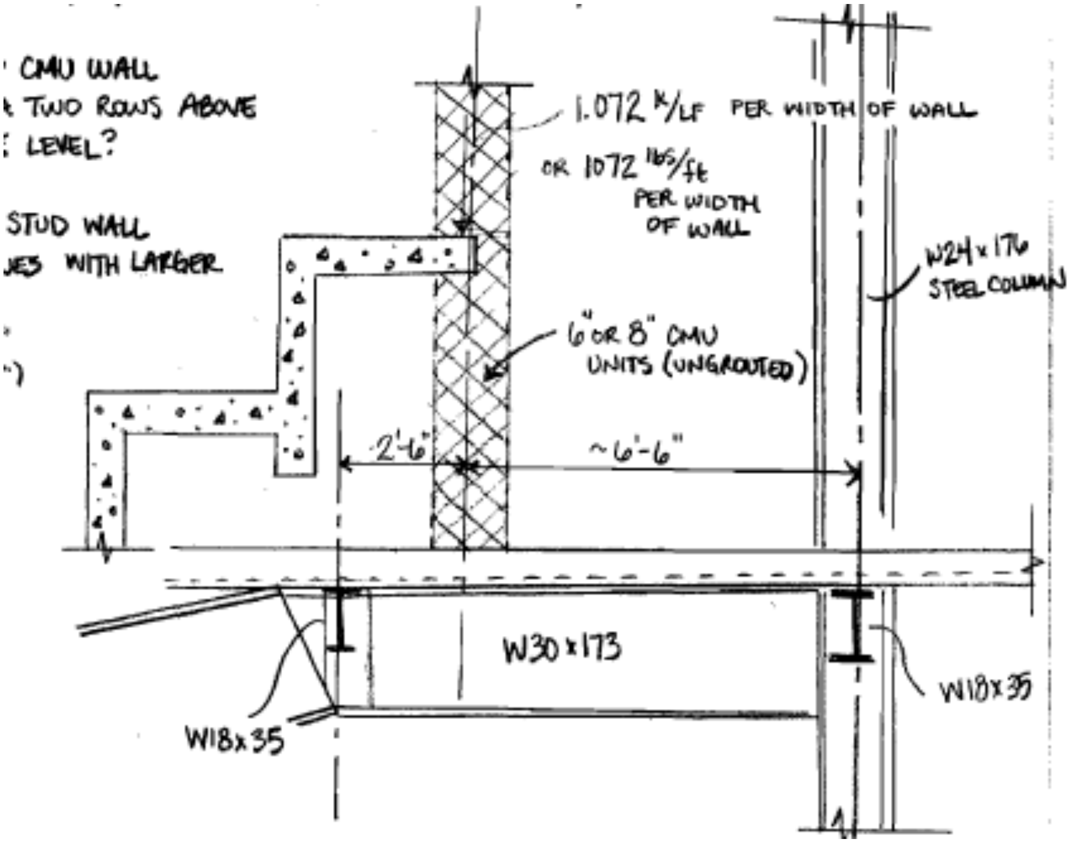
$I_x = 53.8 \text{ in}^4 > 15.9 \text{ in}^4 \therefore$ OK✓

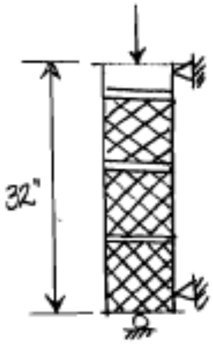
$\phi M_n = 46.9'^{k} > 17.2'^{k} \therefore$ OK✓

$\phi V_n = 56.3^{k} >> 4.7^{k} \therefore$ OK✓

Masonry Bearing Wall Design – ASD Design

Precast Stadia Bearing on CMU Detail Above Lower Bowl





DEAD LOAD: 90 PSF (4') = 360 lb/ft
LIVE LOAD: 100 PSF (4') : 400 lb/ft

- * ASSUME 4" URM BLOCKS, $f'_m = 1800$ PSI (S0.1)
- * NEGLECT LATERAL LOADS → NO FLEXURE
- * ASSUME TYPE S PCL MORTAR
- * ASSUME UNGROUTED 8" CMU HOLLOW UNITS, FACE SHELL EMBEDDED

LOAD COMBINATIONS: D
(ASD) D+L → CONTROLS

$$D+L = 360 + \left(46\left(\frac{2.67'}{2}\right)\right) + 400 = 822 \text{ lb/ft}$$

<u>CHECK UNITY EQUATION:</u> $\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1$

$$f_a = \frac{822 \text{ lb}}{30 \text{ in}^2} = 27.4 \text{ psi}$$

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{334}{30}} = 3.34 \rightarrow \frac{h}{r} = \frac{2.67 \times 12}{3.34} = 9.6 < 99$$

$$F_a = 0.25(1800)\left[1 - \left(\frac{9.6}{140}\right)^2\right] = 448$$

$$f_a/F_a \leq 1 \Rightarrow \frac{27.4}{448} = \underline{0.061 \ll 1 \therefore \text{OK}✓}$$

<u>CHECK TENSILE STRESS:</u>

$$f_t = f_b - f_a = 0 - 27.4 = \underline{-27.4 \text{ psi} \therefore \text{NO TENSILE STRESS} \rightarrow \text{OK}✓}$$

→ <u>TYPE S PCL ⇒ $F_t = 25$ PSI</u>

<u>CHECK STABILITY EQUATION:</u>

$$P \leq P_e/4 \qquad P_e = \frac{\pi^2(900 \times 1800)(334)}{(2.67)^2}\left(1 - \cancelto{0}{0.577\left(\frac{e}{r}\right)^3}\right)$$

$$\underline{P_e/4 = 187{,}274{,}529 \text{ lb.} >>>> 822 \text{ lb.} \therefore \text{OK}✓}$$

<u>CHECK SHEAR:</u>

<u>V = 0 (PURE AXIAL) ∴ OK✓</u>

Figure 119: Sample Calculation: Masonry Bearing Wall ASD Design

Prominence Package Hand Calculations

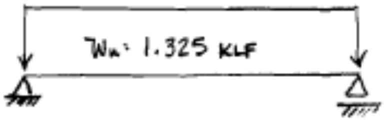
Sample Calculations – Supplementary Framing Purlin Design

DESIGN OF A ROOF PURLIN

LOADS: DEAD: 3N18 ACOUSTICAL ROOF DECK = 4 PSF
AIR BARRIER & VAPOR BARRIER = 0 PSF
3/4" PLYWOOD UNDERLAYMENT = 3 PSF
6" RIGID INSULATION = 1.5 × 6 = 9 PSF
3/4" PLYWOOD SHEATHING = 3 PSF
TPO MEMBRANE = 0 PSF
SUPER IMPOSED DL = 15 PSF
34 PSF + 10 PSF
↳ BM. SW.

SNOW: 36 PSF

SPAN = 37'-2"



DL = 44 PSF × 12' = 528 PLF
S = 36 PSF × 12' = 432 PLF

LC: $1.2D + 1.6L + 0.5S \Rightarrow w_u = 1.2(528) + 0.5(432) = 850$ PLF
$1.2D + 1.6S + 1.0L \Rightarrow w_u = 1.2(528) + 1.6(432) = 1325$ PLF → CONTROLS

$M_u = \frac{wL^2}{8} = 229'^k$ $\phi M_{px} = 261'^k$ (W14×43) $\phi V_{nx} = 125^k$
$V_u = \frac{wL}{2} = 24.6^k$ $\phi M_{px} = 294'^k$ (W14×48) $\phi V_{nx} = 141^k$

CHECK DEFLECTION:

$\Delta_L \leq L/240$ $37.167'(12)/180 = \frac{5(1.325)(37.167)^4(1728)}{384(29000)\,I_x} =$ $I_x \geq 792$ in^4

$\Delta_T \leq L/180$ (PONDING)   → Try W14×82 ($I_x = 881$ in$^4 > 792$ in^4)
↳ $\phi M_{px} = 521'^k > 229'^k$ ∴ OK✓
$\phi V_{nx} = 219^k > 24.6^k$ ∴ OK✓

→ SAP ANALYSIS: W14×99

→ SPAN: 41'-0" $\frac{41(12)}{180} = \frac{5(1.325)(41^4)(1728)}{384(29000)\,I_x}$ $I_x \geq 1063$ in^4

→ USE W14×99 ($I_x = 1110$ in$^4 > 1063$ in^4)
↳ $\phi M_{px} = 646'^k > 278'^k$ ∴ OK✓
$\phi V_{nx} = 206^k > 27.2^k$ ∴ OK✓

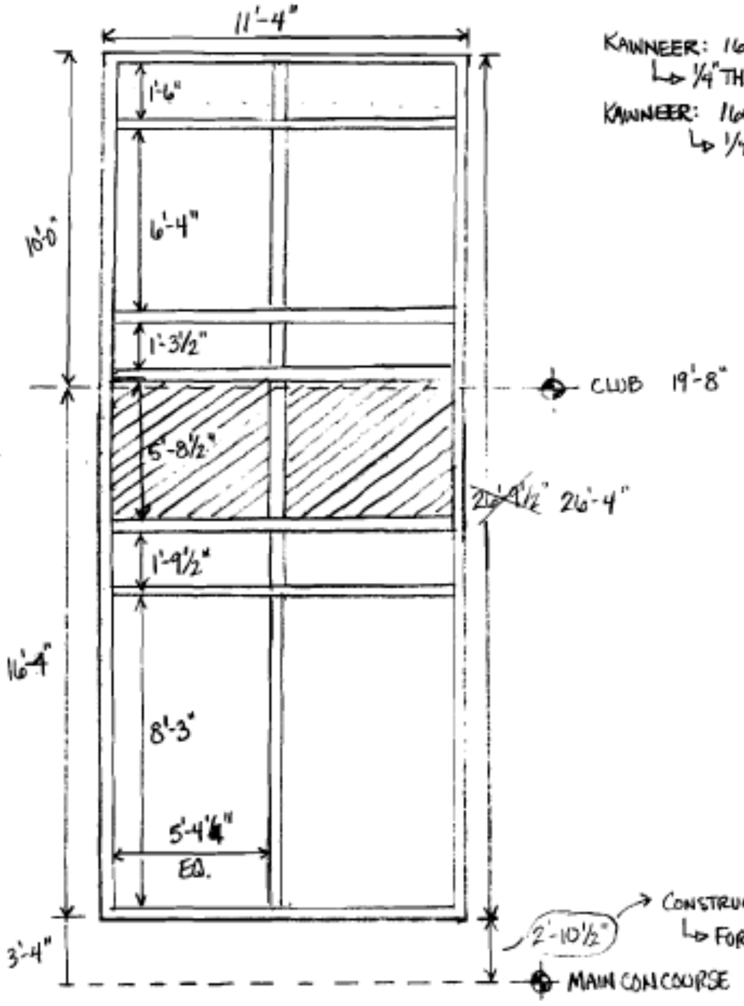
Function Package Hand Calculations

Curtain Wall Glazing Design – Strength and Wind Borne Debris

Glazing & Structural Mullion Design per ASTM E1300 and ASTM E2025

DESIGN OF TYPICAL CURTAIN WALL SYSTEM → EAST FACADE

KAWNEER: 1600 WALL SYSTEM
↳ 1/4" THICK LAMINATED GLASS (2) w/ 1/2" AIR
KAWNEER: 1600UT SYSTEM™ 2
↳ 1/4" DOUBLE GLAZED IGU'S
↳ 1/2" AIRSPACE



→ CONSTRUCTABILITY
↳ FOR CMU MAKE CURTAIN WALL 40" (3'-4") OFF LEVEL
(45½")

CHECK WORST CASE WINDOW PANE: 8'-3" × 5'-4"
(99") (64")
↳ CHECK FOR WIND CRITERIA & AIR BORNE DEBRIS

$V = 90$ mph
BUILDING CATEGORY III
$I = 1.15$
$K_{zt} \cdot K_d = K_t = 1.0$
$G = 0.85$
$GC_{pi} = \pm 0.18$
$C_p = 0.80$

$q_h = 0.00256(1)(1)(1)(90^2)(1.15) = 23.8$ PSF

$p = 23.8(0.85(0.80) + 0.18)) = \underline{20.5 \text{ PSF}}$ → CONTROLS
$-0.18 = 11.9$ PSF

$\rightarrow 20.5 \text{ PSF} \left(\frac{1 \text{ KPa}}{20.9 \text{ PSF}}\right) = \underline{\underline{0.98 \text{ KPa}}}$

DESIGN GLAZING: PANEL WIDTH = 64"
PANEL HEIGHT = 99"

FOR 1/4" LAMINATED GLAZING: * USING ASTM E1300

GLASS TYPE FACTOR (GTF) = 0.9 (ANNEALED LAMINATED)
NON FACTORED LOADS (NFL) = 1.10 (64"x99" 1/4" THK, LAMINATED GLASS)
* ASSUME IGNORE LOAD SHARING FACTOR (LS)

LOAD RESISTANCE (LR) = NFL × GTF × $\cancel{LS}^{0}$

LR = 1.1 × 0.9 = 0.99 kPa > 0.98 kPa ∴ 1/4" LAMINATED ANNEALED GLASS WORKS FOR BOTH KAWNEER SYSTEMS!
↳ FOR WIND CRITERIA.

* KEY ASSUMPTIONS FOR CALCULATIONS:
① PVB LAMINATE IS USED BETWEEN LITES
② FOUR SIDES SIMPLY SUPPORTED
③ P_b (FAILURE RATE) = 8/1000 = 0.008
④ 3-SECOND DURATION LOADING

CHECK 1/4" LAMINATED GLAZING FOR IMPACT CRITERIA:
↳ "SACRIFICAL PLY DESIGN" → DESIGN/CHECK OUTER LITE TO BE ABLE TO WITHSTAND A 2g STEEL BALL (SMALL MISSILE) IMPACT AT 39.6 m/s OR 130 ft/s
~100mph
↳ P_b = 0.008 OF INNER PLY BREAKAGE

→ ACCORDING TO CHART IN ASTM E 2025
↳ 1/4" THICK. LITES OF ANNEALED LAMINATED GLASS WILL WITHSTAND SMALL MISSILE IMPACT CRITERIA.

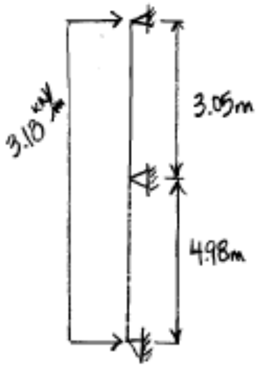
* OK FOR P_b = 0.008 AND P_b = 0.001

DESIGN STRUCTURAL MULLIONS: * ASSUME T5 ALUMINUM MULLIONS
↳ 2.5" WIDE × 6" DEEP

WIND DESIGN PRESSURE = 0.98 kPa

MULLION LENGTH = 26'-4"
TRIBUTARY WIDTH OF PANEL = 5'-4" (64") = 1.6256 m
UNIFORM LOAD ON MULLION = 0.98 kPa (1.6256 m) = 1.59 kN/m × 2 = 3.18 kN/m

→ FRAME SHOULD BE TWICE AS STRONG AS GLAZING



+Mmax = 0.0703 (3.18)(4.98²) = 5.54 kN/m (NEAR MIDSPAN OF LARGEST SPAN)

−Mmax = −0.125 (3.18)(4.98²) = −9.86 kN/m (AT MIDDLE SUPPORT)
↳ CONTROLS!

Qmax = 0.625 (3.18)(4.98) = 9.90 kN

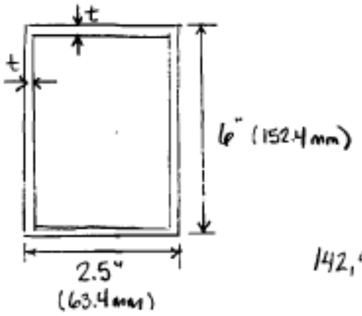
$f_{max} = 0.521(3.18)(4.98)^4/100EI = \frac{10.19\ kN \cdot m^3}{EI\ kN \cdot m^3}$

FOR T5 ALUMINUM: $\sigma_a = 62{,}000\ ^{kN}/_{m^3}$ (AXIAL)
$\sigma_b = 69.000\ ^{kN}/_{m^3}$ (BENDING)
$\sigma_v = 37{,}000\ ^{kN}/_{m^3}$ (SHEAR)
$\sigma_b \cdot 117{,}000\ ^{kN}/_{m^3}$ (BEARING)

ALLOWABLE DEFLECTION FOR A MULLION OR TRANSOM:

↳ $f_{allow} = {}^{L}/_{180}$ OR 20 mm (LEAST VALUE)

* ASSUME UNIFORM WALL THICKNESS ON ALL CROSS SECTION SIDES



BENDING $\sigma_{bending} = \frac{M}{S} = \frac{Mc}{I}$

$$69\ ^{N}/_{mm^2} = \frac{M}{S_{req}} = \frac{9.86 \times 10^6\ N \cdot mm}{S_{req.}}$$

$$\underline{S_{req.} \geq 142{,}900\ mm^3}$$

$$142{,}900 \leq \frac{\frac{1}{12}(152.4)(63.4)^3 - \frac{1}{12}(152.4-2t)(63.4-2t)^3}{76.2}$$

76.2 ← 152.4 (6")/2

$$9.18E7 \geq (152.4-2t)(63.4-2t)^3$$

→ TRY 5mm

$(152.4-10)(63.4-10)^3 = 2.17E^7 \leq 9.18E7$ ∴ WORKS ✓

→ <u>USE 5mm THK. STRUCT MULLIONS</u>

CHECK SHEAR:

$\tau_{max} = \frac{3}{2}\frac{V}{A} \rightarrow 37\ ^{N}/_{mm^2} = 1.5\left(\frac{9900}{A}\right)$ $A_{reqd} = 401.35\ mm^2$

$A = (152.4)(63.4) - (142.4)(53.4) = 2058\ mm^2 \geq 401\ mm^2$ ∴ OK FOR SHEAR!

CHECK DEFLECTION:

$f_{allow} = \frac{4980}{180} = 27.67\ mm$ → USE 20mm (MIN.)

$$f_{max} = \frac{10.19 \times 10^{12}\ (N \cdot mm^3)}{70{,}000\ ^{N}/_{m^2}\left[\frac{1}{12}(63.4)(152.4)^3 - \frac{1}{12}(53.4)(142.4)^3\right]} = 24.88\ mm > 20mm\ \therefore NG\ X$$

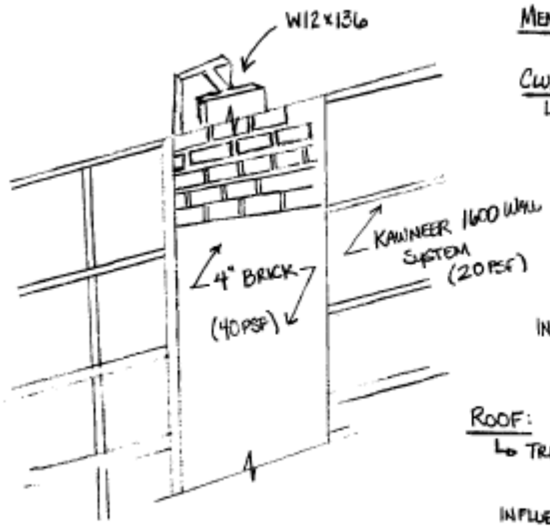
→ TRY 7mm STRUCT. MULLION THICKNESS

$$f_{max} = \frac{10.19 \times 10^{12}}{70{,}000\left[\frac{1}{12}(63.4)(152.4)^3 - \frac{1}{12}(39.4)(138.4)^3\right]} = 14.56mm < 20mm\ \therefore WORKS!$$

→ 7mm MULLION PASSES SHEAR & BENDING BY INSPECTION!
* DID NOT CHECK BEARING CRITERIA → OUT OF SCOPE!

Sample Calculation: Exterior Column X15-Y7 Capacity Check

VERIFY EXTERIOR EAST FACADE COLUMN X15-Y7



MEMBER SIZE: W12×136

CLUB LEVEL & MAIN CONCOURSE:
↳ TRIB. AREA = 14'-5" × 32'-8"
= 470.94 ft²

LOADS:
DL = 75 PSF (SLAB + DECK)
= 15 PSF (SI)
LL = 100 PSF (CORRIDOR)

INFLUENCE AREA:
$A_T = 4 \times 470.94 = 1884 \text{ ft}^2$

ROOF:
↳ TRIB AREA = 29'-2" × 32'-8"
= 952.8 ft²
INFLUENCE AREA = 4 × 952.8 ft²
DL = 35 PSF (ROOF DECK + ASSEMBLY)
SI = 15 PSF
SNOW = 36 PSF (FLAT ROOF SNOW)

FACADE LOADS:
4" BRICK = 40 PSF
3" RIGID INSUL. = 5 PSF
½" SHEATHING = 3 PSF
6" METAL STUD = 4 PSF
(2) ½" GYP. BOARDS = 4 PSF ⇒ 56 PSF

CURTAIN WALL = 20 PSF
METAL PANELS = 4 PSF

COLUMN LOADS:

ROOF:
$P_D = 953(50)/1000 = 47.65^K$
$P_S = 953(36)/1000 = 33.36^K$

CLUB:
$P_D = 471(90)/1000 = 42.39^K$
$P_L = 471(100)/1000 = 47.10^K$

MAIN CON.:
$P_D = 42.39^K$
$P_L = 47.10^K$

$P_{D_T} = 192.3^K$
$P_{L_T} = 94.2^K$
$P_{S_T} = 33.4^K$

FACADE:
CURTAIN WALL = (30.25 × 26.33')(20 PSF) = 15.93^K
BRICK PIERS = (4.33' × 38.83')(56 PSF) = 9.42^K × 4 = 37.66^K
METAL PANELS = (32.667' × 7.75')(4 PSF) = 1.01^K ↳ 4 SIDES

SELF WEIGHT:
136 PLF × 39' = 5.304^K

LC: $1.2D + 1.6L + 0.5S = 398.2^K \rightarrow$ CONTROLS (P_u)
$1.2D + 1.6S + 1.0L = 378.4^K$

$\phi P_n = 1180^K >> 378.4^K \therefore$ OK ✓
↳ KL = 20'-0"

* DID NOT INCLUDE WIND, PLUS AXIAL!

Sample Calculations – Main & Student Entrance Steel Design

MAIN ENTRANCE:

DESIGN ROOF BEAMS: (WORST CASE)

SPAN: 28'-4"
SPACING: 5'-9"

LOADS: DEAD → 34 PSF (3N ROOF ASSEMBLY)
5 PSF (SELF WEIGHT)
15 PSF (JI DL)
SNOW → 36 PSF

LC: 1.2D + 1.6S
↳ $1.2(54) + 1.6(36) = 122.4$ PSF × 5.75' = 0.704 KLF

$M_u = 70.6'^{k}$
$V_u = 10^{k}$

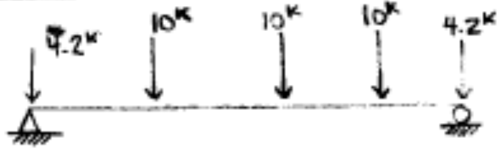
$\Delta_{TL} \leq \ell/360 = 0.944''$

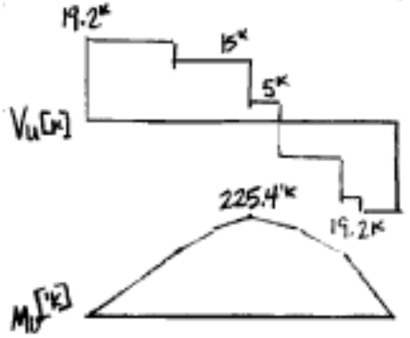
$$\Delta = \frac{5(0.704)(28.33^4)(1728)}{384(29000)I_x} \qquad I_x \geq 373 \text{ in}^4$$

→ USE W16×31 $I_x = 375 \text{ in}^4 > 373 \text{ in}^4 \therefore$ OK✓
$\phi M_n = 203'^{k} > 71'^{k} \therefore$ OK✓
$\phi V_n = 131^{k} \gg 10^{k} \therefore$ OK✓

DESIGN ROOF EDGE BEAM:

SPAN: 26'-0"





$M_u = 225.4'^{k}$
$V_u = 19.2^{k}$

$\Delta_{TL} \leq \ell/360 = 0.867''$

$$\Delta = \frac{0.063(10)(26)^3}{29000\, I_x} \qquad I_x \geq 761 \text{ in}^4$$

→ USE W16×57 $I_x = 758 \approx 760 \text{ in}^4 \approx I_{x\,REQD}$
$\phi M_n = 394'^{k} > 225'^{k} \therefore$ OK✓
$\phi V_n = 212^{k} > 19.2^{k} \therefore$ OK✓

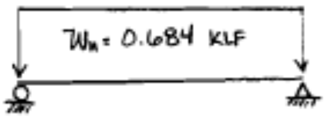
DESIGN OF NEW ENTRANCE – ROOF FRAMING MEMBERS

SPAN: 17'-6"
SPACING: 5'-10½"

LOADS: D = 34 PSF (3N18 ROOF DECK ASSEMBLY)
= 15 PSF (SUPERIMPOSED DL)
S = 36 PSF

LC: $1.2D + 1.6S + 1.0L$

$= 1.2(49) + 1.6(36) = 116.4$ PSF × $5.875' = 0.684$ KLF



$M_u = \frac{w_u \ell^2}{8} = 26.2'^{K}$

$V_u = \frac{w_u \ell}{2} = 6.0^{K}$

$\Delta_{TL} \leq \ell/360 = 17.5{\times}12/360 = 0.583"$ (ALLOWABLE)

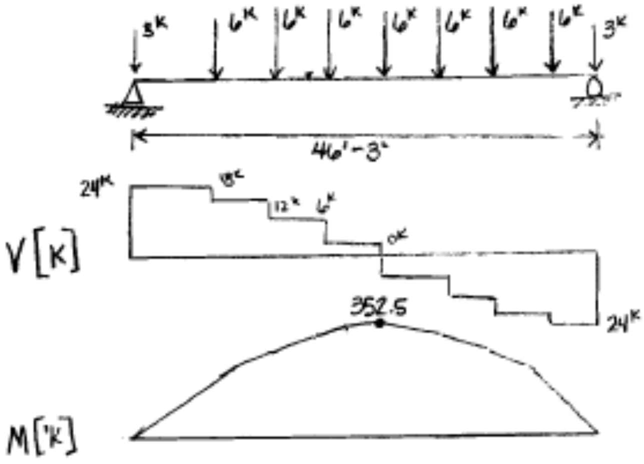
$\Delta = \frac{5(0.684)(17.5)^4(1728)}{384(29000)\,I_x}$ $\quad I_x \geq 85.4\ in^4$

→ USE W8×28 $\quad I_x = 98.0\ in^4 > 85.4\ in^4$

$\phi M_n = 102'^{K} >> 26.2'^{K}$

$\phi V_n = 68.9^{K} >> 6.0^{K}$

DESIGN NEW GIRDER – STUDENT ENTRANCE



$M_u = 352.5'^{K}$

$V_u = 24^{K}$

$\Delta_{TL} \leq \ell/360 = 1.54"$

$\Delta = \frac{5(1.04)(46.25^4)(1728)}{384(29000)\,I_x}$

*ASSUMED Δ WILL BE APPROX. A UNIFORM LOAD DIAGRAM

$I_x \geq 2397\ in^4$

→ USE W24×94

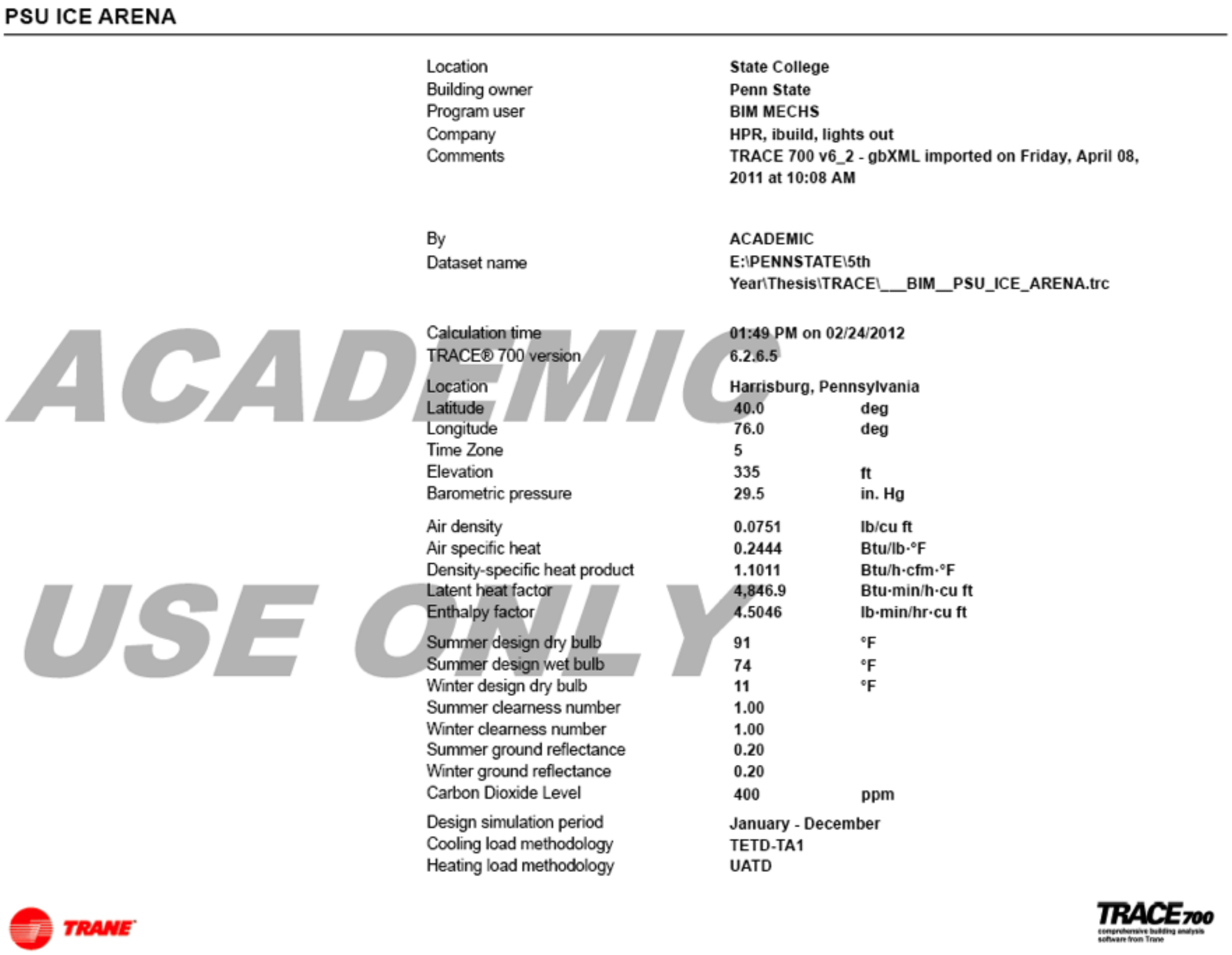
$I_x = 2700\ in^4 \geq 2397\ in^4$ ∴ OK✓

$\phi M_n = 953'^{K} > 352.5'^{K}$ ∴ OK✓

$\phi V_n = 376^{K} >> 24^{K}$ ∴ OK✓

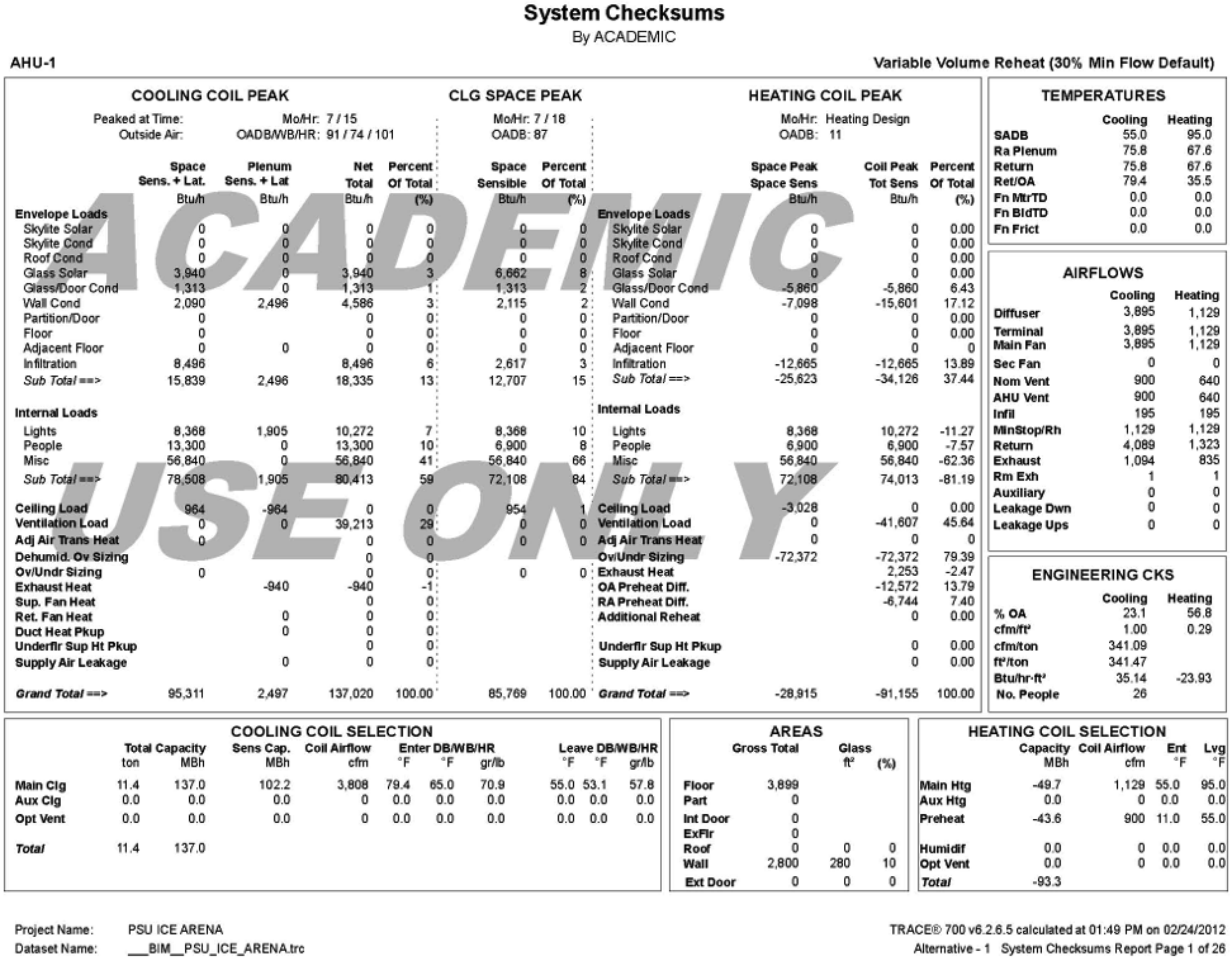
Mechanical Calculations

Trane Trace Load Calculations Based of the DD Drawings



PSU ICE ARENA

Location	State College	
Building owner	Penn State	
Program user	BIM MECHS	
Company	HPR, ibuild, lights out	
Comments	TRACE 700 v6_2 - gbXML imported on Friday, April 08, 2011 at 10:08 AM	
By	ACADEMIC	
Dataset name	E:\PENNSTATE\5th Year\Thesis\TRACE___BIM__PSU_ICE_ARENA.trc	
Calculation time	01:49 PM on 02/24/2012	
TRACE® 700 version	6.2.6.5	
Location	Harrisburg, Pennsylvania	
Latitude	40.0	deg
Longitude	76.0	deg
Time Zone	5	
Elevation	335	ft
Barometric pressure	29.5	in. Hg
Air density	0.0751	lb/cu ft
Air specific heat	0.2444	Btu/lb·°F
Density-specific heat product	1.1011	Btu/h·cfm·°F
Latent heat factor	4,846.9	Btu·min/h·cu ft
Enthalpy factor	4.5046	lb·min/hr·cu ft
Summer design dry bulb	91	°F
Summer design wet bulb	74	°F
Winter design dry bulb	11	°F
Summer clearness number	1.00	
Winter clearness number	1.00	
Summer ground reflectance	0.20	
Winter ground reflectance	0.20	
Carbon Dioxide Level	400	ppm
Design simulation period	January - December	
Cooling load methodology	TETD-TA1	
Heating load methodology	UATD	



System Checksums

By ACADEMIC

AHU-1 — **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 91 / 74 / 101

Clg Space Peak — Mo/Hr: 7 / 18; OADB: 87

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	3,940	0	3,940	3	6,662	8
Glass/Door Cond	1,313	0	1,313	1	1,313	2
Wall Cond	2,090	2,496	4,586	3	2,115	2
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	8,496		8,496	6	2,617	3
Sub Total ==>	15,839	2,496	18,335	13	12,707	15
Internal Loads						
Lights	8,368	1,905	10,272	7	8,368	10
People	13,300	0	13,300	10	6,900	8
Misc	56,840	0	56,840	41	56,840	66
Sub Total ==>	78,508	1,905	80,413	59	72,108	84
Ceiling Load	964	-964	0	0	954	1
Ventilation Load	0	0	39,213	29	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-940	-940	-1		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	95,311	2,497	137,020	100.00	85,769	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	-5,860	-5,860	6.43
Wall Cond	-7,098	-15,601	17.12
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-12,665	-12,665	13.89
Sub Total ==>	-25,623	-34,126	37.44
Internal Loads			
Lights	8,368	10,272	-11.27
People	6,900	6,900	-7.57
Misc	56,840	56,840	-62.36
Sub Total ==>	72,108	74,013	-81.19
Ceiling Load	-3,028	0	0.00
Ventilation Load	0	-41,607	45.64
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-72,372	-72,372	79.39
Exhaust Heat		2,253	-2.47
OA Preheat Diff.		-12,572	13.79
RA Preheat Diff.		-6,744	7.40
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-28,915	-91,155	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.8	67.6
Return	75.8	67.6
Ret/OA	79.4	35.5
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	3,895	1,129
Terminal	3,895	1,129
Main Fan	3,895	1,129
Sec Fan	0	0
Nom Vent	900	640
AHU Vent	900	640
Infil	195	195
MinStop/Rh	1,129	1,129
Return	4,089	1,323
Exhaust	1,094	835
Rm Exh	1	1
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	23.1	56.8
cfm/ft²	1.00	0.29
cfm/ton	341.09	
ft²/ton	341.47	
Btu/hr·ft²	35.14	-23.93
No. People	26	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	11.4	137.0	102.2	3,808	79.4	65.0	70.9	55.0	53.1	57.8
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.4	137.0								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	3,899		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	2,800	280	10
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-49.7	1,129	55.0	95.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-43.6	900	11.0	55.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-93.3			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

TRACE® 700 v6.2.6.5 calculated at 01:49 PM on 02/24/2012
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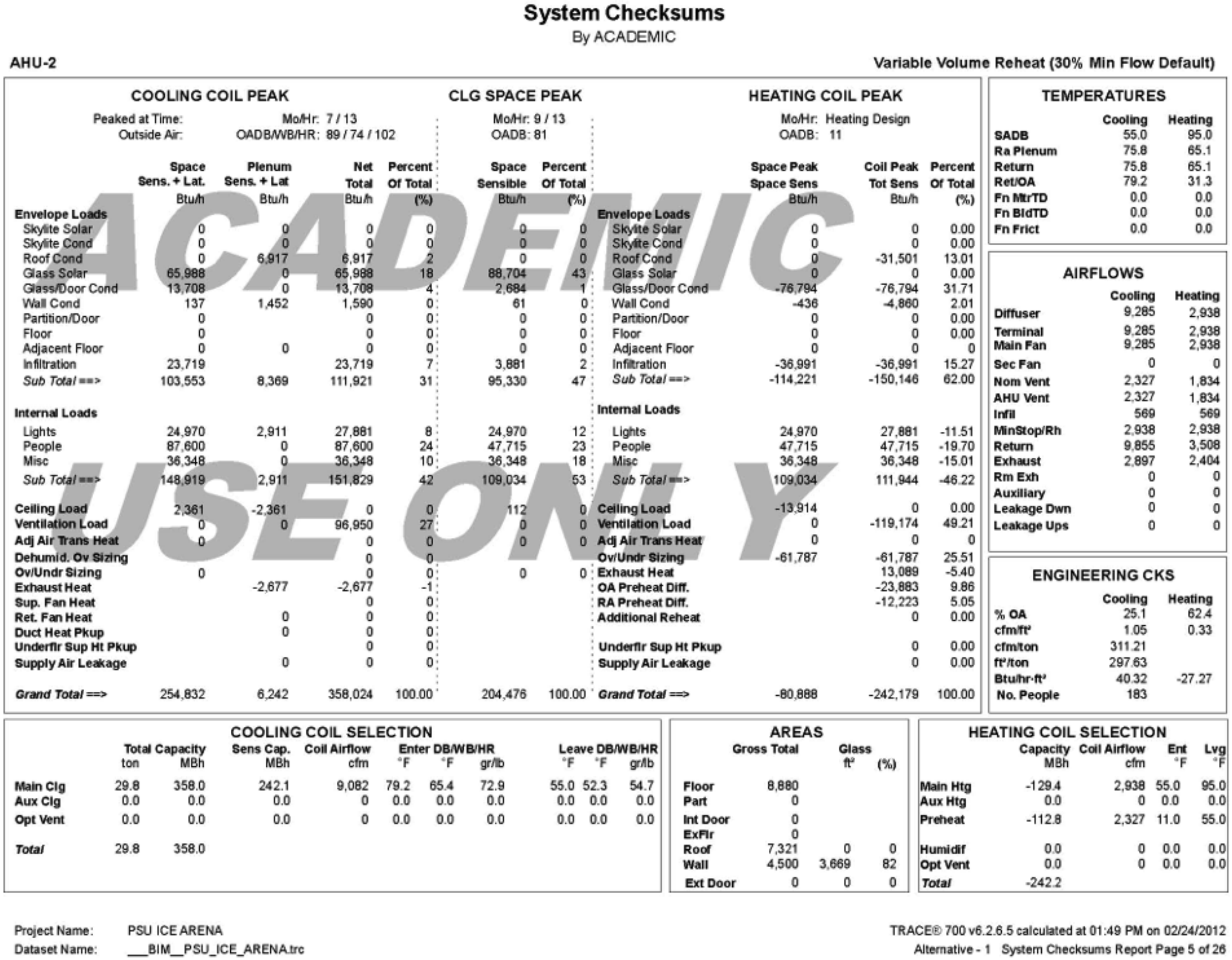

System Checksums

By ACADEMIC

AHU-2 **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK / CLG SPACE PEAK

Peaked at Time: Mo/Hr: 7 / 13
Outside Air: OADB/WB/HR: 89 / 74 / 102

CLG SPACE PEAK: Mo/Hr: 9 / 13
OADB: 81

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	6,917	6,917	2	0	0
Glass Solar	65,988	0	65,988	18	88,704	43
Glass/Door Cond	13,708	0	13,708	4	2,684	1
Wall Cond	137	1,452	1,590	0	61	0
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	23,719		23,719	7	3,881	2
Sub Total ==>	103,553	8,369	111,921	31	95,330	47
Internal Loads						
Lights	24,970	2,911	27,881	8	24,970	12
People	87,600	0	87,600	24	47,715	23
Misc	36,348	0	36,348	10	36,348	18
Sub Total ==>	148,919	2,911	151,829	42	109,034	53
Ceiling Load	2,361	-2,361	0	0	112	0
Ventilation Load	0	0	96,950	27	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-2,677	-2,677	-1		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	254,832	6,242	358,024	100.00	204,476	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	-31,501	13.01
Glass Solar	0	0	0.00
Glass/Door Cond	-76,794	-76,794	31.71
Wall Cond	-436	-4,860	2.01
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-36,991	-36,991	15.27
Sub Total ==>	-114,221	-150,146	62.00
Internal Loads			
Lights	24,970	27,881	-11.51
People	47,715	47,715	-19.70
Misc	36,348	36,348	-15.01
Sub Total ==>	109,034	111,944	-46.22
Ceiling Load	-13,914	0	0.00
Ventilation Load	0	-119,174	49.21
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-61,787	-61,787	25.51
Exhaust Heat		13,089	-5.40
OA Preheat Diff.		-23,883	9.86
RA Preheat Diff.		-12,223	5.05
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-80,888	-242,179	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.8	65.1
Return	75.8	65.1
Ret/OA	79.2	31.3
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	9,285	2,938
Terminal	9,285	2,938
Main Fan	9,285	2,938
Sec Fan	0	0
Nom Vent	2,327	1,834
AHU Vent	2,327	1,834
Infil	569	569
MinStop/Rh	2,938	2,938
Return	9,855	3,508
Exhaust	2,897	2,404
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	25.1	62.4
cfm/ft²	1.05	0.33
cfm/ton	311.21	
ft²/ton	297.63	
Btu/hr·ft²	40.32	-27.27
No. People	183	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	29.8	358.0	242.1	9,082	79.2	65.4	72.9	55.0	52.3	54.7
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	29.8	358.0								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	8,880		
Part	0		
Int Door	0		
ExFlr	0		
Roof	7,321	0	0
Wall	4,500	3,669	82
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-129.4	2,938	55.0	95.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-112.8	2,327	11.0	55.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-242.2			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

TRACE® 700 v6.2.6.5 calculated at 01:49 PM on 02/24/2012
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System Checksums

By ACADEMIC

AHU-3 — Variable Volume Reheat (30% Min Flow Default)

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 13; Outside Air: OADB/WB/HR: 89 / 74 / 102

CLG Space Peak — Mo/Hr: 7 / 11; OADB: 84

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	4,596	4,596	0	0	0
Glass Solar	165,223	0	165,223	17	229,798	39
Glass/Door Cond	42,788	0	42,788	4	22,948	4
Wall Cond	4,013	5,809	9,822	1	4,064	1
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	65,283		65,283	7	16,056	3
Sub Total ==>	277,308	10,405	287,712	29	272,865	46
Internal Loads						
Lights	88,055	16,170	104,224	11	88,055	15
People	288,460	0	288,460	29	174,273	30
Misc	46,137	0	46,137	5	46,137	8
Sub Total ==>	422,651	16,170	438,821	44	308,464	53
Ceiling Load	6,402	-6,402	0	0	5,581	1
Ventilation Load	0	0	265,950	27	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-6,279	-6,279	-1		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	706,361	13,893	986,204	100.00	586,910	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	-22,035	3.31
Glass Solar	0	0	0.00
Glass/Door Cond	-231,729	-231,729	34.78
Wall Cond	-14,322	-35,572	5.34
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-106,436	-106,436	15.97
Sub Total ==>	-352,487	-395,772	59.40
Internal Loads			
Lights	88,055	104,224	-15.64
People	174,273	174,273	-26.15
Misc	46,137	46,137	-6.92
Sub Total ==>	308,464	324,634	-48.72
Ceiling Load	-12,650	0	0.00
Ventilation Load	0	-258,712	38.83
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-152,219	-152,219	22.84
Exhaust Heat		8,371	-1.26
OA Preheat Diff.		-131,196	19.69
RA Preheat Diff.		-61,427	9.22
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-208,891	-666,320	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.7	68.7
Return	75.7	68.7
Ret/OA	79.2	40.2
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	26,651	8,071
Terminal	26,651	8,071
Main Fan	26,651	8,071
Sec Fan	0	0
Nom Vent	6,690	3,982
AHU Vent	6,690	3,982
Infil	1,638	1,638
MinStop/Rh	8,071	8,071
Return	28,284	9,703
Exhaust	8,323	5,615
Rm Exh	6	6
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	25.1	49.3
cfm/ft²	0.90	0.27
cfm/ton	324.29	
ft²/ton	358.78	
Btu/hr·ft²	33.45	-23.06
No. People	709	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	82.2	986.2	669.2	25,073	79.2	66.2	77.0	55.0	53.4	59.0
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	82.2	986.2								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	29,486		
Part	0		
Int Door	0		
ExFlr	0		
Roof	4,802	0	0
Wall	16,764	11,072	66
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-355.9	8,071	55.0	95.1
Aux Htg	0.0	0	0.0	0.0
Preheat	-324.1	6,690	11.0	55.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-680.0			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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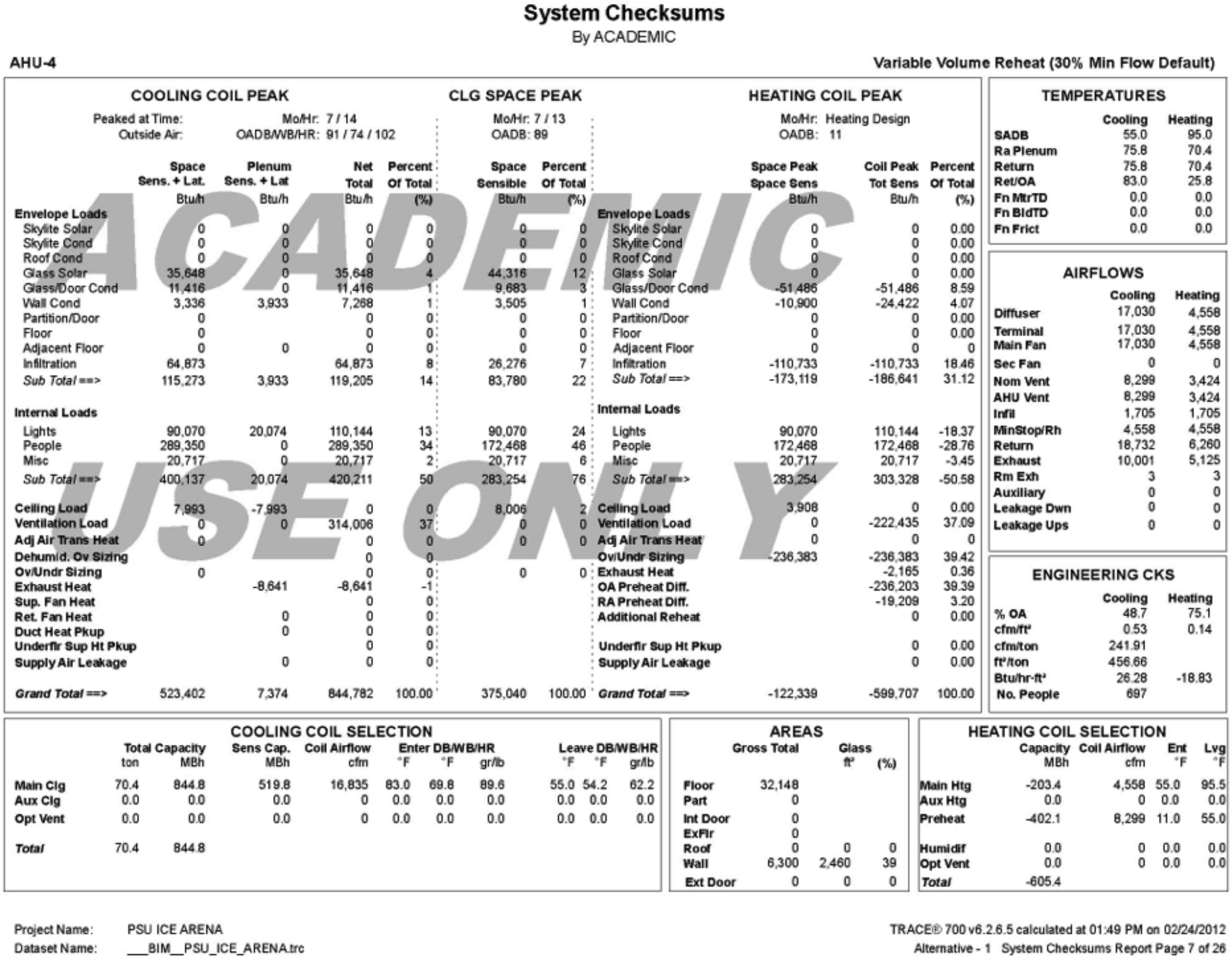

System Checksums

By ACADEMIC

AHU-4

Variable Volume Reheat (30% Min Flow Default)

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 14; Outside Air: OADB/WB/HR: 91 / 74 / 102

Clg Space Peak — Mo/Hr: 7 / 13; OADB: 89

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	35,648	0	35,648	4	44,316	12
Glass/Door Cond	11,416	0	11,416	1	9,683	3
Wall Cond	3,336	3,933	7,268	1	3,505	1
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	64,873		64,873	8	26,276	7
Sub Total ==>	115,273	3,933	119,205	14	83,780	22
Internal Loads						
Lights	90,070	20,074	110,144	13	90,070	24
People	289,350	0	289,350	34	172,468	46
Misc	20,717	0	20,717	2	20,717	6
Sub Total ==>	400,137	20,074	420,211	50	283,254	76
Ceiling Load	7,993	-7,993	0	0	8,006	2
Ventilation Load	0	0	314,006	37	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-8,641	-8,641	-1		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	523,402	7,374	844,782	100.00	375,040	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	-51,486	-51,486	8.59
Wall Cond	-10,900	-24,422	4.07
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-110,733	-110,733	18.46
Sub Total ==>	-173,119	-186,641	31.12
Internal Loads			
Lights	90,070	110,144	-18.37
People	172,468	172,468	-28.76
Misc	20,717	20,717	-3.45
Sub Total ==>	283,254	303,328	-50.58
Ceiling Load	3,908	0	0.00
Ventilation Load	0	-222,435	37.09
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-236,383	-236,383	39.42
Exhaust Heat		-2,165	0.36
OA Preheat Diff.		-236,203	39.39
RA Preheat Diff.		-19,209	3.20
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-122,339	-599,707	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.8	70.4
Return	75.8	70.4
Ret/OA	83.0	25.8
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	17,030	4,558
Terminal	17,030	4,558
Main Fan	17,030	4,558
Sec Fan	0	0
Nom Vent	8,299	3,424
AHU Vent	8,299	3,424
Infil	1,705	1,705
MinStop/Rh	4,558	4,558
Return	18,732	6,260
Exhaust	10,001	5,125
Rm Exh	3	3
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	48.7	75.1
cfm/ft²	0.53	0.14
cfm/ton	241.91	
ft²/ton	456.66	
Btu/hr-ft²	26.28	-18.83
No. People	697	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	70.4	844.8	519.8	16,835	83.0	69.8	89.6	55.0	54.2	62.2
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	70.4	844.8								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	32,148		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	6,300	2,460	39
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-203.4	4,558	55.0	95.5
Aux Htg	0.0	0	0.0	0.0
Preheat	-402.1	8,299	11.0	55.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-605.4			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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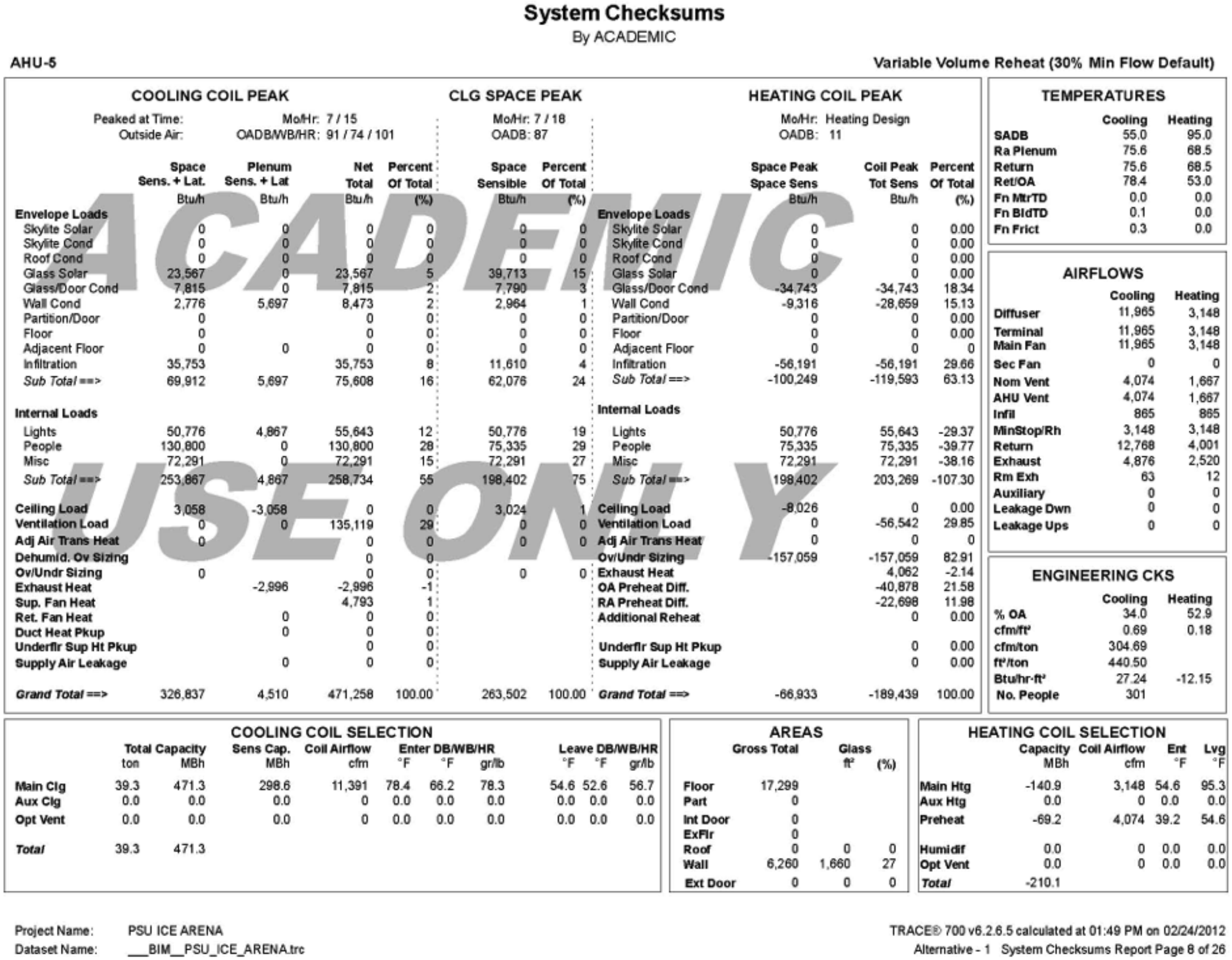

System Checksums

By ACADEMIC

AHU-5

Variable Volume Reheat (30% Min Flow Default)

COOLING COIL PEAK / CLG SPACE PEAK

Peaked at Time: Mo/Hr: 7 / 15 | CLG Space Peak Mo/Hr: 7 / 18

Outside Air: OADB/WB/HR: 91 / 74 / 101 | OADB: 87

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	23,567	0	23,567	5	39,713	15
Glass/Door Cond	7,815	0	7,815	2	7,790	3
Wall Cond	2,776	5,697	8,473	2	2,964	1
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	35,753		35,753	8	11,610	4
Sub Total ==>	69,912	5,697	75,608	16	62,076	24
Internal Loads						
Lights	50,776	4,867	55,643	12	50,776	19
People	130,800	0	130,800	28	75,335	29
Misc	72,291	0	72,291	15	72,291	27
Sub Total ==>	253,867	4,867	258,734	55	198,402	75
Ceiling Load	3,058	-3,058	0	0	3,024	1
Ventilation Load	0	0	135,119	29	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-2,996	-2,996	-1		
Sup. Fan Heat			4,793	1		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	326,837	4,510	471,258	100.00	263,502	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design

OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	-34,743	-34,743	18.34
Wall Cond	-9,316	-28,659	15.13
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-56,191	-56,191	29.66
Sub Total ==>	-100,249	-119,593	63.13
Internal Loads			
Lights	50,776	55,643	-29.37
People	75,335	75,335	-39.77
Misc	72,291	72,291	-38.16
Sub Total ==>	198,402	203,269	-107.30
Ceiling Load	-8,026	0	0.00
Ventilation Load	0	-56,542	29.85
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-157,059	-157,059	82.91
Exhaust Heat		4,062	-2.14
OA Preheat Diff.		-40,878	21.58
RA Preheat Diff.		-22,698	11.98
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-66,933	-189,439	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.6	68.5
Return	75.6	68.5
Ret/OA	78.4	53.0
Fn MtrTD	0.0	0.0
Fn BldTD	0.1	0.0
Fn Frict	0.3	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	11,965	3,148
Terminal	11,965	3,148
Main Fan	11,965	3,148
Sec Fan	0	0
Nom Vent	4,074	1,667
AHU Vent	4,074	1,667
Infil	865	865
MinStop/Rh	3,148	3,148
Return	12,768	4,001
Exhaust	4,876	2,520
Rm Exh	63	12
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	34.0	52.9
cfm/ft²	0.69	0.18
cfm/ton	304.69	
ft²/ton	440.50	
Btu/hr-ft²	27.24	-12.15
No. People	301	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	39.3	471.3	298.6	11,391	78.4	66.2	78.3	54.6	52.6	56.7
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	39.3	471.3								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	17,299		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	6,260	1,660	27
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-140.9	3,148	54.6	95.3
Aux Htg	0.0	0	0.0	0.0
Preheat	-69.2	4,074	39.2	54.6
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-210.1			

Project Name: PSU ICE ARENA

Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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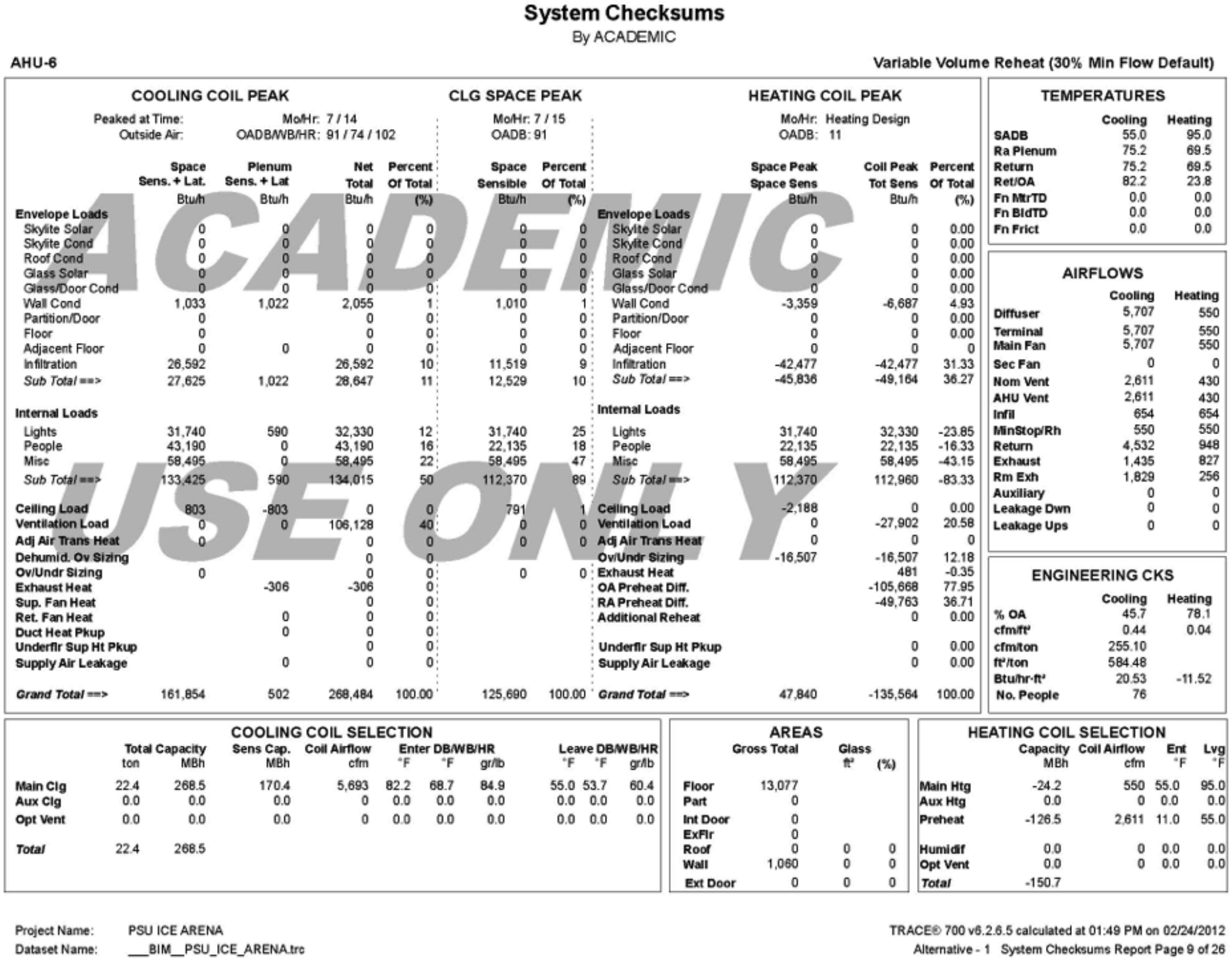

System Checksums

By ACADEMIC

AHU-6

Variable Volume Reheat (30% Min Flow Default)

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 14; Outside Air: OADB/WB/HR: 91 / 74 / 102

CLG Space Peak — Mo/Hr: 7 / 15; OADB: 91

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	1,033	1,022	2,055	1	1,010	1
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	26,592		26,592	10	11,519	9
Sub Total ==>	27,625	1,022	28,647	11	12,529	10
Internal Loads						
Lights	31,740	590	32,330	12	31,740	25
People	43,190	0	43,190	16	22,135	18
Misc	58,495	0	58,495	22	58,495	47
Sub Total ==>	133,425	590	134,015	50	112,370	89
Ceiling Load	803	-803	0	0	791	1
Ventilation Load	0	0	106,128	40	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-306	-306	0		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	161,854	502	268,484	100.00	125,690	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	-3,359	-6,687	4.93
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-42,477	-42,477	31.33
Sub Total ==>	-45,836	-49,164	36.27
Internal Loads			
Lights	31,740	32,330	-23.85
People	22,135	22,135	-16.33
Misc	58,495	58,495	-43.15
Sub Total ==>	112,370	112,960	-83.33
Ceiling Load	-2,188	0	0.00
Ventilation Load	0	-27,902	20.58
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-16,507	-16,507	12.18
Exhaust Heat		481	-0.35
OA Preheat Diff.		-105,668	77.95
RA Preheat Diff.		-49,763	36.71
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	47,840	-135,564	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.2	69.5
Return	75.2	69.5
Ret/OA	82.2	23.8
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	5,707	550
Terminal	5,707	550
Main Fan	5,707	550
Sec Fan	0	0
Nom Vent	2,611	430
AHU Vent	2,611	430
Infil	654	654
MinStop/Rh	550	550
Return	4,532	948
Exhaust	1,435	827
Rm Exh	1,829	256
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	45.7	78.1
cfm/ft²	0.44	0.04
cfm/ton	255.10	
ft²/ton	584.48	
Btu/hr-ft²	20.53	-11.52
No. People	76	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	22.4	268.5	170.4	5,693	82.2	68.7	84.9	55.0	53.7	60.4
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	22.4	268.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	13,077		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	1,060	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-24.2	550	55.0	95.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-126.5	2,611	11.0	55.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-150.7			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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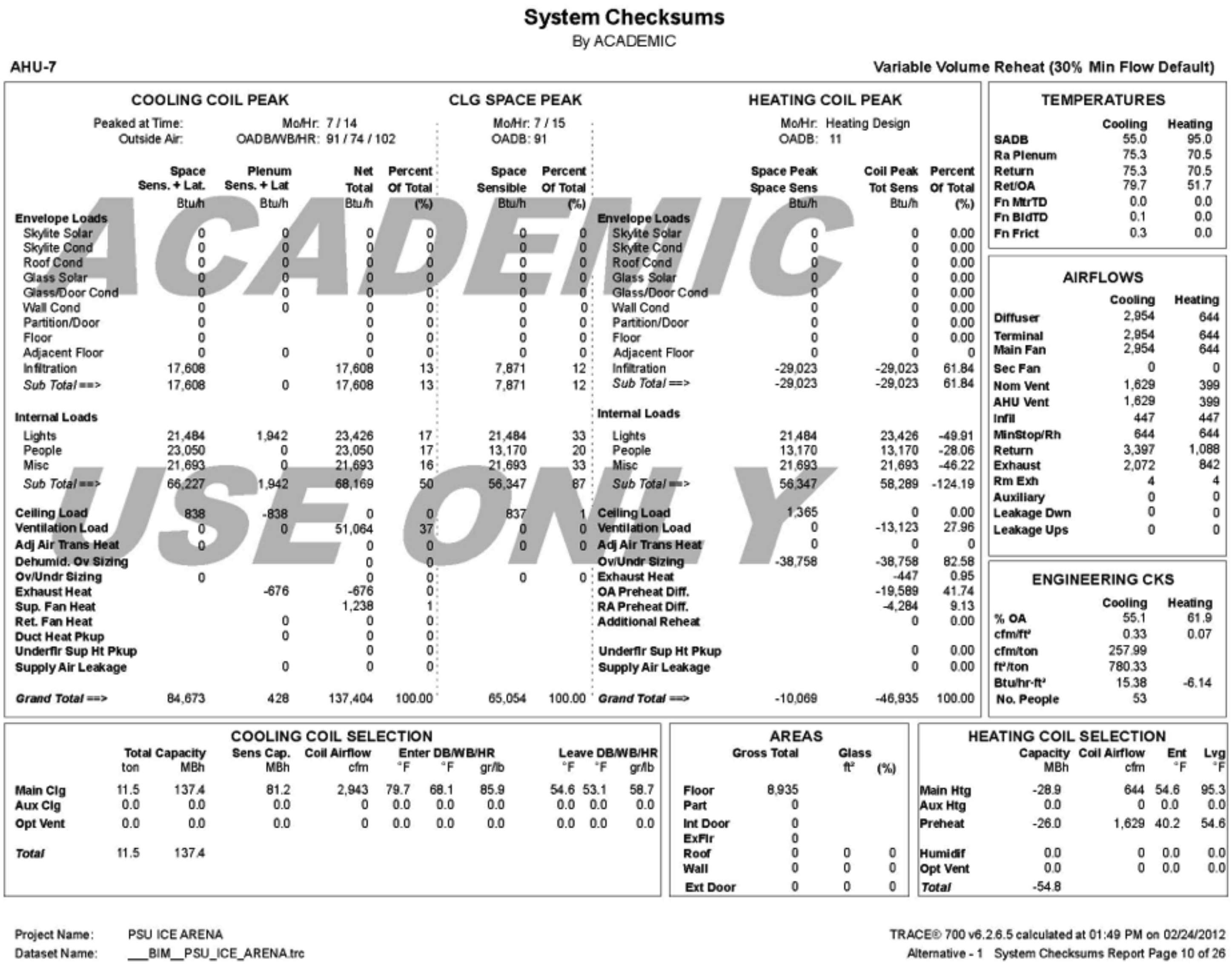

System Checksums

By ACADEMIC

AHU-7

Variable Volume Reheat (30% Min Flow Default)

COOLING COIL PEAK / CLG SPACE PEAK

Peaked at Time: Mo/Hr: 7 / 14
Outside Air: OADB/WB/HR: 91 / 74 / 102

CLG SPACE PEAK: Mo/Hr: 7 / 15, OADB: 91

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	0	0	0	0	0	0
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	17,608		17,608	13	7,871	12
Sub Total ==>	17,608	0	17,608	13	7,871	12
Internal Loads						
Lights	21,484	1,942	23,426	17	21,484	33
People	23,050	0	23,050	17	13,170	20
Misc	21,693	0	21,693	16	21,693	33
Sub Total ==>	66,227	1,942	68,169	50	56,347	87
Ceiling Load	838	-838	0	0	837	1
Ventilation Load	0	0	51,064	37	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-676	-676	0		
Sup. Fan Heat			1,238	1		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	84,673	428	137,404	100.00	65,054	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-29,023	-29,023	61.84
Sub Total ==>	-29,023	-29,023	61.84
Internal Loads			
Lights	21,484	23,426	-49.91
People	13,170	13,170	-28.06
Misc	21,693	21,693	-46.22
Sub Total ==>	56,347	58,289	-124.19
Ceiling Load	1,365	0	0.00
Ventilation Load	0	-13,123	27.96
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-38,758	-38,758	82.58
Exhaust Heat		-447	0.95
OA Preheat Diff.		-19,589	41.74
RA Preheat Diff.		-4,284	9.13
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-10,069	-46,935	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.3	70.5
Return	75.3	70.5
Ret/OA	79.7	51.7
Fn MtrTD	0.0	0.0
Fn BldTD	0.1	0.0
Fn Frict	0.3	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	2,954	644
Terminal	2,954	644
Main Fan	2,954	644
Sec Fan	0	0
Nom Vent	1,629	399
AHU Vent	1,629	399
Infil	447	447
MinStop/Rh	644	644
Return	3,397	1,088
Exhaust	2,072	842
Rm Exh	4	4
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	55.1	61.9
cfm/ft²	0.33	0.07
cfm/ton	257.99	
ft²/ton	780.33	
Btu/hr-ft²	15.38	-6.14
No. People	53	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	11.5	137.4	81.2	2,943	79.7	68.1	85.9	54.6	53.1	58.7
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.5	137.4								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	8,935		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-28.9	644	54.6	95.3
Aux Htg	0.0	0	0.0	0.0
Preheat	-26.0	1,629	40.2	54.6
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-54.8			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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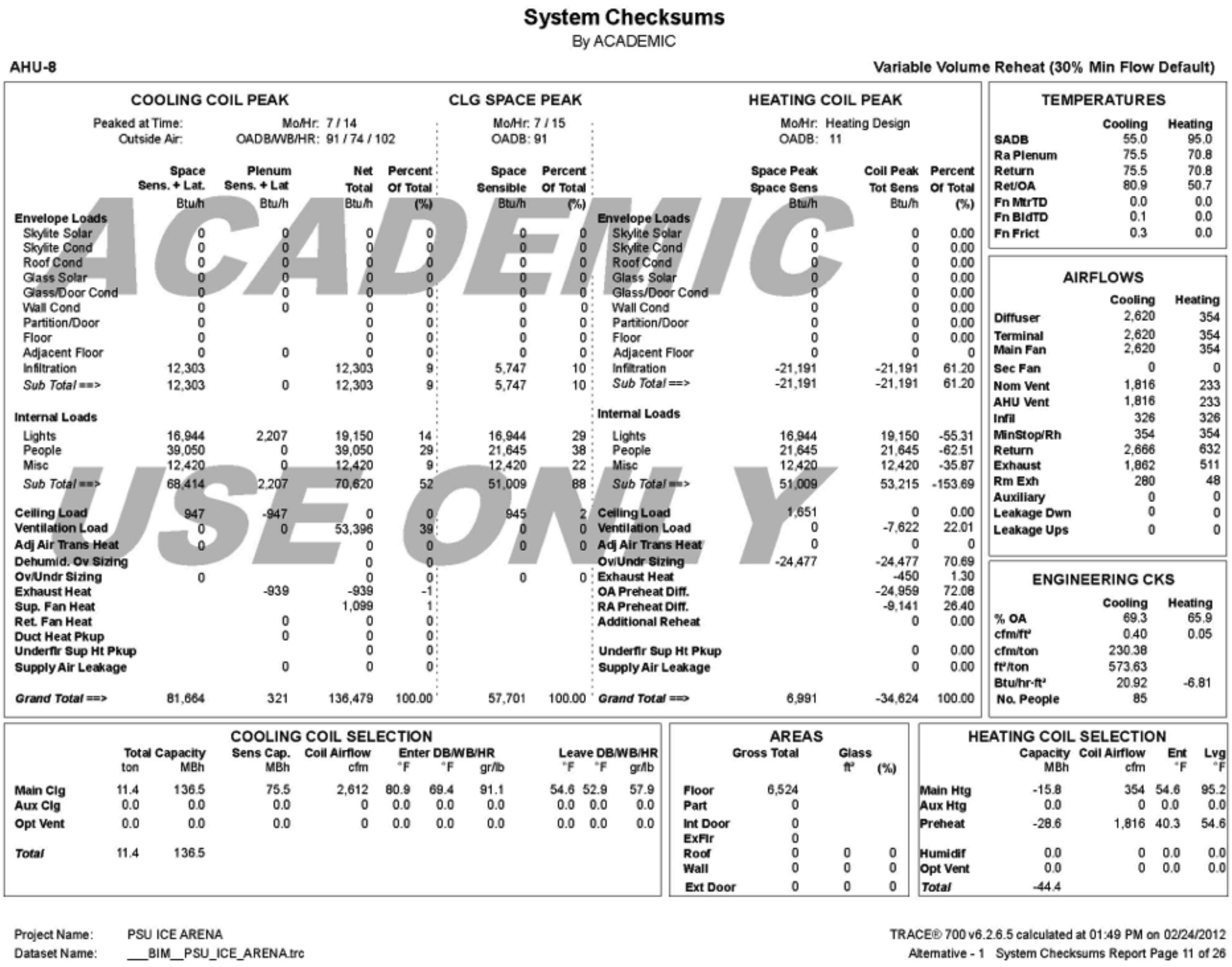

System Checksums

By ACADEMIC

AHU-8

Variable Volume Reheat (30% Min Flow Default)

COOLING COIL PEAK / CLG SPACE PEAK

Peaked at Time: Mo/Hr: 7 / 14 — Mo/Hr: 7 / 15
Outside Air: OADB/WB/HR: 91 / 74 / 102 — OADB: 91

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	0	0	0	0	0	0
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	12,303		12,303	9	5,747	10
Sub Total ==>	12,303	0	12,303	9	5,747	10
Internal Loads						
Lights	16,944	2,207	19,150	14	16,944	29
People	39,050	0	39,050	29	21,645	38
Misc	12,420	0	12,420	9	12,420	22
Sub Total ==>	68,414	2,207	70,620	52	51,009	88
Ceiling Load	947	-947	0	0	945	2
Ventilation Load	0	0	53,396	39	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-939	-939	-1		
Sup. Fan Heat			1,099	1		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	81,664	321	136,479	100.00	57,701	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-21,191	-21,191	61.20
Sub Total ==>	-21,191	-21,191	61.20
Internal Loads			
Lights	16,944	19,150	-55.31
People	21,645	21,645	-62.51
Misc	12,420	12,420	-35.87
Sub Total ==>	51,009	53,215	-153.69
Ceiling Load	1,651	0	0.00
Ventilation Load	0	-7,622	22.01
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-24,477	-24,477	70.69
Exhaust Heat		-450	1.30
OA Preheat Diff.		-24,959	72.08
RA Preheat Diff.		-9,141	26.40
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	6,991	-34,624	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.5	70.8
Return	75.5	70.8
Ret/OA	80.9	50.7
Fn MtrTD	0.0	0.0
Fn BldTD	0.1	0.0
Fn Frict	0.3	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	2,620	354
Terminal	2,620	354
Main Fan	2,620	354
Sec Fan	0	0
Nom Vent	1,816	233
AHU Vent	1,816	233
Infil	326	326
MinStop/Rh	354	354
Return	2,666	632
Exhaust	1,862	511
Rm Exh	280	48
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	69.3	65.9
cfm/ft²	0.40	0.05
cfm/ton	230.38	
ft²/ton	573.63	
Btu/hr-ft²	20.92	-6.81
No. People	85	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	11.4	136.5	75.5	2,612	80.9	69.4	91.1	54.6	52.9	57.9
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.4	136.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	6,524		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-15.8	354	54.6	95.2
Aux Htg	0.0	0	0.0	0.0
Preheat	-28.6	1,816	40.3	54.6
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-44.4			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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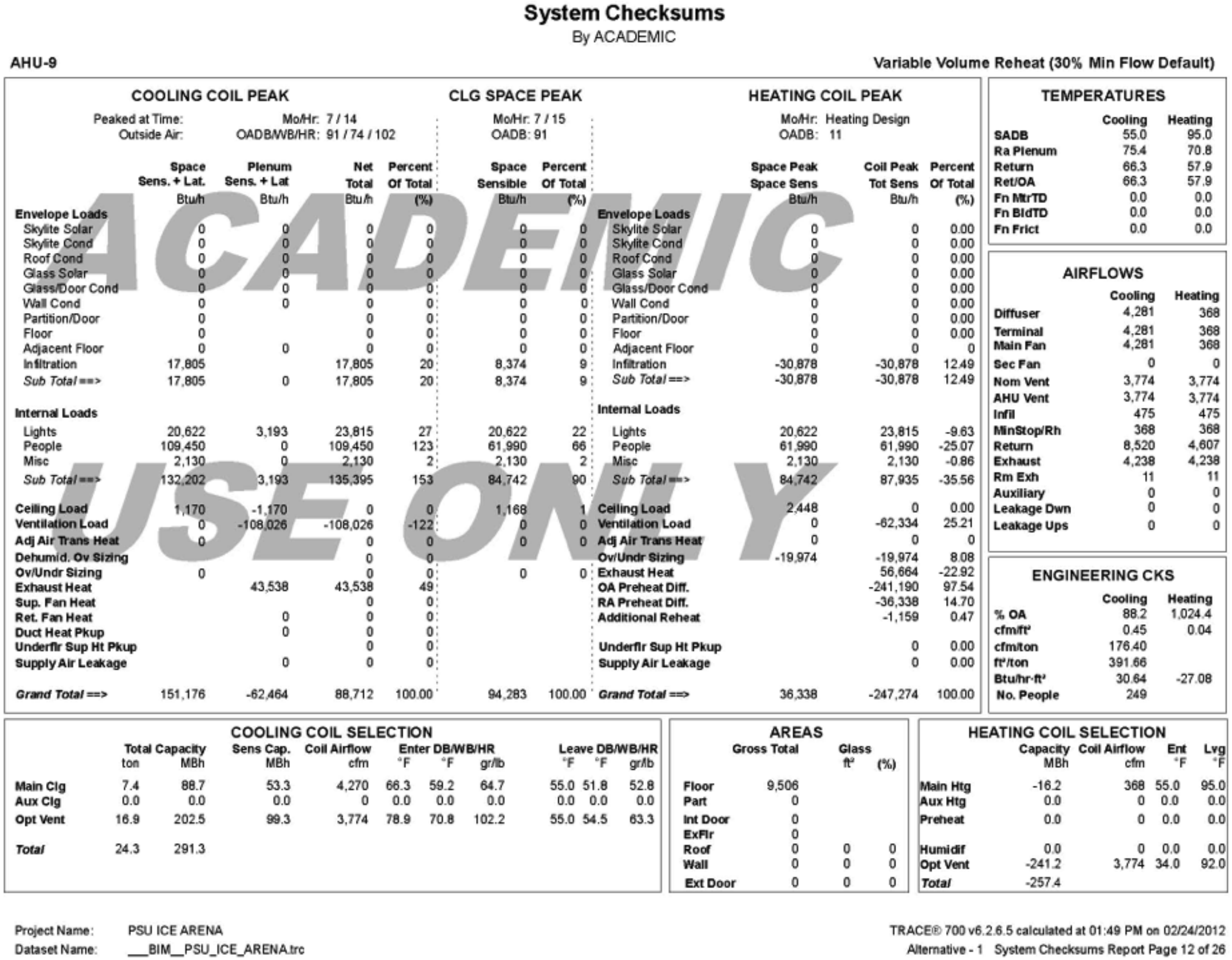

System Checksums

By ACADEMIC

AHU-9

Variable Volume Reheat (30% Min Flow Default)

COOLING COIL PEAK

Peaked at Time: Mo/Hr: 7 / 14
Outside Air: OADB/WB/HR: 91 / 74 / 102

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)
Envelope Loads				
Skylite Solar	0	0	0	0
Skylite Cond	0	0	0	0
Roof Cond	0	0	0	0
Glass Solar	0	0	0	0
Glass/Door Cond	0	0	0	0
Wall Cond	0	0	0	0
Partition/Door	0		0	0
Floor	0		0	0
Adjacent Floor	0	0	0	0
Infiltration	17,805		17,805	20
Sub Total ==>	17,805	0	17,805	20
Internal Loads				
Lights	20,622	3,193	23,815	27
People	109,450	0	109,450	123
Misc	2,130	0	2,130	2
Sub Total ==>	132,202	3,193	135,395	153
Ceiling Load	1,170	-1,170	0	0
Ventilation Load	0	-108,026	-108,026	-122
Adj Air Trans Heat	0		0	0
Dehumid. Ov Sizing			0	0
Ov/Undr Sizing	0		0	0
Exhaust Heat		43,538	43,538	49
Sup. Fan Heat			0	0
Ret. Fan Heat		0	0	0
Duct Heat Pkup		0	0	0
Underflr Sup Ht Pkup			0	0
Supply Air Leakage		0	0	0
Grand Total ==>	151,176	-62,464	88,712	100.00

CLG SPACE PEAK

Mo/Hr: 7 / 15
OADB: 91

	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads		
Skylite Solar	0	0
Skylite Cond	0	0
Roof Cond	0	0
Glass Solar	0	0
Glass/Door Cond	0	0
Wall Cond	0	0
Partition/Door	0	0
Floor	0	0
Adjacent Floor	0	0
Infiltration	8,374	9
Sub Total ==>	8,374	9
Internal Loads		
Lights	20,622	22
People	61,990	66
Misc	2,130	2
Sub Total ==>	84,742	90
Ceiling Load	1,168	1
Ventilation Load	0	0
Adj Air Trans Heat	0	0
Ov/Undr Sizing	0	0
Grand Total ==>	94,283	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-30,878	-30,878	12.49
Sub Total ==>	-30,878	-30,878	12.49
Internal Loads			
Lights	20,622	23,815	-9.63
People	61,990	61,990	-25.07
Misc	2,130	2,130	-0.86
Sub Total ==>	84,742	87,935	-35.56
Ceiling Load	2,448	0	0.00
Ventilation Load	0	-62,334	25.21
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-19,974	-19,974	8.08
Exhaust Heat		56,664	-22.92
OA Preheat Diff.		-241,190	97.54
RA Preheat Diff.		-36,338	14.70
Additional Reheat		-1,159	0.47
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	36,338	-247,274	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.4	70.8
Return	66.3	57.9
Ret/OA	66.3	57.9
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	4,281	368
Terminal	4,281	368
Main Fan	4,281	368
Sec Fan	0	0
Nom Vent	3,774	3,774
AHU Vent	3,774	3,774
Infil	475	475
MinStop/Rh	368	368
Return	8,520	4,607
Exhaust	4,238	4,238
Rm Exh	11	11
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	88.2	1,024.4
cfm/ft²	0.45	0.04
cfm/ton	176.40	
ft²/ton	391.66	
Btu/hr·ft²	30.64	-27.08
No. People	249	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	7.4	88.7	53.3	4,270	66.3	59.2	64.7	55.0	51.8	52.8
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	16.9	202.5	99.3	3,774	78.9	70.8	102.2	55.0	54.5	63.3
Total	24.3	291.3								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	9,506		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-16.2	368	55.0	95.0
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-241.2	3,774	34.0	92.0
Total	-257.4			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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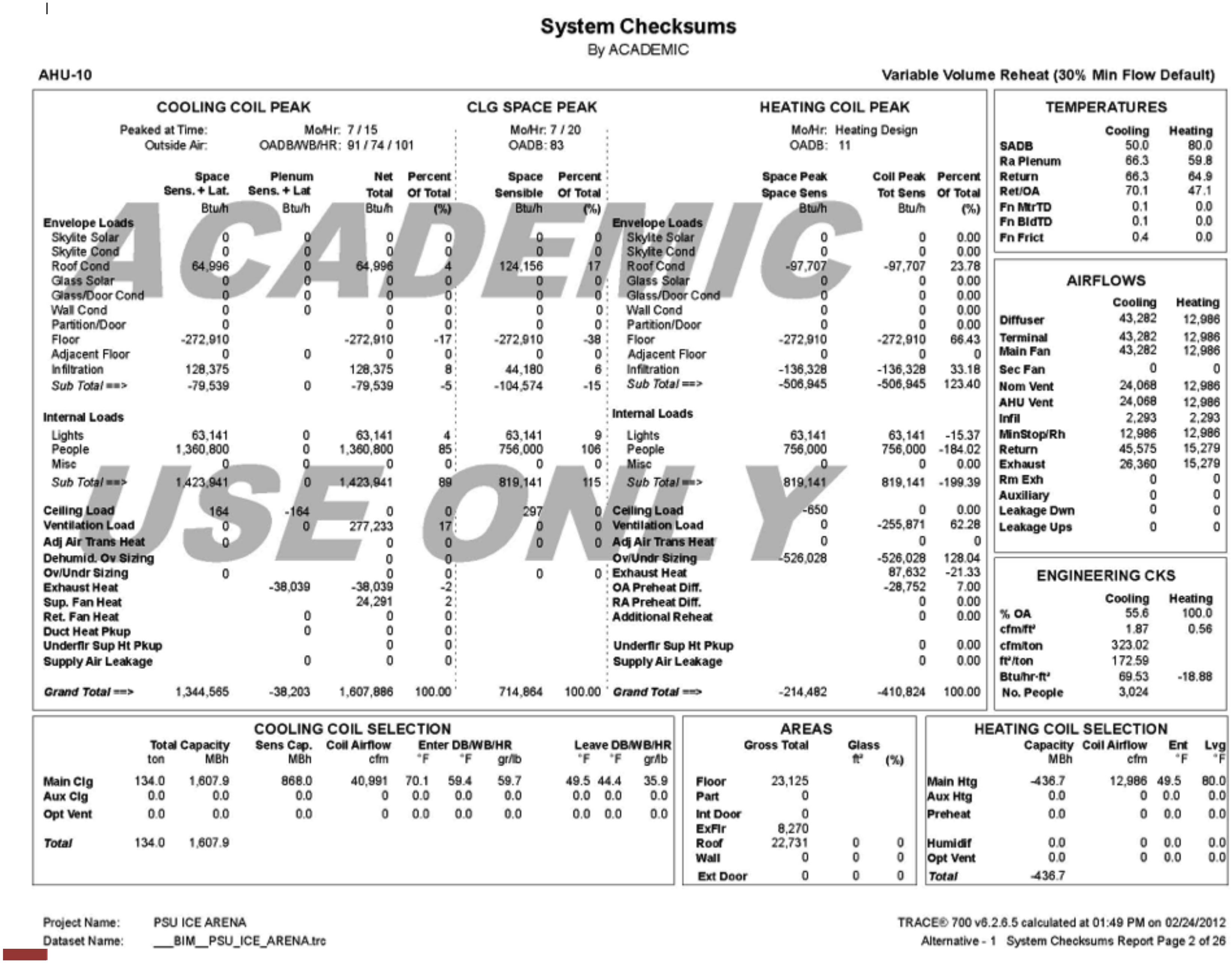

System Checksums

By ACADEMIC

AHU-10 **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 91 / 74 / 101

CLG Space Peak — Mo/Hr: 7 / 20; OADB: 83

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	64,996	0	64,996	4	124,156	17
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	0	0	0	0	0	0
Partition/Door	0		0	0	0	0
Floor	-272,910		-272,910	-17	-272,910	-38
Adjacent Floor	0	0	0	0	0	0
Infiltration	128,375		128,375	8	44,180	6
Sub Total ==>	-79,539	0	-79,539	-5	-104,574	-15
Internal Loads						
Lights	63,141	0	63,141	4	63,141	9
People	1,360,800	0	1,360,800	85	756,000	106
Misc	0	0	0	0	0	0
Sub Total ==>	1,423,941	0	1,423,941	89	819,141	115
Ceiling Load	164	-164	0	0	297	0
Ventilation Load	0	0	277,233	17	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-38,039	-38,039	-2		
Sup. Fan Heat			24,291	2		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	1,344,565	-38,203	1,607,886	100.00	714,864	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	-97,707	-97,707	23.78
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	-272,910	-272,910	66.43
Adjacent Floor	0	0	0
Infiltration	-136,328	-136,328	33.18
Sub Total ==>	-506,945	-506,945	123.40
Internal Loads			
Lights	63,141	63,141	-15.37
People	756,000	756,000	-184.02
Misc	0	0	0.00
Sub Total ==>	819,141	819,141	-199.39
Ceiling Load	-650	0	0.00
Ventilation Load	0	-255,871	62.28
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-526,028	-526,028	128.04
Exhaust Heat		87,632	-21.33
OA Preheat Diff.		-28,752	7.00
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-214,482	-410,824	100.00

TEMPERATURES

	Cooling	Heating
SADB	50.0	80.0
Ra Plenum	66.3	59.8
Return	66.3	64.9
Ret/OA	70.1	47.1
Fn MtrTD	0.1	0.0
Fn BldTD	0.1	0.0
Fn Frict	0.4	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	43,282	12,986
Terminal	43,282	12,986
Main Fan	43,282	12,986
Sec Fan	0	0
Nom Vent	24,068	12,986
AHU Vent	24,068	12,986
Infil	2,293	2,293
MinStop/Rh	12,986	12,986
Return	45,575	15,279
Exhaust	26,360	15,279
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	55.6	100.0
cfm/ft²	1.87	0.56
cfm/ton	323.02	
ft²/ton	172.59	
Btu/hr·ft²	69.53	-18.88
No. People	3,024	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	134.0	1,607.9	868.0	40,991	70.1	59.4	59.7	49.5	44.4	35.9
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	134.0	1,607.9								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	23,125		
Part	0		
Int Door	0		
ExFlr	8,270		
Roof	22,731	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-436.7	12,986	49.5	80.0
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-436.7			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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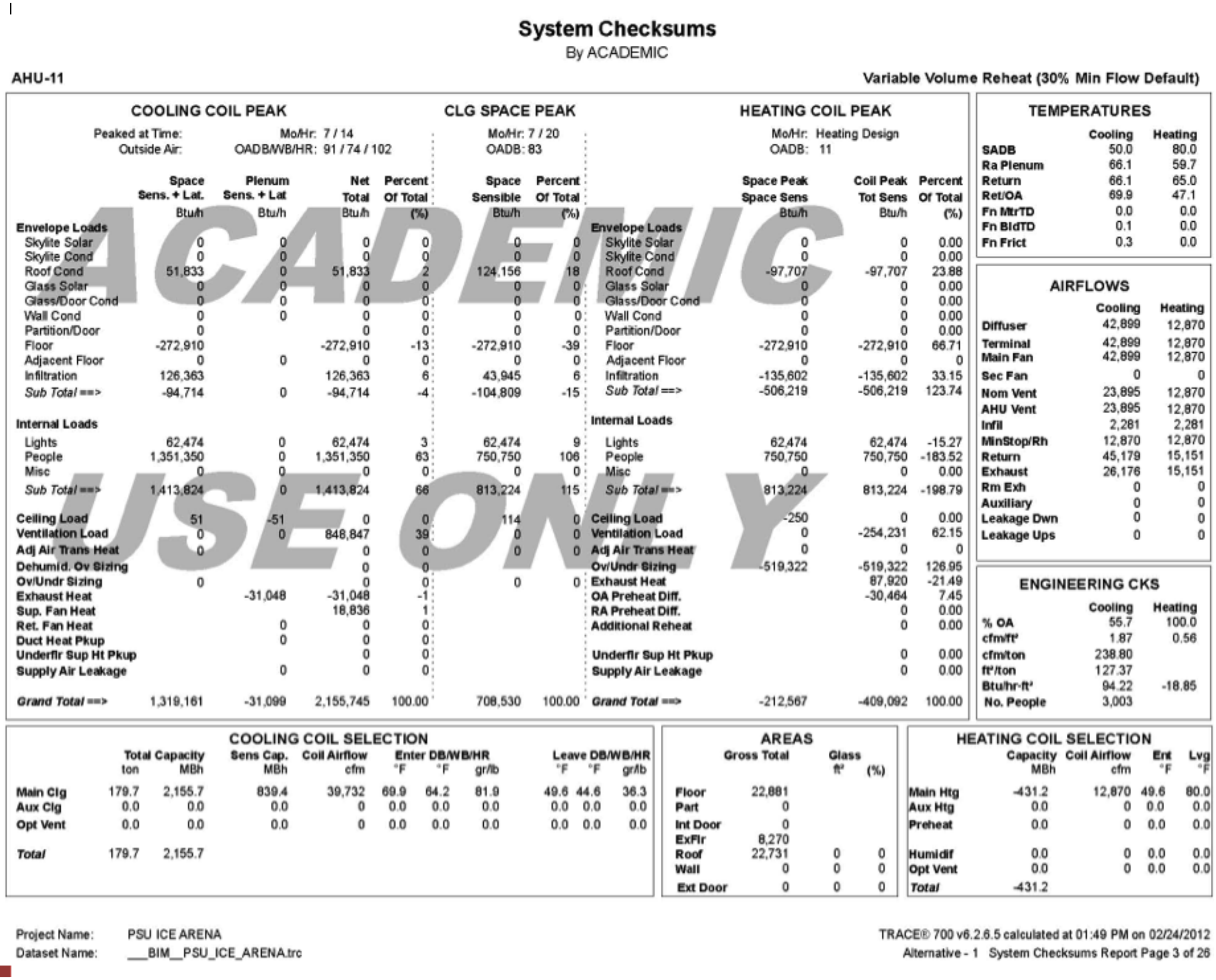

System Checksums
By ACADEMIC

AHU-11 **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling coil peak: Peaked at Time: Mo/Hr: 7 / 14; Outside Air: OADB/WB/HR: 91 / 74 / 102

Clg space peak: Mo/Hr: 7 / 20; OADB: 83

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	51,833	0	51,833	2	124,156	18
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	0	0	0	0	0	0
Partition/Door	0		0	0	0	0
Floor	-272,910		-272,910	-13	-272,910	-39
Adjacent Floor	0	0	0	0	0	0
Infiltration	126,363		126,363	6	43,945	6
Sub Total ==>	-94,714	0	-94,714	-4	-104,809	-15
Internal Loads						
Lights	62,474	0	62,474	3	62,474	9
People	1,351,350	0	1,351,350	63	750,750	106
Misc	0	0	0	0	0	0
Sub Total ==>	1,413,824	0	1,413,824	66	813,224	115
Ceiling Load	51	-51	0	0	114	0
Ventilation Load	0	0	848,847	39	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-31,048	-31,048	-1		
Sup. Fan Heat			18,836	1		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	1,319,161	-31,099	2,155,745	100.00	708,530	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	-97,707	-97,707	23.88
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	-272,910	-272,910	66.71
Adjacent Floor	0	0	0
Infiltration	-135,602	-135,602	33.15
Sub Total ==>	-506,219	-506,219	123.74
Internal Loads			
Lights	62,474	62,474	-15.27
People	750,750	750,750	-183.52
Misc	0	0	0.00
Sub Total ==>	813,224	813,224	-198.79
Ceiling Load	-250	0	0.00
Ventilation Load	0	-254,231	62.15
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-519,322	-519,322	126.95
Exhaust Heat		87,920	-21.49
OA Preheat Diff.		-30,464	7.45
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-212,567	-409,092	100.00

TEMPERATURES

	Cooling	Heating
SADB	50.0	80.0
Ra Plenum	66.1	59.7
Return	66.1	65.0
Ret/OA	69.9	47.1
Fn MtrTD	0.0	0.0
Fn BldTD	0.1	0.0
Fn Frict	0.3	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	42,899	12,870
Terminal	42,899	12,870
Main Fan	42,899	12,870
Sec Fan	0	0
Nom Vent	23,895	12,870
AHU Vent	23,895	12,870
Infil	2,281	2,281
MinStop/Rh	12,870	12,870
Return	45,179	15,151
Exhaust	26,176	15,151
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	55.7	100.0
cfm/ft²	1.87	0.56
cfm/ton	238.80	
ft²/ton	127.37	
Btu/hr-ft²	94.22	-18.85
No. People	3,003	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	179.7	2,155.7	839.4	39,732	69.9	64.2	81.9	49.6	44.6	36.3
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	179.7	2,155.7								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	22,881		
Part	0		
Int Door	0		
ExFlr	8,270		
Roof	22,731	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-431.2	12,870	49.6	80.0
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-431.2			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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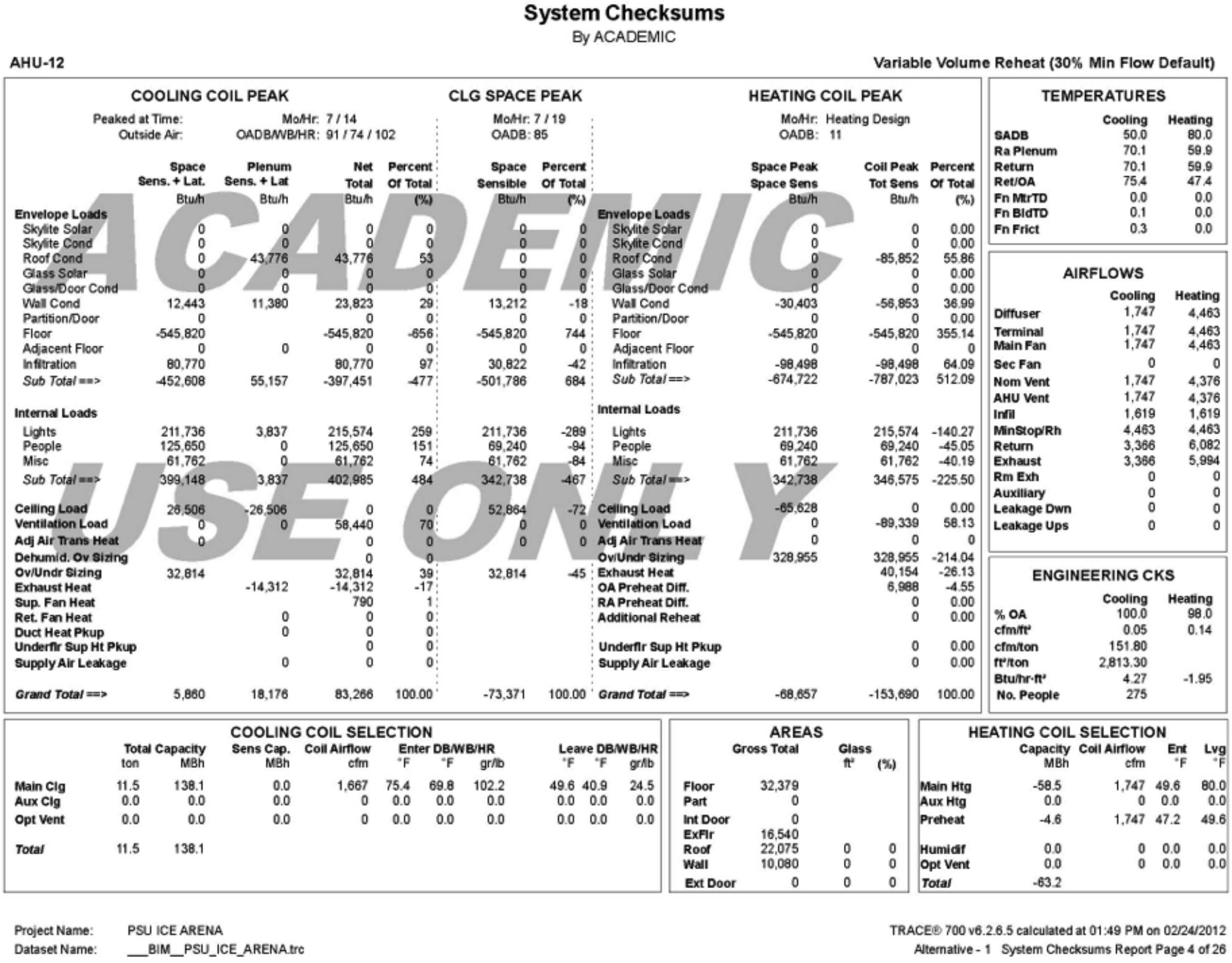

System Checksums

By ACADEMIC

AHU-12

Variable Volume Reheat (30% Min Flow Default)

COOLING COIL PEAK / CLG SPACE PEAK

Peaked at Time: Mo/Hr: 7 / 14
Outside Air: OADB/WB/HR: 91 / 74 / 102

CLG SPACE PEAK: Mo/Hr: 7 / 19
OADB: 85

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	43,776	43,776	53	0	0
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	12,443	11,380	23,823	29	13,212	-18
Partition/Door	0		0	0	0	0
Floor	-545,820		-545,820	-656	-545,820	744
Adjacent Floor	0	0	0	0	0	0
Infiltration	80,770		80,770	97	30,822	-42
Sub Total ==>	-452,608	55,157	-397,451	-477	-501,786	684
Internal Loads						
Lights	211,736	3,837	215,574	259	211,736	-289
People	125,650	0	125,650	151	69,240	-94
Misc	61,762	0	61,762	74	61,762	-84
Sub Total ==>	399,148	3,837	402,985	484	342,738	-467
Ceiling Load	26,506	-26,506	0	0	52,864	-72
Ventilation Load	0	0	58,440	70	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	32,814		32,814	39	32,814	-45
Exhaust Heat		-14,312	-14,312	-17		
Sup. Fan Heat			790	1		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	5,860	18,176	83,266	100.00	-73,371	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	-85,852	55.86
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	-30,403	-56,853	36.99
Partition/Door	0	0	0.00
Floor	-545,820	-545,820	355.14
Adjacent Floor	0	0	0
Infiltration	-98,498	-98,498	64.09
Sub Total ==>	-674,722	-787,023	512.09
Internal Loads			
Lights	211,736	215,574	-140.27
People	69,240	69,240	-45.05
Misc	61,762	61,762	-40.19
Sub Total ==>	342,738	346,575	-225.50
Ceiling Load	-65,628	0	0.00
Ventilation Load	0	-89,339	58.13
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	328,955	328,955	-214.04
Exhaust Heat		40,154	-26.13
OA Preheat Diff.		6,988	-4.55
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-68,657	-153,690	100.00

TEMPERATURES

	Cooling	Heating
SADB	50.0	80.0
Ra Plenum	70.1	59.9
Return	70.1	59.9
Ret/OA	75.4	47.4
Fn MtrTD	0.0	0.0
Fn BldTD	0.1	0.0
Fn Frict	0.3	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	1,747	4,463
Terminal	1,747	4,463
Main Fan	1,747	4,463
Sec Fan	0	0
Nom Vent	1,747	4,376
AHU Vent	1,747	4,376
Infil	1,619	1,619
MinStop/Rh	4,463	4,463
Return	3,366	6,082
Exhaust	3,366	5,994
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	100.0	98.0
cfm/ft²	0.05	0.14
cfm/ton	151.80	
ft²/ton	2,813.30	
Btu/hr·ft²	4.27	-1.95
No. People	275	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	11.5	138.1	0.0	1,667	75.4	69.8	102.2	49.6	40.9	24.5
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.5	138.1								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	32,379		
Part	0		
Int Door	0		
ExFlr	16,540		
Roof	22,075	0	0
Wall	10,080	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-58.5	1,747	49.6	80.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-4.6	1,747	47.2	49.6
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-63.2			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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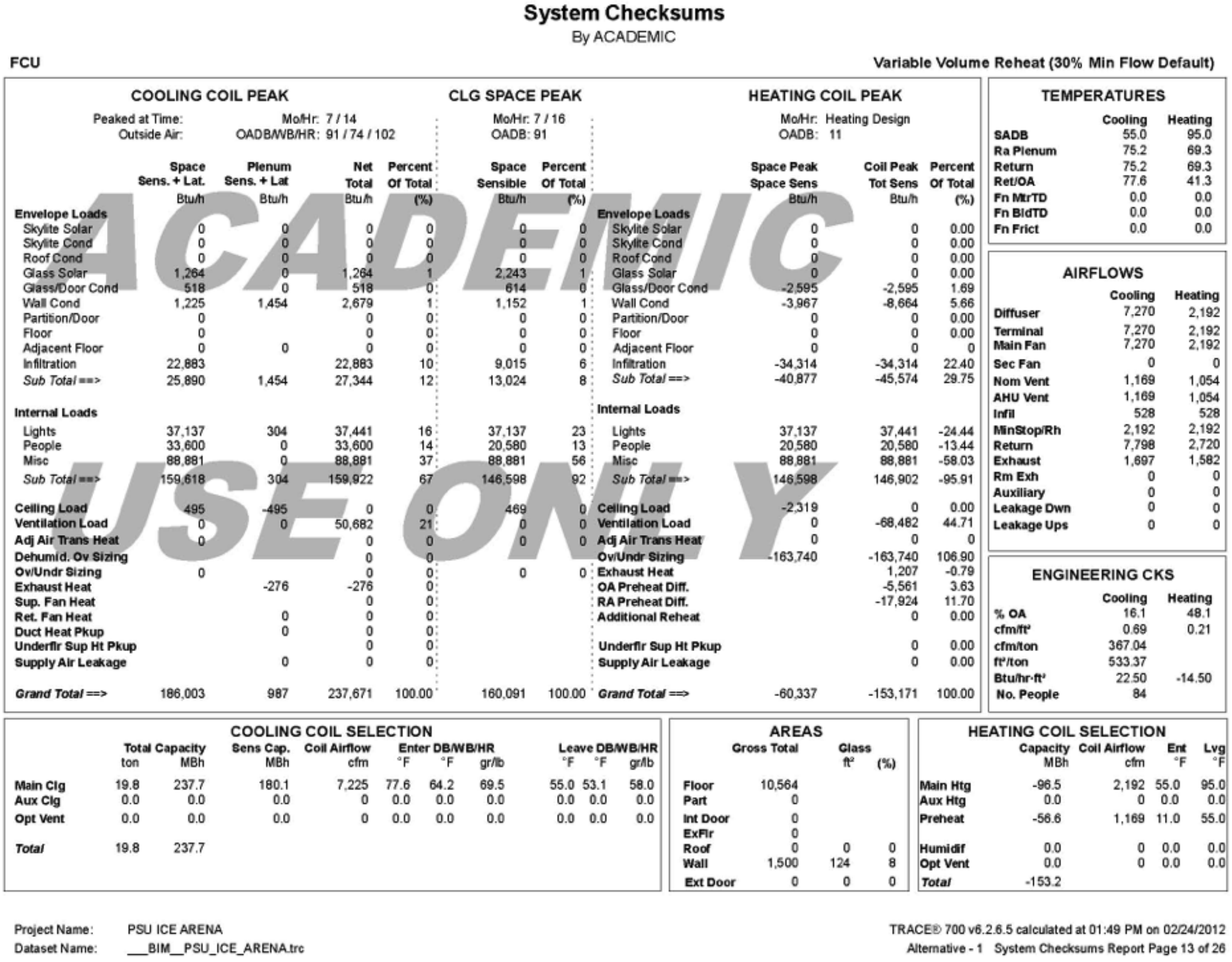

System Checksums

By ACADEMIC

FCU

Variable Volume Reheat (30% Min Flow Default)

COOLING COIL PEAK / CLG SPACE PEAK

Peaked at Time: Mo/Hr: 7 / 14
Outside Air: OADB/WB/HR: 91 / 74 / 102

CLG SPACE PEAK: Mo/Hr: 7 / 16
OADB: 91

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	1,264	0	1,264	1	2,243	1
Glass/Door Cond	518	0	518	0	614	0
Wall Cond	1,225	1,454	2,679	1	1,152	1
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	22,883		22,883	10	9,015	6
Sub Total ==>	25,890	1,454	27,344	12	13,024	8
Internal Loads						
Lights	37,137	304	37,441	16	37,137	23
People	33,600	0	33,600	14	20,580	13
Misc	88,881	0	88,881	37	88,881	56
Sub Total ==>	159,618	304	159,922	67	146,598	92
Ceiling Load	495	-495	0	0	469	0
Ventilation Load	0	0	50,682	21	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-276	-276	0		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	186,003	987	237,671	100.00	160,091	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	-2,595	-2,595	1.69
Wall Cond	-3,967	-8,664	5.66
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-34,314	-34,314	22.40
Sub Total ==>	-40,877	-45,574	29.75
Internal Loads			
Lights	37,137	37,441	-24.44
People	20,580	20,580	-13.44
Misc	88,881	88,881	-58.03
Sub Total ==>	146,598	146,902	-95.91
Ceiling Load	-2,319	0	0.00
Ventilation Load	0	-68,482	44.71
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-163,740	-163,740	106.90
Exhaust Heat		1,207	-0.79
OA Preheat Diff.		-5,561	3.63
RA Preheat Diff.		-17,924	11.70
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-60,337	-153,171	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	95.0
Ra Plenum	75.2	69.3
Return	75.2	69.3
Ret/OA	77.6	41.3
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	7,270	2,192
Terminal	7,270	2,192
Main Fan	7,270	2,192
Sec Fan	0	0
Nom Vent	1,169	1,054
AHU Vent	1,169	1,054
Infil	528	528
MinStop/Rh	2,192	2,192
Return	7,798	2,720
Exhaust	1,697	1,582
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	16.1	48.1
cfm/ft²	0.69	0.21
cfm/ton	367.04	
ft²/ton	533.37	
Btu/hr·ft²	22.50	-14.50
No. People	84	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	19.8	237.7	180.1	7,225	77.6	64.2	69.5	55.0	53.1	58.0
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	19.8	237.7								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	10,564		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	1,500	124	8
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-96.5	2,192	55.0	95.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-56.6	1,169	11.0	55.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-153.2			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA.trc

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APPENDIX F: Event Level Raising

Bedrock & Soil Excavation

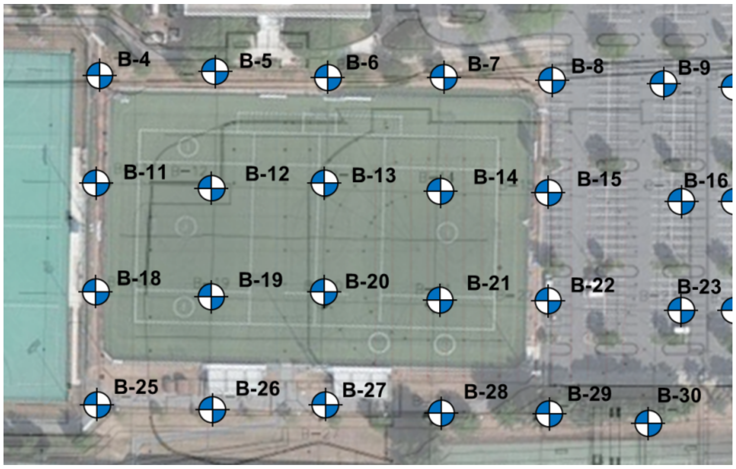


Figure 120: Boring Points on Site

Table 32: Rock Elevation Averages

Bore #	PT	Elevation	Bore #	PT	Elevation	Bore #	PT	Elevation
B-25	15	1159 4/5	B-18	25	1170	B-11	15	1170
B-26	20	1162 1/2	B-19	10	1170	B-12	10	1170
B-18	25	1170	B-11	15	1170	B-4	21	1170 1/2
B-19	10	1170	B-12	10	1170	B-5	16	1170 1/2
AVE	**17 1/2**	**1165 4/7**	**AVE**	**15**	**1170**	**AVE**	**15 1/2**	**1170 1/4**
B-26	20	1162 1/2	B-19	10	1170	B-12	10	1170
B-27	15	1165	B-20	15	1170	B-13	25	1170
B-19	10	1170	B-12	10	1170	B-5	16	1170 1/2
B-20	15	1170	B-13	25	1170	B-6	7	1176
AVE	**15**	**1166 7/8**	**AVE**	**15**	**1170**	**AVE**	**14 1/2**	**1171 5/8**
B-27	15	1165	B-20	15	1170	B-13	25	1170
B-28	10	1168	B-21	15	1170	B-14	25	1170
B-20	15	1170	B-13	25	1170	B-6	7	1176
B-21	15	1170	B-14	25	1170	B-7	13	1173 1/2
AVE	**13 3/4**	**1168 1/4**	**AVE**	**20**	**1170**	**AVE**	**17 1/2**	**1172 3/8**
B-28	10	1168	B-21	15	1170	B-14	25	1170
B-29	7	1169	B-22	2	1170 1/2	B-15	9	1170
B-21	15	1170	B-14	25	1170	B-7	13	1173 1/2
B-22	2	1170 1/2	B-15	9	1173	B-8	8	1172 1/2
AVE	**8 1/2**	**1169 3/8**	**AVE**	**12 3/4**	**1170 7/8**	**AVE**	**13 3/4**	**1171 1/2**
B-29	7	1169	B-22	2	1170 1/2	B-15	9	1170
B-30	6	1170	B-23	4	1171	B-16	5	1173 1/2
B-22	2	1170 1/2	B-15	9	1173	B-8	8	1172 1/2
B-23	4	1171	B-16	5	1173 1/2	B-9	2	1174
AVE	**4 3/4**	**1170 1/8**	**AVE**	**5**	**1172**	**AVE**	**6**	**1172 1/2**

Table 33: Current Design Excavation Amounts

Geotech Report Elevation (ft)	1170
Entrance Elevation (ft)	1176 5/6
Excavation Level (ft)	1153 2/3
Ice Melt Pit Elevation Level (ft)	1152 2/3
Hydro Pit Elevation Level (ft)	1146 7/12
Elevator Elevation Level 1 (ft)	1150 1/2
Elevator Elevation Level 2 (ft)	1148 1/2

Boring Section	Ave Boring Elevation	Ave Rock Elevation	Sectional Area	Ave Sect Area Rock Depth Below 1170	Rock Above /Below Exc Lvl	Rock Depth to be Rmvd	CF Rock to be Rmvd	CY Rock to be Rmvd	Soil Depth to be Rmvd	CF Soil to be Rmvd	CY Soil to be Rmvd
B-25, 26, 18, 19	1165 4/7	1152 1/2	8500	17 1/2	1 1/6	0	0	0	12	102000	3778
B-25, 26, 32, 33			5100						12	61200	2267
B-26, 27, 19, 20	1166 7/8	1155	10000	15	-1 1/3	2	20000	741	12	120000	4445
B-26, 27, 33, 34			6000		-1 1/3	2	12000	445	12	72000	2667
B-27, 28, 20, 21	1168 1/4	1156 1/4	10000	13 3/4	-2 7/12	3	30000	1112	12	120000	4445
B-27, 28, 34, 35			6000		-2 7/12	3	18000	667	12	72000	2667
Elevator #3 Pit Level 1		1156 1/4	296	13 3/4	-5 3/4	4	1184	44	0	0	0
Elevator #3 Pit Level 2		1156 1/4	76	13 3/4	-7 3/4	2	152	6	0	0	0
B-28, 29, 21, 22	1169 3/8	1161 1/2	11000	8 1/2	-7 5/6	8	88000	3260	8	88000	3260
B-29, 30, 22, 23	1170 1/8	1165 1/4	12100	4 3/4	-11 7/12	12	145200	5378	5	60500	2241
Elevator #2 Pit Level 1		1165 1/4	307	4 3/4	-14 3/4	4	1228	46	0	0	0
Elevator #2 Pit Level 2		1165 1/4	64	4 3/4	-16 3/4	2	128	5	0	0	0
B-18, 19, 11, 12	1170	1155	8500	15	-1 1/3	2	17000	630	15	127500	4723
B-19, 20, 12, 13	1170	1155	10000	15	-1 1/3	2	20000	741	15	150000	5556
B-20, 21, 13, 14	1170	1150	10000	20	3 2/3	0	0	0	17	170000	6297
B-21, 22, 14, 15	1170 7/8	1157 1/4	10000	12 3/4	-3 7/12	4	40000	1482	14	140000	5186
B-22, 23, 15, 16	1172	1165	11000	5	-11 1/3	12	132000	4889	7	77000	2852
B-11, 12, 4, 5	1170 1/4	1154 1/2	5625	15 1/2	- 5/6	1	5625	209	16	90000	3334
B-12, 13, 5, 6	1171 5/8	1155 1/2	8500	14 1/2	-1 5/6	2	17000	630	17	144500	5352
Ice Melt Sump		1155 1/2	353	14 1/2	-2 5/6	1	353	14	0	0	0
B-13, 14, 6, 7	1172 3/8	1152 1/2	8500	17 1/2	1 1/6	0	0	0	19	161500	5982
B-14, 15, 7, 8	1171 1/2	1156 1/4	8500	13 3/4	-2 7/12	3	25500	945	16	136000	5038
Hydro Pit		1156 1/4	1170	13 3/4	-9 2/3	8	9360	347	0	0	0
B-15, 16, 8, 9	1172 1/2	1164	9350	6	-10 1/3	11	102850	3810	9	84150	3117
Elevator #1 Pit Level 1		1164	266	6	-13 1/2	4	1064	40	0	0	0
Elevator #1 Pit Level 2		1164	78	6	-15 1/2	2	156	6	0	0	0
						Total	**685580** CF	**25401** CY		**1976350** CF	**73207** CY

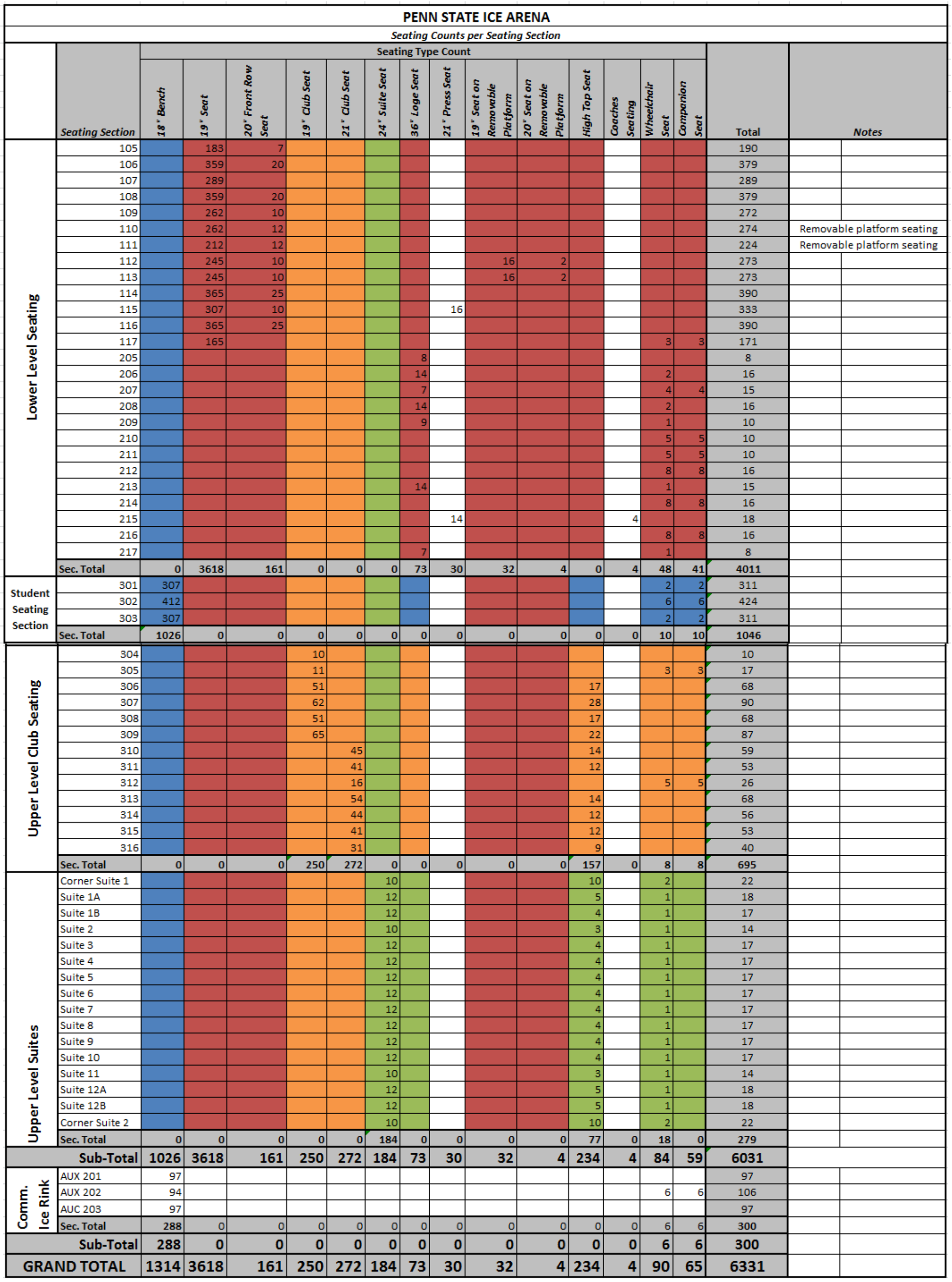
Table 34: Event Level Raising Excavation Amounts

Geotech Report Elevation (ft)	1170
Main Concourse Elevation (ft)	1176 5/6
Excavation Level (ft)	1156 5/6
Ice Melt Pit Elevation Level (ft)	1155 5/6
Hydro Pit Elevation Level (ft)	1149 3/4
Elevator Elevation Level 1 (ft)	1153 2/3
Elevator Elevation Level 2 (ft)	1151 2/3

Boring Section	Ave Boring Elevation	Ave Rock Elevation	Sectional Area	Ave Sec Area Rock Depth Below 1170	Rock Above /Below Exc Lvl	Rock Depth to be Rmvd	CF Rock to be Rmvd	CY Rock to be Rmvd	Soil Depth to be Rmvd	CF Soil to be Rmvd	CY Soil to be Rmvd
B-25, 26, 18, 19	1165 4/7	1152 1/2	8500	17 1/2	4 1/3	0	0	0	9	76500	2834
B-25, 26, 32, 33			5100						9	45900	1700
B-26, 27, 19, 20	1166 7/8	1155	10000	15	1 5/6	0	0	0	11	110000	4075
B-26, 27, 33, 34			6000						11	66000	2445
B-27, 28, 20, 21	1168 1/4	1156 1/4	10000	13 3/4	7/12	0	0	0	12	120000	4445
B-27, 28, 34, 35			6000						12	72000	2667
Elevator #3 Pit Level 1		1156 1/4	296	13 3/4	-2 7/12	3	888	33	0	0	0
Elevator #3 Pit Level 2		1156 1/4	76	13 3/4	-4 7/12	2	152	6	0	0	0
B-28, 29, 21, 22	1169 3/8	1161 1/2	11000	8 1/2	-4 2/3	5	55000	2038	8	88000	3260
B-29, 30, 22, 23	1170 1/8	1165 1/4	12100	4 3/4	-8 5/12	9	108900	4034	5	60500	2241
Elevator #2 Pit Level 1		1165 1/4	307	4 3/4	-11 7/12	4	1228	46	0	0	0
Elevator #2 Pit Level 2		1165 1/4	64	4 3/4	-13 7/12	2	128	5	0	0	0
B-18, 19, 11, 12	1170	1155	8500	15	1 5/6	0	0	0	14	119000	4408
B-19, 20, 12, 13	1170	1155	10000	15	1 5/6	0	0	0	14	140000	5186
B-20, 21, 13, 14	1170	1150	10000	20	6 5/6	0	0	0	14	140000	5186
B-21, 22, 14, 15	1170 7/8	1157 1/4	10000	12 3/4	- 5/12	1	10000	371	14	140000	5186
B-22, 23, 15, 16	1172	1165	11000	5	-8 1/6	9	99000	3667	7	77000	2852
B-11, 12, 4, 5	1170 1/4	1154 1/2	5625	15 1/2	2 1/3	0	0	0	14	78750	2917
B-12, 13, 5, 6	1171 5/8	1155 1/2	8500	14 1/2	1 1/3	0	0	0	15	127500	4723
Ice Melt Sump		1155 1/2	353	14 1/2	1/3	0	0	0	1	353	14
B-13, 14, 6, 7	1172 3/8	1152 1/2	8500	17 1/2	4 1/3	0	0	0	16	136000	5038
B-14, 15, 7, 8	1171 1/2	1156 1/4	8500	13 3/4	7/12	0	0	0	15	127500	4723
Hydro Pit		1156 1/4	1170	13 3/4	-6 1/2	7	8190	304	1	1170	44
B-15, 16, 8, 9	1172 1/2	1164	9350	6	-7 1/6	8	74800	2771	9	84150	3117
Elevator #1 Pit Level 1		1164	266	6	-10 1/3	4	1064	40	0	0	0
Elevator #1 Pit Level 2		1164	78	6	-12 1/3	2	156	6	0	0	0
						Total	**358286 CF**	**13275 CY**		**1810323 CF**	**67061 CY**

Seating Capacity & Price Points

Table 35: Existing Seating Layout



PENN STATE ICE ARENA

Seating Counts per Seating Section

	Seating Section	*Seating Type Count*														*Total*	*Notes*
		18" Bench	*19" Seat*	*20" Front Row Seat*	*19" Club Seat*	*21" Club Seat*	*24" Suite Seat*	*36" Loge Seat*	*21" Press Seat*	*19" Seat on Removable Platform*	*20" Seat on Removable Platform*	*High Top Seat*	*Coaches Seating*	*Wheelchair Seat*	*Companion Seat*		
Lower Level Seating	105		183	7												190	
	106		359	20												379	
	107		289													289	
	108		359	20												379	
	109		262	10												272	
	110		262	12												274	Removable platform seating
	111		212	12												224	Removable platform seating
	112		245	10						16	2					273	
	113		245	10						16	2					273	
	114		365	25												390	
	115		307	10					16							333	
	116		365	25												390	
	117		165											3	3	171	
	205							8								8	
	206							14						2		16	
	207							7						4	4	15	
	208							14						2		16	
	209							9						1		10	
	210													5	5	10	
	211													5	5	10	
	212													8	8	16	
	213							14						1		15	
	214													8	8	16	
	215								14				4			18	
	216													8	8	16	
	217							7						1		8	
	Sec. Total	0	3618	161	0	0	0	73	30	32	4	0	4	48	41	4011	
Student Seating Section	301	307												2	2	311	
	302	412												6	6	424	
	303	307												2	2	311	
	Sec. Total	1026	0	0	0	0	0	0	0	0	0	0	0	10	10	1046	
Upper Level Club Seating	304				10											10	
	305				11									3	3	17	
	306				51							17				68	
	307				62							28				90	
	308				51							17				68	
	309				65							22				87	
	310					45						14				59	
	311					41						12				53	
	312					16								5	5	26	
	313					54						14				68	
	314					44						12				56	
	315					41						12				53	
	316					31						9				40	
	Sec. Total	0	0	0	250	272	0	0	0	0	0	157	0	8	8	695	
Upper Level Suites	Corner Suite 1						10					10		2		22	
	Suite 1A						12					5		1		18	
	Suite 1B						12					4		1		17	
	Suite 2						10					3		1		14	
	Suite 3						12					4		1		17	
	Suite 4						12					4		1		17	
	Suite 5						12					4		1		17	
	Suite 6						12					4		1		17	
	Suite 7						12					4		1		17	
	Suite 8						12					4		1		17	
	Suite 9						12					4		1		17	
	Suite 10						12					4		1		17	
	Suite 11						10					3		1		14	
	Suite 12A						12					5		1		18	
	Suite 12B						12					5		1		18	
	Corner Suite 2						10					10		2		22	
	Sec. Total	0	0	0	0	0	184	0	0	0	0	77	0	18	0	279	
Sub-Total		**1026**	**3618**	**161**	**250**	**272**	**184**	**73**	**30**	**32**	**4**	**234**	**4**	**84**	**59**	**6031**	
Comm. Ice Rink	AUX 201	97														97	
	AUX 202	94												6	6	106	
	AUC 203	97														97	
	Sec. Total	288	0	0	0	0	0	0	0	0	0	0	0	6	6	300	
Sub-Total		**288**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**6**	**6**	**300**	
GRAND TOTAL		**1314**	**3618**	**161**	**250**	**272**	**184**	**73**	**30**	**32**	**4**	**234**	**4**	**90**	**65**	**6331**	

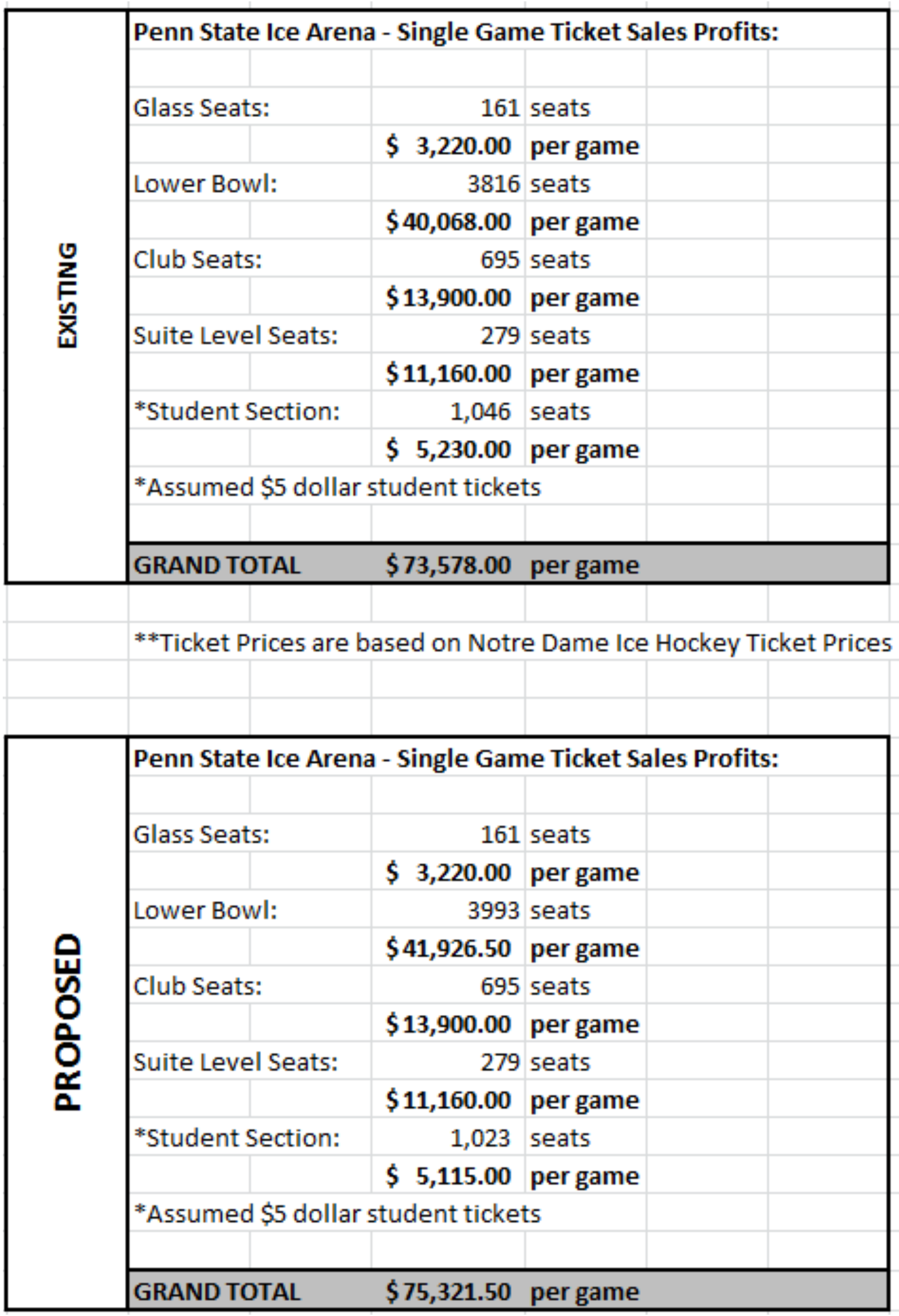
Table 36: Proposed Alternative Seating Layout

PENN STATE ICE ARENA

Seating Counts per Seating Section

	Seating Section	Seating Type Count														Total	Notes
		18" Bench	19" Seat	20" Front Row Seat	19" Club Seat	21" Club Seat	24" Suite Seat	36" Loge Seat	21" Press Seat	19" Seat on Removable Platform	20" Seat on Removable Platform	High Top Seat	Coaches Seating	Wheelchair Seat	Companion Seat		
	105		185	7												192	
	106		369	20												389	
	107		293													293	
	108		381	20												401	
	109		326	10												336	
	110		317	12												329	Removable platform seating
	111		221	12												233	Removable platform seating
	112		285	10						16	2					313	
	113		285	10						16	2					313	
	114		387	25												412	
	115		279	10					16							305	
	116		387	25												412	
	117		180											3	3	186	
	205							0						2	2	4	
	206							0						4	4	8	
	207							0						4	4	8	
	208							0						3	3	6	
	209							0						1	1	2	
	210							0						1	1	2	
	211							0						2	2	4	
	212													2	2	4	
	213							0						2	2	4	
	214													3	3	6	
	215								14				4			18	
	216													3	3	6	
	217							0						1	1	2	
	Sec. Total	0	3895	161	0	0	0	0	30	32	4	0	4	31	31	4188	
	301	307												2	2	311	
	302	389												6	6	401	
	303	307												2	2	311	
	Sec. Total	1003	0	0	0	0	0	0	0	0	0	0	0	10	10	1023	
Upper Level Club Seating	304				10											10	
	305				11									3	3	17	
	306				51							17				68	
	307				62							28				90	
	308				51							17				68	
	309				65							22				87	
	310					45						14				59	
	311					41						12				53	
	312					16								5	5	26	
	313					54						14				68	
	314					44						12				56	
	315					41						12				53	
	316					31						9				40	
	Sec. Total	0	0	0	250	272	0	0	0	0	0	157	0	8	8	695	
Upper Level Suites	Corner Suite 1						10					10		2		22	
	Suite 1A						12					5		1		18	
	Suite 1B						12					4		1		17	
	Suite 2						10					3		1		14	
	Suite 3						12					4		1		17	
	Suite 4						12					4		1		17	
	Suite 5						12					4		1		17	
	Suite 6						12					4		1		17	
	Suite 7						12					4		1		17	
	Suite 8						12					4		1		17	
	Suite 9						12					4		1		17	
	Suite 10						12					4		1		17	
	Suite 11						10					3		1		14	
	Suite 12A						12					5		1		18	
	Suite 12B						12					5		1		18	
	Corner Suite 2						10					10		2		22	
	Sec. Total	0	0	0	0	0	184	0	0	0	0	77	0	18	0	279	
Sub-Total		1003	3895	161	250	272	184	0	30	32	4	234	4	67	49	6185	
Comm. Ice Rink	AUX 201	97														97	
	AUX 202	94												6	6	106	
	AUC 203	97														97	
	Sec. Total	288	0	0	0	0	0	0	0	0	0	0	0	6	6	300	
Sub-Total		288	0	0	0	0	0	0	0	0	0	0	0	6	6	300	
GRAND TOTAL		1291	3895	161	250	272	184	0	30	32	4	234	4	73	55	6485	

Table 37: Price Comparisons



EXISTING	**Penn State Ice Arena - Single Game Ticket Sales Profits:**		
	Glass Seats:	161	seats
		$ 3,220.00	**per game**
	Lower Bowl:	3816	seats
		$ 40,068.00	**per game**
	Club Seats:	695	seats
		$ 13,900.00	**per game**
	Suite Level Seats:	279	seats
		$ 11,160.00	**per game**
	*Student Section:	1,046	seats
		$ 5,230.00	**per game**
	*Assumed $5 dollar student tickets		
	GRAND TOTAL	**$ 73,578.00**	**per game**

**Ticket Prices are based on Notre Dame Ice Hockey Ticket Prices

PROPOSED	**Penn State Ice Arena - Single Game Ticket Sales Profits:**		
	Glass Seats:	161	seats
		$ 3,220.00	**per game**
	Lower Bowl:	3993	seats
		$ 41,926.50	**per game**
	Club Seats:	695	seats
		$ 13,900.00	**per game**
	Suite Level Seats:	279	seats
		$ 11,160.00	**per game**
	*Student Section:	1,023	seats
		$ 5,115.00	**per game**
	*Assumed $5 dollar student tickets		
	GRAND TOTAL	**$ 75,321.50**	**per game**

Sightline Sections

Figure 121: Student Section - Section "E"

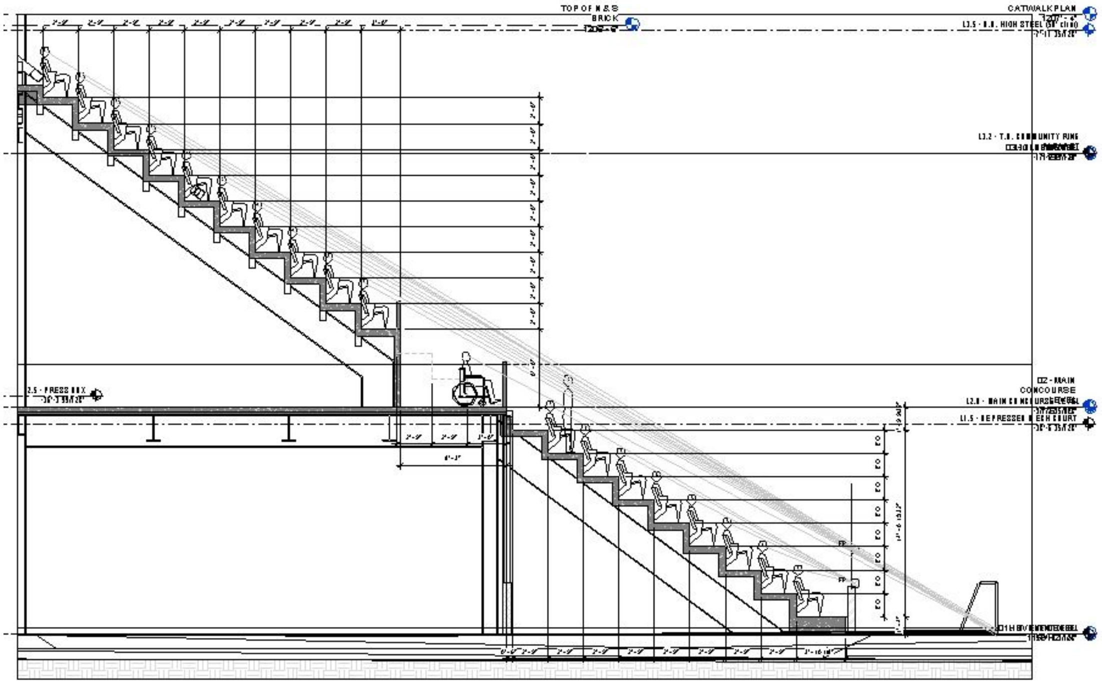
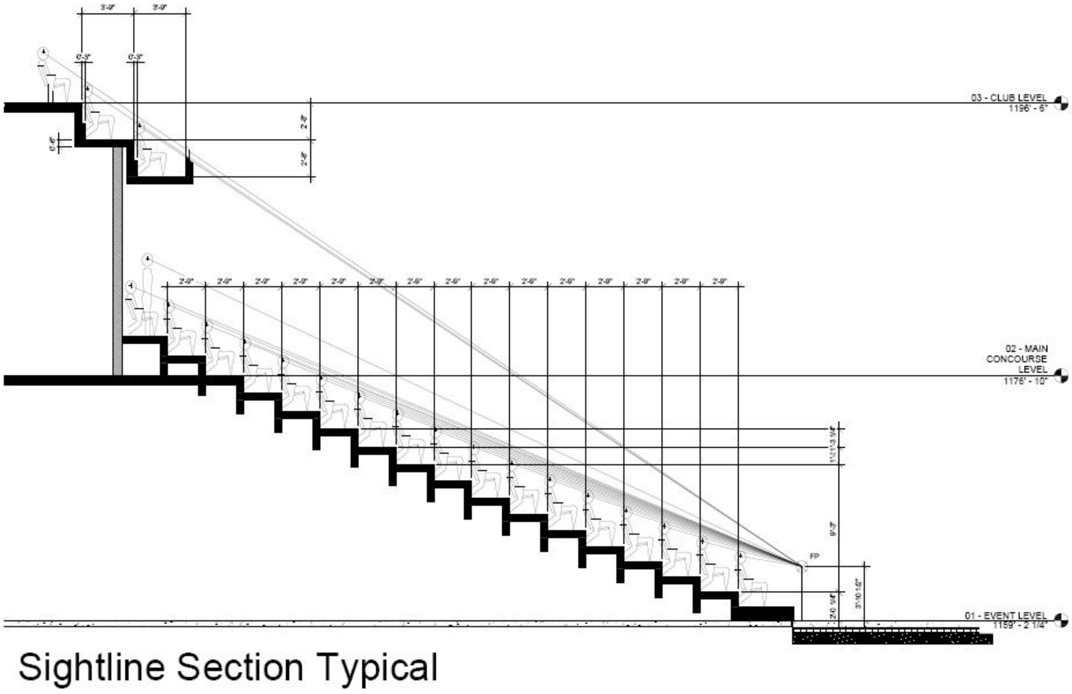
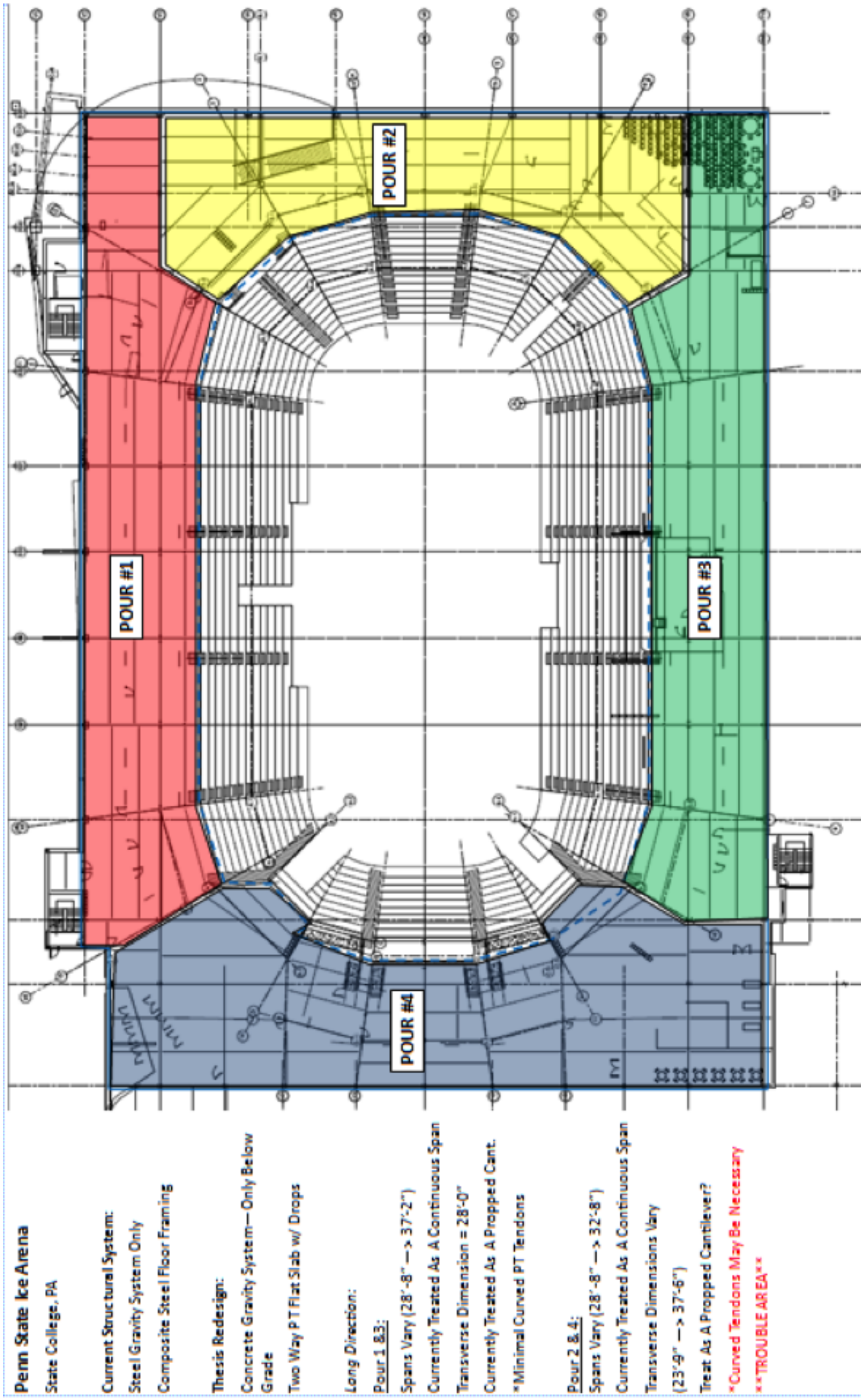


Figure 122: Typical Section - Continuous Lower Bowl Seating



Two-Way Post-Tensioned Flat Plate Calculations

Figure 123: Constructability Review



Penn State Ice Arena
State College, PA

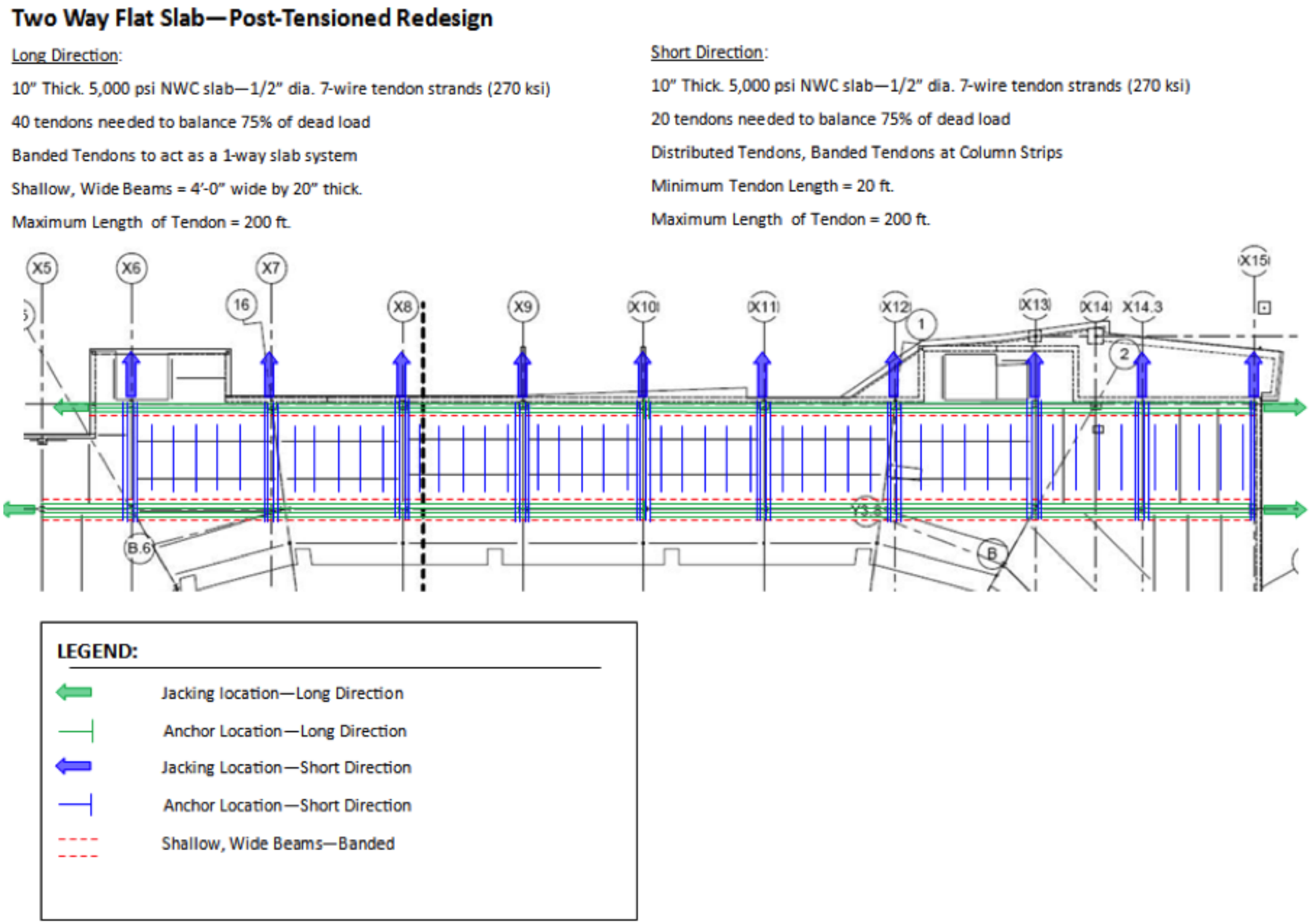
Current Structural System:
Steel Gravity System Only
Composite Steel Floor Framing

Thesis Redesign:
Concrete Gravity System—Only Below Grade
Two Way PT Flat Slab w/ Drops

Long Direction:
Pour 1 &3:
Spans Vary (28'-8" —> 37'-2")
Currently Treated As A Continuous Span
Transverse Dimension = 28'-0"
Currently Treated As A Propped Cant.
*Minimal Curved PT Tendons

Pour 2 & 4:
Spans Vary (28'-8" —> 32'-8")
Currently Treated As A Continuous Span
Transverse Dimensions Vary
(23'-9" —> 37'-6")
Treat As A Propped Cantilever?
*Curved Tendons May Be Necessary
TROUBLE AREA

Figure 124: Two-Way PT Flat Plate - Tendon Layout



Two Way Flat Slab—Post-Tensioned Redesign

Long Direction:

10" Thick. 5,000 psi NWC slab—1/2" dia. 7-wire tendon strands (270 ksi)

40 tendons needed to balance 75% of dead load

Banded Tendons to act as a 1-way slab system

Shallow, Wide Beams = 4'-0" wide by 20" thick.

Maximum Length of Tendon = 200 ft.

Short Direction:

10" Thick. 5,000 psi NWC slab—1/2" dia. 7-wire tendon strands (270 ksi)

20 tendons needed to balance 75% of dead load

Distributed Tendons, Banded Tendons at Column Strips

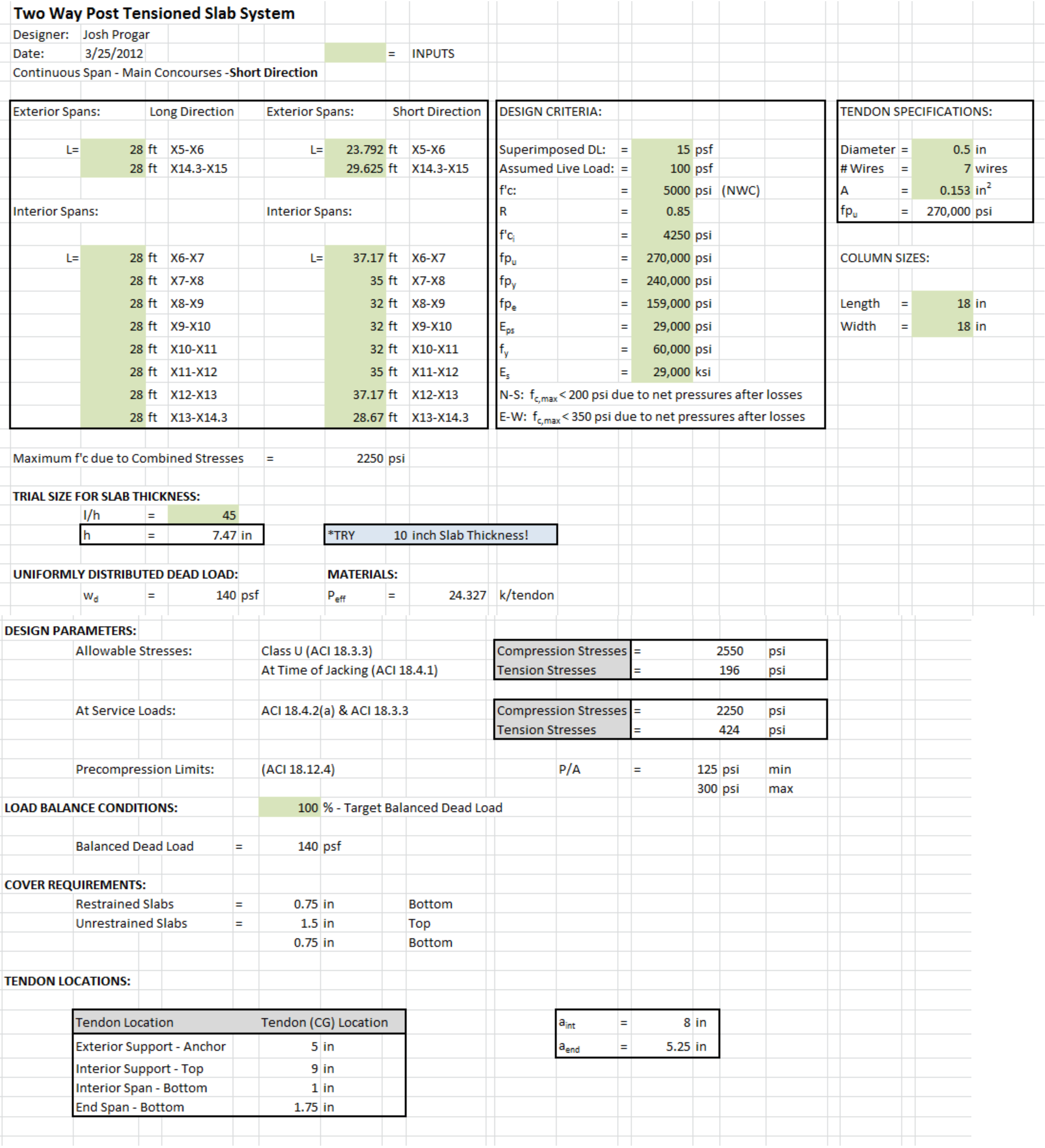
Minimum Tendon Length = 20 ft.

Maximum Length of Tendon = 200 ft.

LEGEND:

⬅	Jacking location—Long Direction
⊣	Anchor Location—Long Direction
⬅	Jacking Location—Short Direction
⊣	Anchor Location—Short Direction
- - -	Shallow, Wide Beams—Banded

Table 38: Two-Way PT Flat Plate Calculations



Two Way Post Tensioned Slab System

Designer: Josh Progar

Date: 3/25/2012

🟩 = INPUTS

Continuous Span - Main Concourses -**Short Direction**

Exterior Spans:			Long Direction	Exterior Spans:			Short Direction
L=	28	ft	X5-X6	L=	23.792	ft	X5-X6
	28	ft	X14.3-X15		29.625	ft	X14.3-X15
Interior Spans:				Interior Spans:			
L=	28	ft	X6-X7	L=	37.17	ft	X6-X7
	28	ft	X7-X8		35	ft	X7-X8
	28	ft	X8-X9		32	ft	X8-X9
	28	ft	X9-X10		32	ft	X9-X10
	28	ft	X10-X11		32	ft	X10-X11
	28	ft	X11-X12		35	ft	X11-X12
	28	ft	X12-X13		37.17	ft	X12-X13
	28	ft	X13-X14.3		28.67	ft	X13-X14.3

DESIGN CRITERIA:				
Superimposed DL:	=	15	psf	
Assumed Live Load:	=	100	psf	
f'c:	=	5000	psi	(NWC)
R	=	0.85		
$f'c_i$	=	4250	psi	
fp_u	=	270,000	psi	
fp_y	=	240,000	psi	
fp_e	=	159,000	psi	
E_{ps}	=	29,000	psi	
f_y	=	60,000	psi	
E_s	=	29,000	ksi	

N-S: $f_{c,max} < 200$ psi due to net pressures after losses

E-W: $f_{c,max} < 350$ psi due to net pressures after losses

TENDON SPECIFICATIONS:			
Diameter	=	0.5	in
# Wires	=	7	wires
A	=	0.153	in^2
fp_u	=	270,000	psi

COLUMN SIZES:

Length = 18 in

Width = 18 in

Maximum f'c due to Combined Stresses = 2250 psi

TRIAL SIZE FOR SLAB THICKNESS:

l/h = 45

h = 7.47 in

*TRY 10 inch Slab Thickness!

UNIFORMLY DISTRIBUTED DEAD LOAD:

w_d = 140 psf

MATERIALS:

P_{eff} = 24.327 k/tendon

DESIGN PARAMETERS:

Allowable Stresses:	Class U (ACI 18.3.3) At Time of Jacking (ACI 18.4.1)	Compression Stresses	=	2550	psi
		Tension Stresses	=	196	psi
At Service Loads:	ACI 18.4.2(a) & ACI 18.3.3	Compression Stresses	=	2250	psi
		Tension Stresses	=	424	psi

Precompression Limits: (ACI 18.12.4) P/A = 125 psi min

300 psi max

LOAD BALANCE CONDITIONS: 100 % - Target Balanced Dead Load

Balanced Dead Load = 140 psf

COVER REQUIREMENTS:

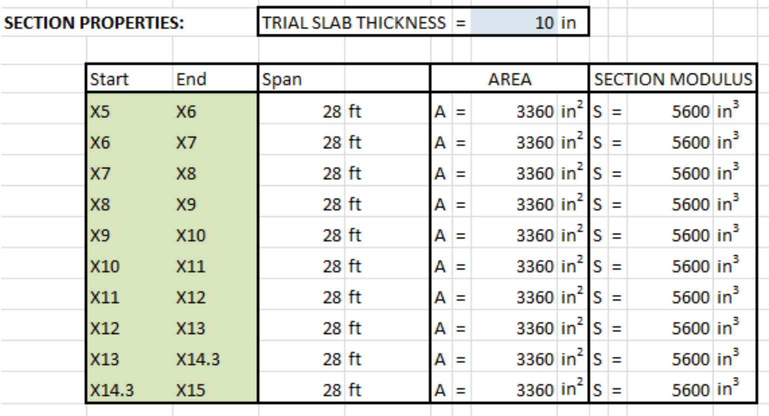
Restrained Slabs	=	0.75	in	Bottom
Unrestrained Slabs	=	1.5	in	Top
		0.75	in	Bottom

TENDON LOCATIONS:

Tendon Location	Tendon (CG) Location	
Exterior Support - Anchor	5	in
Interior Support - Top	9	in
Interior Span - Bottom	1	in
End Span - Bottom	1.75	in

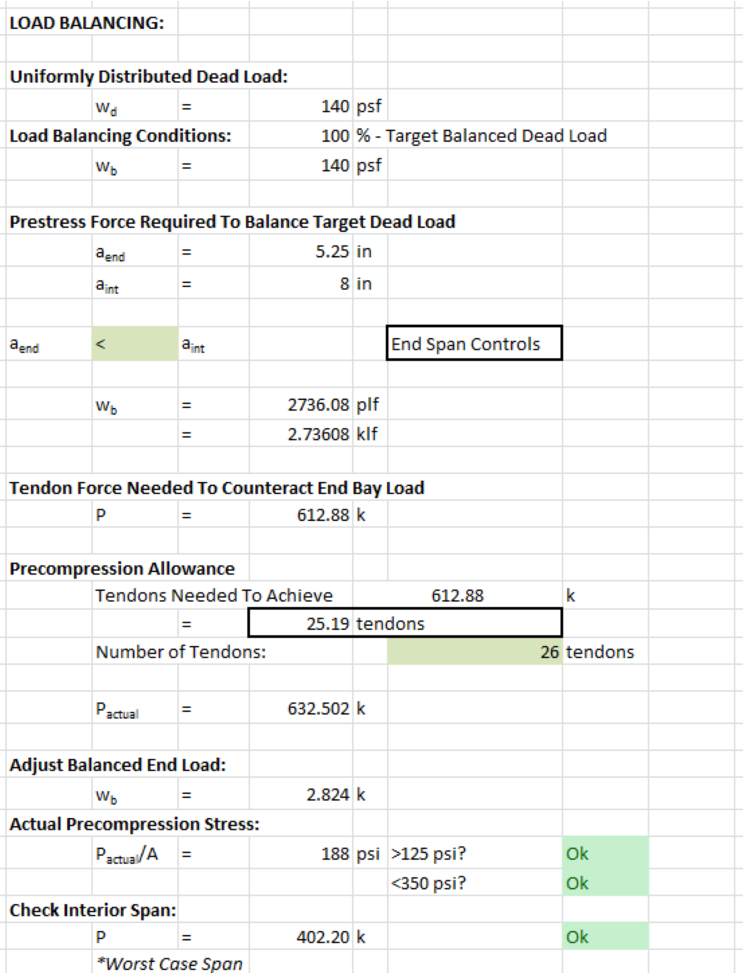
a_{int} = 8 in

a_{end} = 5.25 in



SECTION PROPERTIES: TRIAL SLAB THICKNESS = 10 in

Start	End	Span	AREA	SECTION MODULUS
X5	X6	28 ft	A = 3360 in^2	S = 5600 in^3
X6	X7	28 ft	A = 3360 in^2	S = 5600 in^3
X7	X8	28 ft	A = 3360 in^2	S = 5600 in^3
X8	X9	28 ft	A = 3360 in^2	S = 5600 in^3
X9	X10	28 ft	A = 3360 in^2	S = 5600 in^3
X10	X11	28 ft	A = 3360 in^2	S = 5600 in^3
X11	X12	28 ft	A = 3360 in^2	S = 5600 in^3
X12	X13	28 ft	A = 3360 in^2	S = 5600 in^3
X13	X14.3	28 ft	A = 3360 in^2	S = 5600 in^3
X14.3	X15	28 ft	A = 3360 in^2	S = 5600 in^3



LOAD BALANCING:

Uniformly Distributed Dead Load:

w_d = 140 psf

Load Balancing Conditions: 100 % - Target Balanced Dead Load

w_b = 140 psf

Prestress Force Required To Balance Target Dead Load

a_{end} = 5.25 in

a_{int} = 8 in

a_{end} < a_{int} End Span Controls

w_b = 2736.08 plf

= 2.73608 klf

Tendon Force Needed To Counteract End Bay Load

P = 612.88 k

Precompression Allowance

Tendons Needed To Achieve 612.88 k

= 25.19 tendons

Number of Tendons: 26 tendons

P_{actual} = 632.502 k

Adjust Balanced End Load:

w_b = 2.824 k

Actual Precompression Stress:

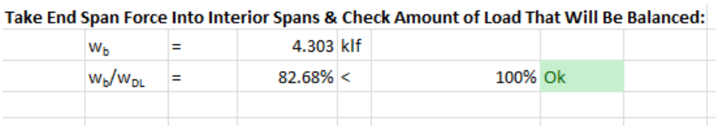
P_{actual}/A = 188 psi >125 psi? Ok

<350 psi? Ok

Check Interior Span:

P = 402.20 k Ok

**Worst Case Span*



Take End Span Force Into Interior Spans & Check Amount of Load That Will Be Balanced:

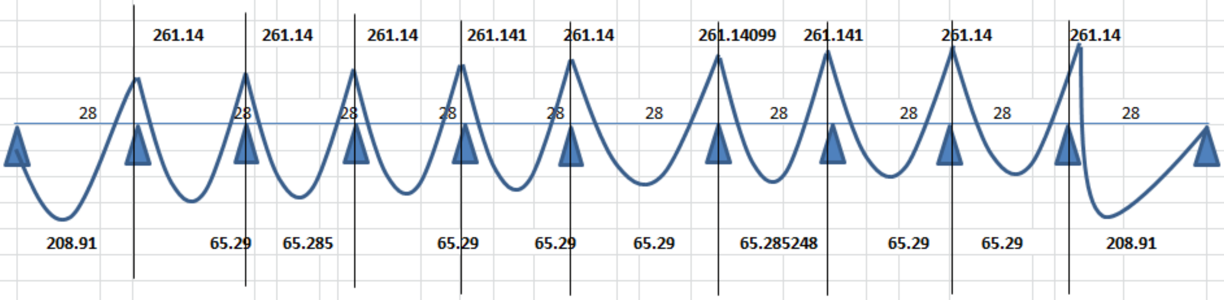
w_b = 4.303 klf

w_b/w_{DL} = 82.68% < 100% Ok

SLAB STRESSES & MOMENTS:

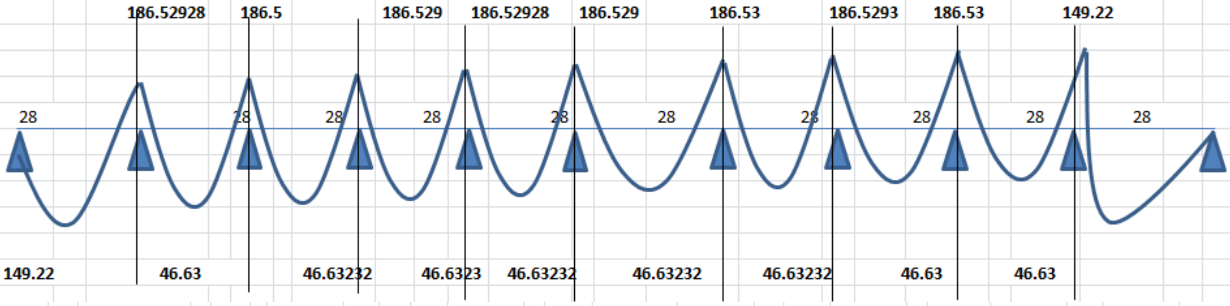
Dead Load Moments: w_{DL} = 3.33088 klf

End Bays @ Midspan:				$0.08wL^2$		*Supports:*			$(-)0.10wL^2$		*Interior Bays @ Midspan*			$0.025wL^2$	
	L=	28	ft	208.9128	k/ft	L=	28	ft	261.14099	k/ft	L=	28	ft	65.28525	k/ft
	L=	28	ft	208.9128	k/ft	L=	28	ft	261.14099	k/ft	L=	28	ft	65.28525	k/ft
						L=	28	ft	261.14099	k/ft	L=	28	ft	65.28525	k/ft
						L=	28	ft	261.14099	k/ft	L=	28	ft	65.28525	k/ft
						L=	28	ft	261.14099	k/ft					



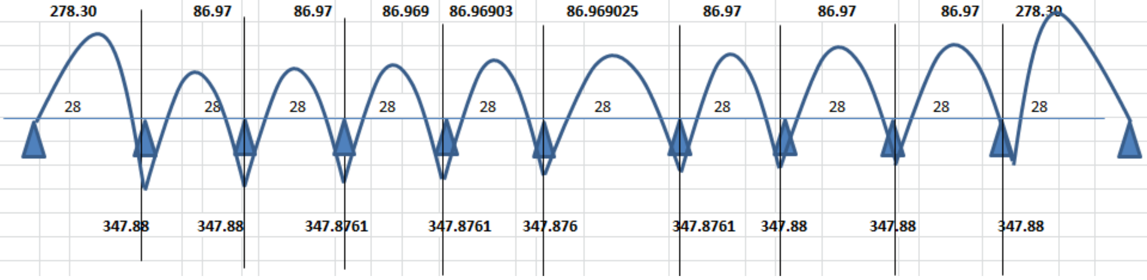
Live Load Moments: w_{LL} = 2.38 klf

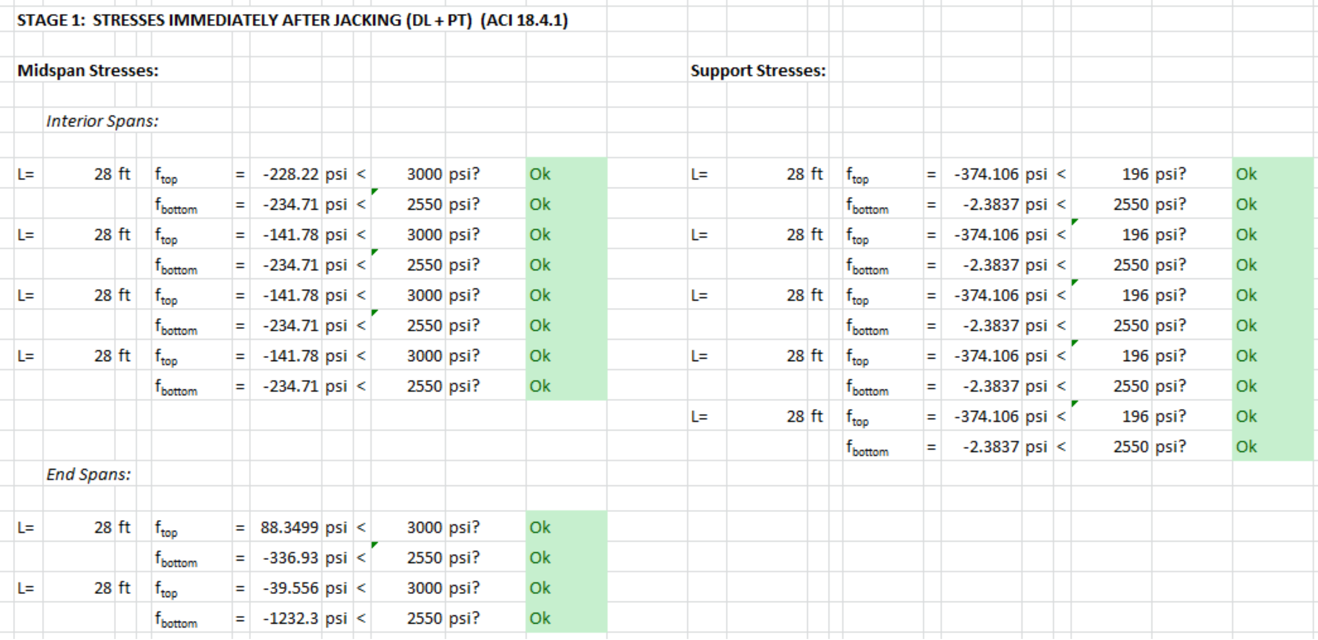
End Bays @ Midspan:				$0.08wL^2$		*Supports:*			$(-)0.10wL^2$		*Interior Bays @ Midspan*			$0.025wL^2$	
	L=	28	ft	149.2234	k/ft	L=	28	ft	186.52928	k/ft	L=	28	ft	46.63232	k/ft
	L=	28	ft	149.2234	k/ft	L=	28	ft	186.52928	k/ft	L=	28	ft	46.63232	k/ft
						L=	28	ft	186.52928	k/ft	L=	28	ft	46.63232	k/ft
						L=	28	ft	186.52928	k/ft	L=	28	ft	46.63232	k/ft
						L=	28	ft	186.52928	k/ft					



Total Balancing Moments, M_{bal} w_{bal} = 4.44 klf

End Bays @ Midspan:				$0.08wL^2$		*Supports:*			$(-)0.10wL^2$		*Interior Bays @ Midspan*			$0.025wL^2$	
	L=	28	ft	278.3009	k/ft	L=	28	ft	347.8761	k/ft	L=	28	ft	86.96903	k/ft
	L=	28	ft	278.3009	k/ft	L=	28	ft	347.8761	k/ft	L=	28	ft	86.96903	k/ft
						L=	28	ft	347.8761	k/ft	L=	28	ft	86.96903	k/ft
						L=	28	ft	347.8761	k/ft	L=	28	ft	86.96903	k/ft
						L=	28	ft	347.8761	k/ft					





STAGE 1: STRESSES IMMEDIATELY AFTER JACKING (DL + PT) (ACI 18.4.1)

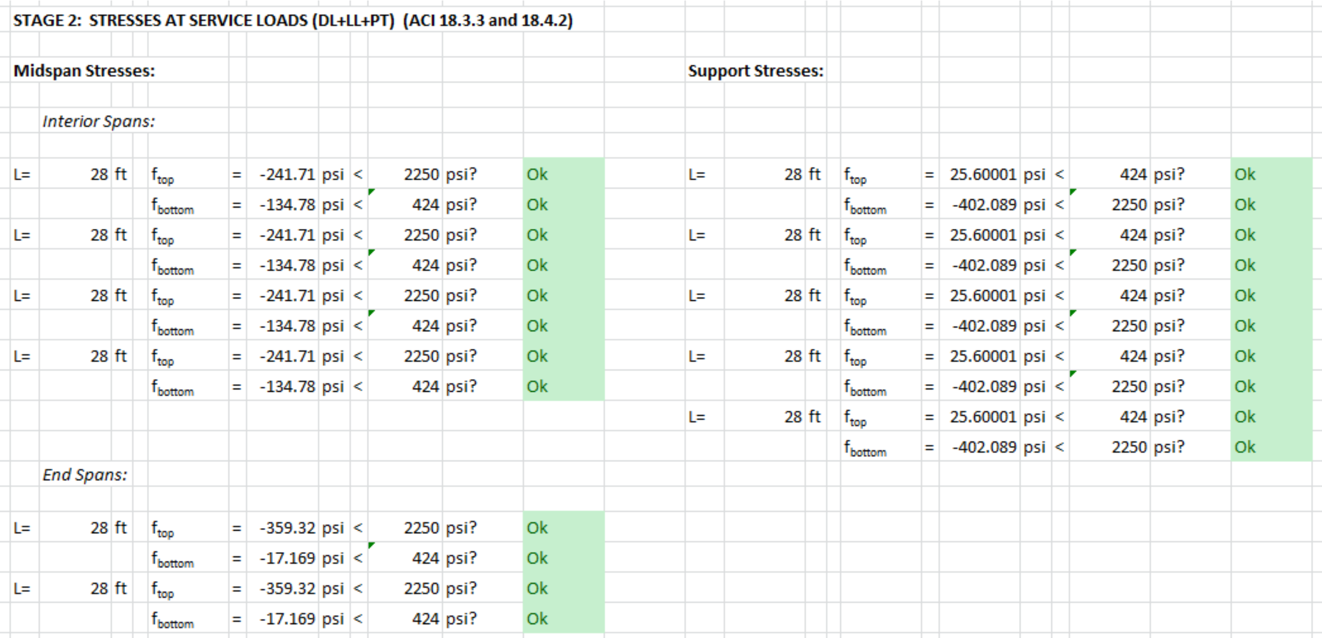
Midspan Stresses: **Support Stresses:**

Interior Spans:

L=	28	ft	f_{top}	=	-228.22	psi	<	3000	psi?	Ok	L=	28	ft	f_{top}	=	-374.106	psi	<	196	psi?	Ok
			f_{bottom}	=	-234.71	psi	<	2550	psi?	Ok				f_{bottom}	=	-2.3837	psi	<	2550	psi?	Ok
L=	28	ft	f_{top}	=	-141.78	psi	<	3000	psi?	Ok	L=	28	ft	f_{top}	=	-374.106	psi	<	196	psi?	Ok
			f_{bottom}	=	-234.71	psi	<	2550	psi?	Ok				f_{bottom}	=	-2.3837	psi	<	2550	psi?	Ok
L=	28	ft	f_{top}	=	-141.78	psi	<	3000	psi?	Ok	L=	28	ft	f_{top}	=	-374.106	psi	<	196	psi?	Ok
			f_{bottom}	=	-234.71	psi	<	2550	psi?	Ok				f_{bottom}	=	-2.3837	psi	<	2550	psi?	Ok
L=	28	ft	f_{top}	=	-141.78	psi	<	3000	psi?	Ok	L=	28	ft	f_{top}	=	-374.106	psi	<	196	psi?	Ok
			f_{bottom}	=	-234.71	psi	<	2550	psi?	Ok				f_{bottom}	=	-2.3837	psi	<	2550	psi?	Ok
											L=	28	ft	f_{top}	=	-374.106	psi	<	196	psi?	Ok
														f_{bottom}	=	-2.3837	psi	<	2550	psi?	Ok

End Spans:

L=	28	ft	f_{top}	=	88.3499	psi	<	3000	psi?	Ok
			f_{bottom}	=	-336.93	psi	<	2550	psi?	Ok
L=	28	ft	f_{top}	=	-39.556	psi	<	3000	psi?	Ok
			f_{bottom}	=	-1232.3	psi	<	2550	psi?	Ok



STAGE 2: STRESSES AT SERVICE LOADS (DL+LL+PT) (ACI 18.3.3 and 18.4.2)

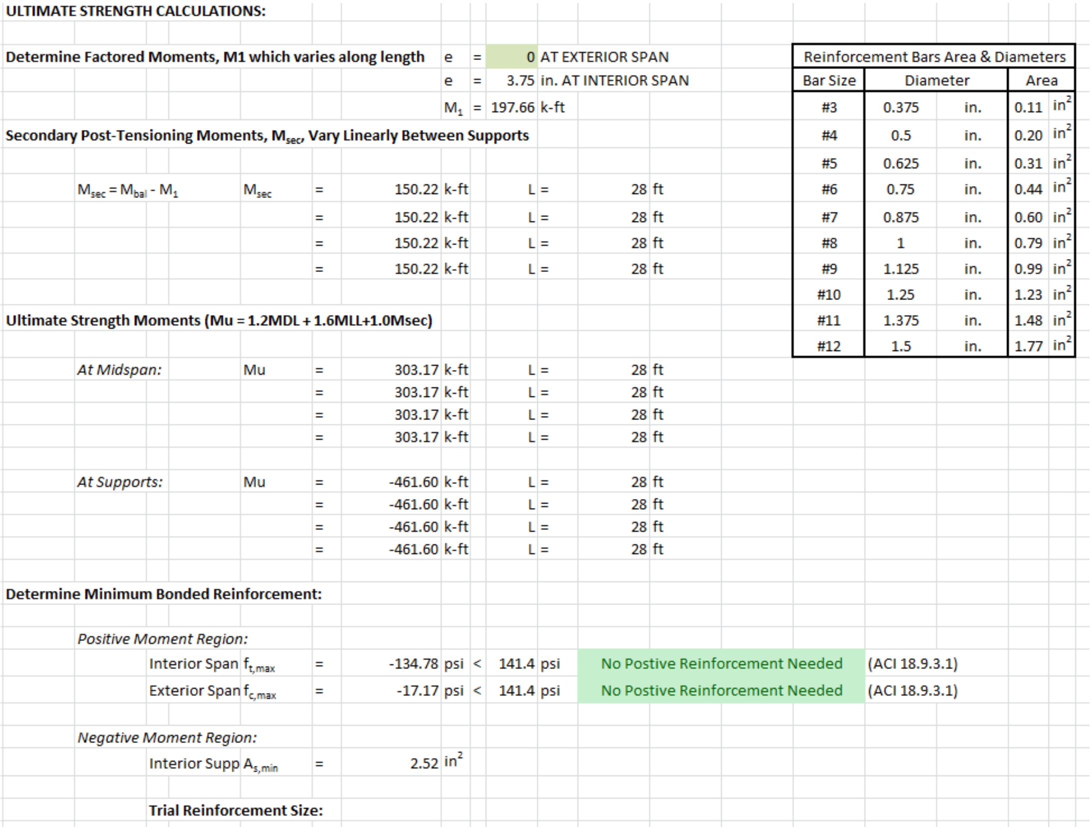
Midspan Stresses: **Support Stresses:**

Interior Spans:

L=	28	ft	f_{top}	=	-241.71	psi	<	2250	psi?	Ok	L=	28	ft	f_{top}	=	25.60001	psi	<	424	psi?	Ok
			f_{bottom}	=	-134.78	psi	<	424	psi?	Ok				f_{bottom}	=	-402.089	psi	<	2250	psi?	Ok
L=	28	ft	f_{top}	=	-241.71	psi	<	2250	psi?	Ok	L=	28	ft	f_{top}	=	25.60001	psi	<	424	psi?	Ok
			f_{bottom}	=	-134.78	psi	<	424	psi?	Ok				f_{bottom}	=	-402.089	psi	<	2250	psi?	Ok
L=	28	ft	f_{top}	=	-241.71	psi	<	2250	psi?	Ok	L=	28	ft	f_{top}	=	25.60001	psi	<	424	psi?	Ok
			f_{bottom}	=	-134.78	psi	<	424	psi?	Ok				f_{bottom}	=	-402.089	psi	<	2250	psi?	Ok
L=	28	ft	f_{top}	=	-241.71	psi	<	2250	psi?	Ok	L=	28	ft	f_{top}	=	25.60001	psi	<	424	psi?	Ok
			f_{bottom}	=	-134.78	psi	<	424	psi?	Ok				f_{bottom}	=	-402.089	psi	<	2250	psi?	Ok
											L=	28	ft	f_{top}	=	25.60001	psi	<	424	psi?	Ok
														f_{bottom}	=	-402.089	psi	<	2250	psi?	Ok

End Spans:

L=	28	ft	f_{top}	=	-359.32	psi	<	2250	psi?	Ok
			f_{bottom}	=	-17.169	psi	<	424	psi?	Ok
L=	28	ft	f_{top}	=	-359.32	psi	<	2250	psi?	Ok
			f_{bottom}	=	-17.169	psi	<	424	psi?	Ok



ULTIMATE STRENGTH CALCULATIONS:

Determine Factored Moments, M1 which varies along length

e = 0 AT EXTERIOR SPAN
e = 3.75 in. AT INTERIOR SPAN
M_1 = 197.66 k-ft

Secondary Post-Tensioning Moments, M_{sec}, Vary Linearly Between Supports

$M_{sec} = M_{bal} - M_1$ M_{sec} = 150.22 k-ft L = 28 ft
= 150.22 k-ft L = 28 ft
= 150.22 k-ft L = 28 ft
= 150.22 k-ft L = 28 ft

Ultimate Strength Moments (Mu = 1.2MDL + 1.6MLL+1.0Msec)

At Midspan: Mu = 303.17 k-ft L = 28 ft
= 303.17 k-ft L = 28 ft
= 303.17 k-ft L = 28 ft
= 303.17 k-ft L = 28 ft

At Supports: Mu = -461.60 k-ft L = 28 ft
= -461.60 k-ft L = 28 ft
= -461.60 k-ft L = 28 ft
= -461.60 k-ft L = 28 ft

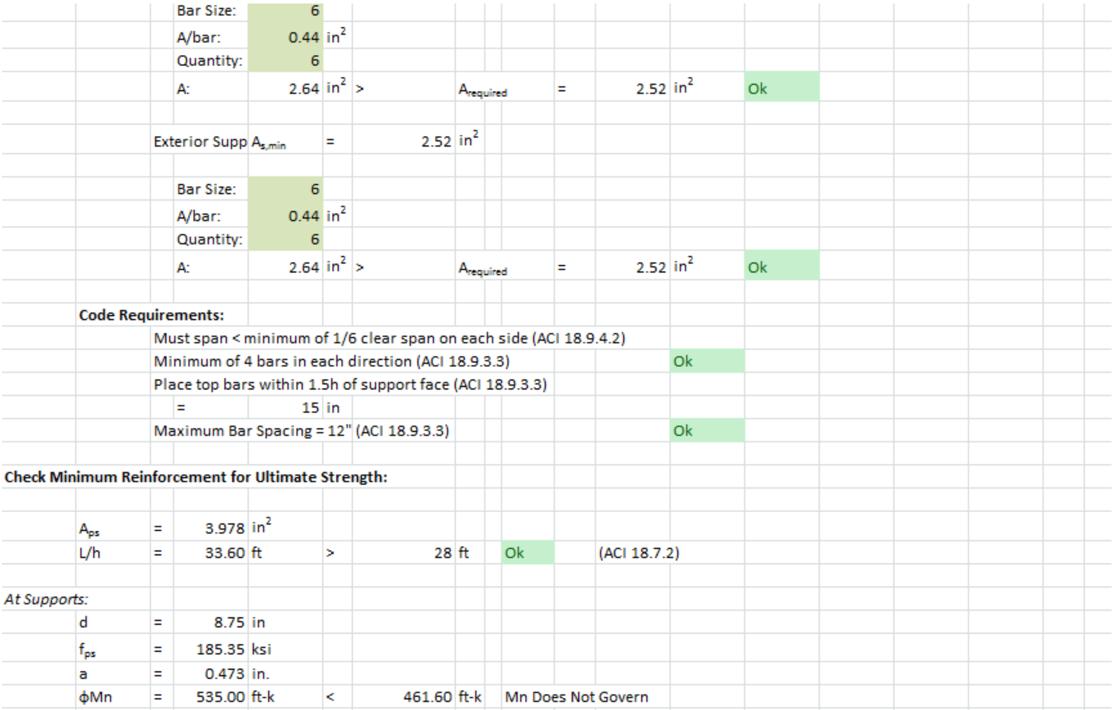
Reinforcement Bars Area & Diameters				
Bar Size	Diameter		Area	
#3	0.375	in.	0.11	in^2
#4	0.5	in.	0.20	in^2
#5	0.625	in.	0.31	in^2
#6	0.75	in.	0.44	in^2
#7	0.875	in.	0.60	in^2
#8	1	in.	0.79	in^2
#9	1.125	in.	0.99	in^2
#10	1.25	in.	1.23	in^2
#11	1.375	in.	1.48	in^2
#12	1.5	in.	1.77	in^2

Determine Minimum Bonded Reinforcement:

Positive Moment Region:
Interior Span $f_{t,max}$ = -134.78 psi < 141.4 psi No Postive Reinforcement Needed (ACI 18.9.3.1)
Exterior Span $f_{c,max}$ = -17.17 psi < 141.4 psi No Postive Reinforcement Needed (ACI 18.9.3.1)

Negative Moment Region:
Interior Supp $A_{s,min}$ = 2.52 in^2

Trial Reinforcement Size:



Bar Size: 6
A/bar: 0.44 in^2
Quantity: 6
A: 2.64 in^2 > $A_{required}$ = 2.52 in^2 Ok

Exterior Supp $A_{s,min}$ = 2.52 in^2

Bar Size: 6
A/bar: 0.44 in^2
Quantity: 6
A: 2.64 in^2 > $A_{required}$ = 2.52 in^2 Ok

Code Requirements:
Must span < minimum of 1/6 clear span on each side (ACI 18.9.4.2)
Minimum of 4 bars in each direction (ACI 18.9.3.3) Ok
Place top bars within 1.5h of support face (ACI 18.9.3.3)
= 15 in
Maximum Bar Spacing = 12" (ACI 18.9.3.3) Ok

Check Minimum Reinforcement for Ultimate Strength:

A_{ps} = 3.978 in^2
L/h = 33.60 ft > 28 ft Ok (ACI 18.7.2)

At Supports:
d = 8.75 in
f_{ps} = 185.35 ksi
a = 0.473 in.
ϕMn = 535.00 ft-k < 461.60 ft-k Mn Does Not Govern

DEFLECTION CALCULATIONS:

Live Load = 100 psf

I_s = 1000 in^3 (12" Strip of Slab)

E_c = 4030509 psi

K	=	1.18	L =	28.00 ft	α_s =	0.042	α_L =	0.042	L_L	=	26.5 ft	L_s =	22.292 ft
	=	0.95	L =	28.00 ft	α_s =	0.045	α_L =	0.039	L_L	=	26.5 ft	L_s =	28.125 ft
	=	0.75	L =	28.00 ft	α_s =	0.051	α_L =	0.025	L_L	=	26.5 ft	L_s =	35.67 ft
	=	0.80	L =	28.00 ft	α_s =	0.050	α_L =	0.028	L_L	=	26.5 ft	L_s =	33.5 ft
	=	0.88	L =	28.00 ft	α_s =	0.044	α_L =	0.035	L_L	=	26.5 ft	L_s =	30.5 ft
	=	0.98	L =	28.67 ft	α_s =	0.042	α_L =	0.041	L_L	=	27.17 ft	L_s =	27.17 ft

*Values from Figure 9-10: Prestressed Concrete: A Fundamental, 5th Edition, Nawy.

Live Load Moments:					**Live Load Deflections:**				
M_s	=	25045 in-lb/ft	L =	28.00 ft	Δ_{LL} =	0.073	Δ_{allow} =	0.933	Ok
M_L	=	35393 in-lb/ft			Δ_{LL} =	0.103	Δ_{allow} =	0.933	Ok
M_s	=	42715 in-lb/ft	L =	28.00 ft	Δ_{LL} =	0.125	Δ_{allow} =	0.933	Ok
M_L	=	32865 in-lb/ft			Δ_{LL} =	0.096	Δ_{allow} =	0.933	Ok
M_s	=	77868 in-lb/ft	L =	28.00 ft	Δ_{LL} =	0.227	Δ_{allow} =	0.933	Ok
M_L	=	21068 in-lb/ft			Δ_{LL} =	0.061	Δ_{allow} =	0.933	Ok
M_s	=	67335 in-lb/ft	L =	28.00 ft	Δ_{LL} =	0.196	Δ_{allow} =	0.933	Ok
M_L	=	23596 in-lb/ft			Δ_{LL} =	0.069	Δ_{allow} =	0.933	Ok
M_s	=	49117 in-lb/ft	L =	28.00 ft	Δ_{LL} =	0.143	Δ_{allow} =	0.933	Ok
M_L	=	29495 in-lb/ft			Δ_{LL} =	0.086	Δ_{allow} =	0.933	Ok
M_s	=	37206 in-lb/ft	L =	28.67 ft	Δ_{LL} =	0.114	Δ_{allow} =	0.956	Ok
M_L	=	36320 in-lb/ft			Δ_{LL} =	0.111	Δ_{allow} =	0.956	Ok

Wide Beam Shear Check:

w_u = 328 psf

Short Direction

V_u = 2601 lb/ft

ϕV_c = 10182 lb/ft Ok

Long Direction (Worst Case)

V_u = 3061 lb/ft

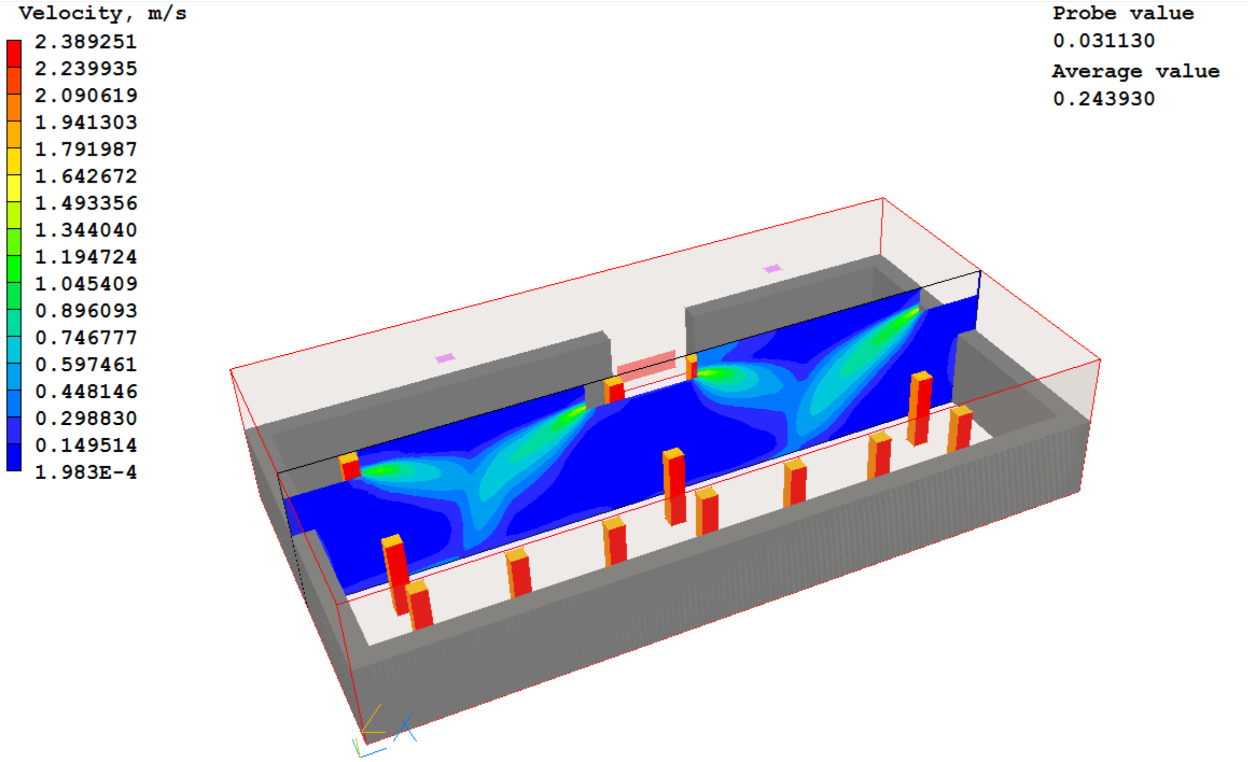
ϕV_c = 10182 lb/ft Ok

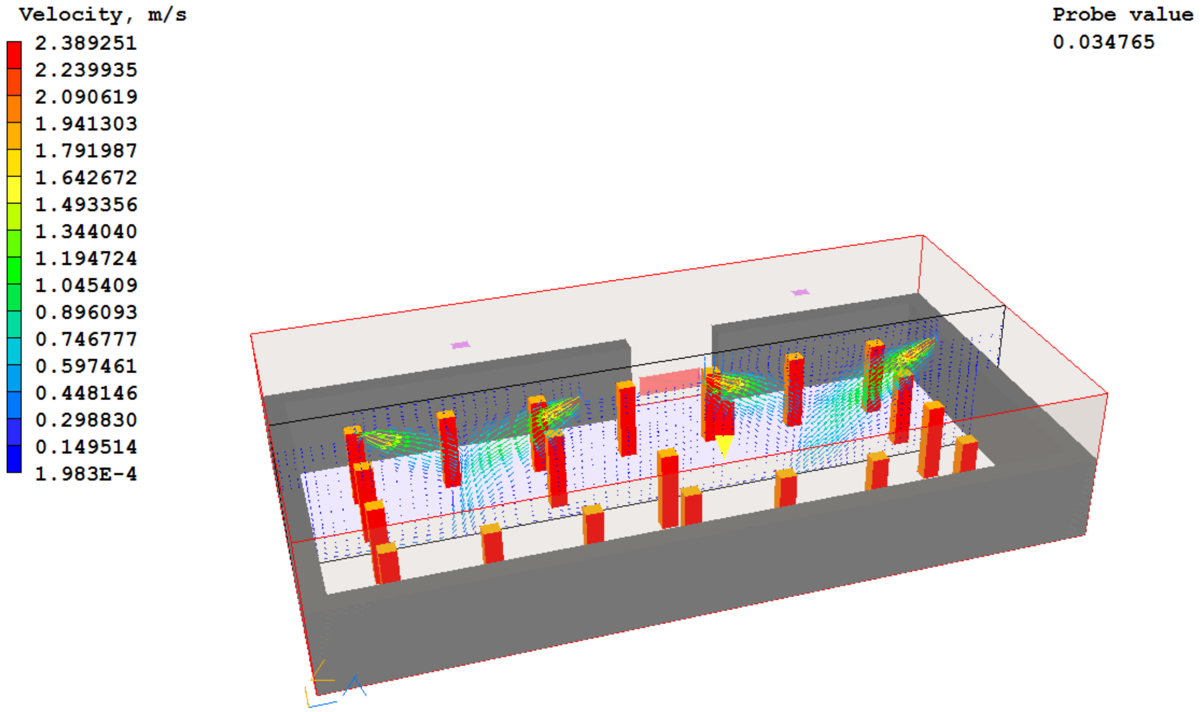
CFD Results

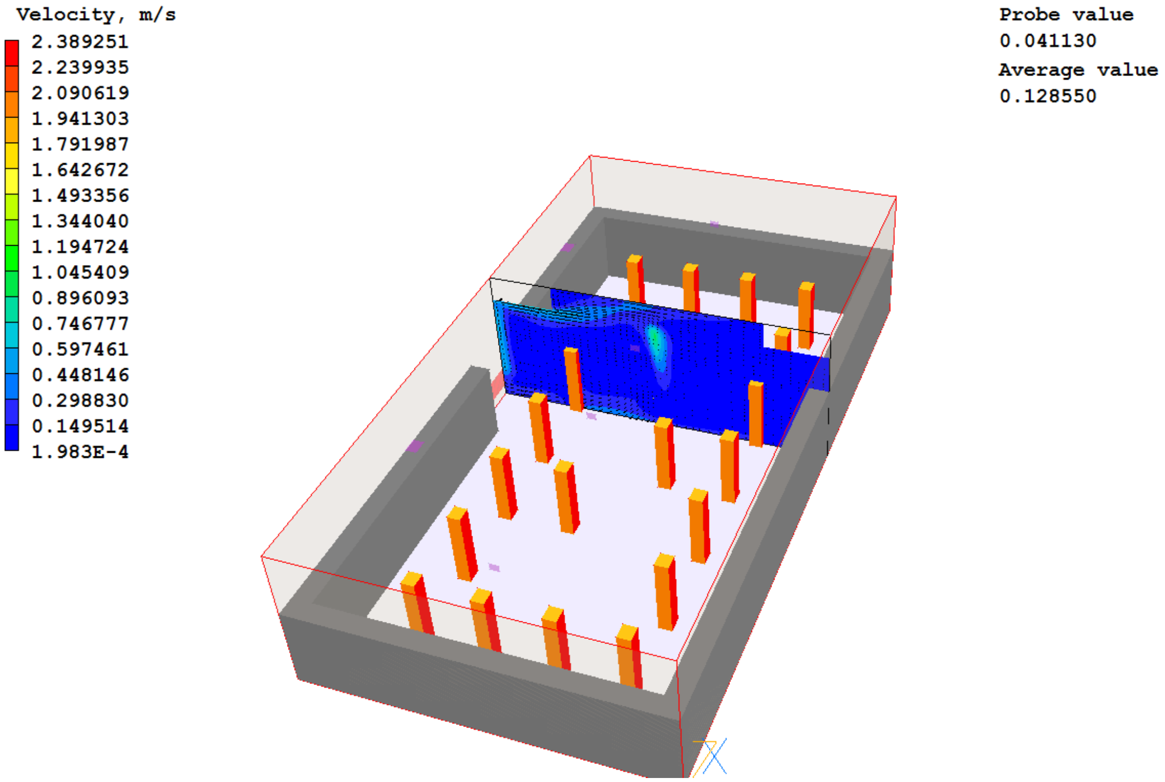
Code

Numerical Scheme	Grid Size	Turbulence model	Computational time (24 GB RAM)
Hybrid	81,46,31	K-E	2:53

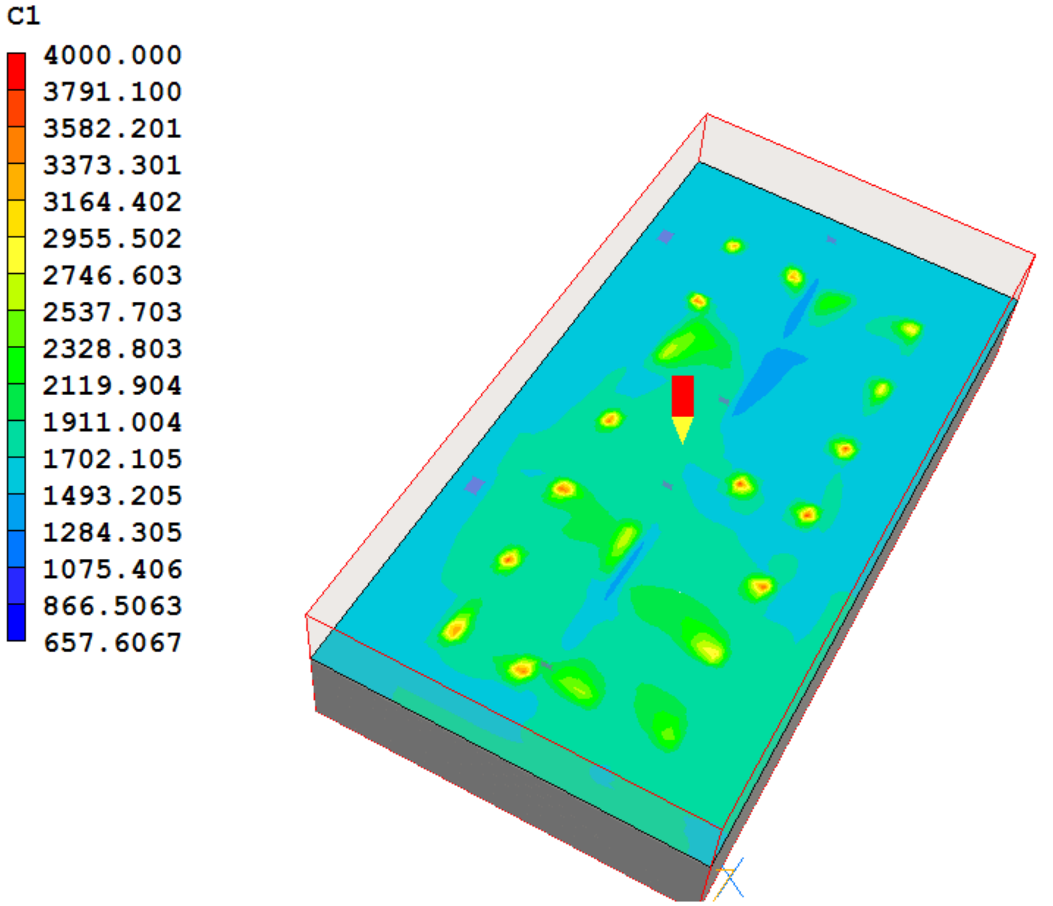
Velocity




Velocity, m/s
2.389251
2.239935
2.090619
1.941303
1.791987
1.642672
1.493356
1.344040
1.194724
1.045409
0.896093
0.746777
0.597461
0.448146
0.298830
0.149514
1.983E-4
Probe value
0.034765


Velocity, m/s
2.389251
2.239935
2.090619
1.941303
1.791987
1.642672
1.493356
1.344040
1.194724
1.045409
0.896093
0.746777
0.597461
0.448146
0.298830
0.149514
1.983E-4
Probe value
0.041130
Average value
0.128550

Concentration:



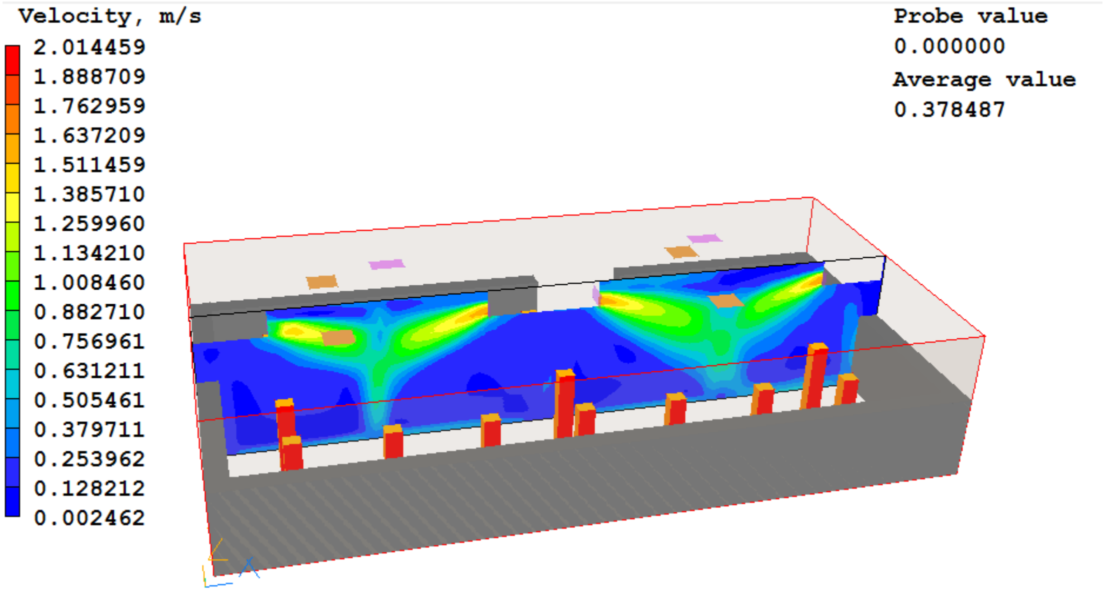
The average room concentration was **1683.4 ppm**. This was calculated by taking 20 plane averages, nine in the Y-direction and 11 in the X-direction and averaging them together.

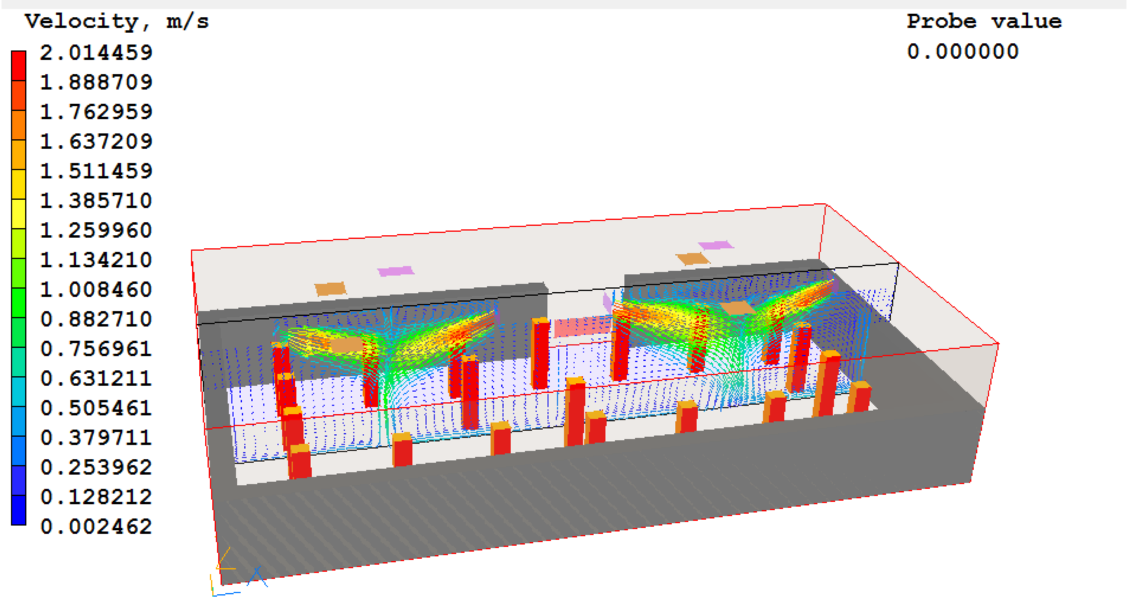
Calculated Ventilation

Residual Calculation		
Mass	P1 Res Sum	4.98E-03
	R1 Pos Sum	4.39E-01
	Residual	**1%**
Temperature	Tem1 Res Sum	5.75E+01
	Tem1 Pos Sum	1.29E+05
	Residual	**0.04%**
Concentration	C1 Res Sum	4.12E+01
	C1 Pos Sum	7.60E+02
	Residual	**5%**

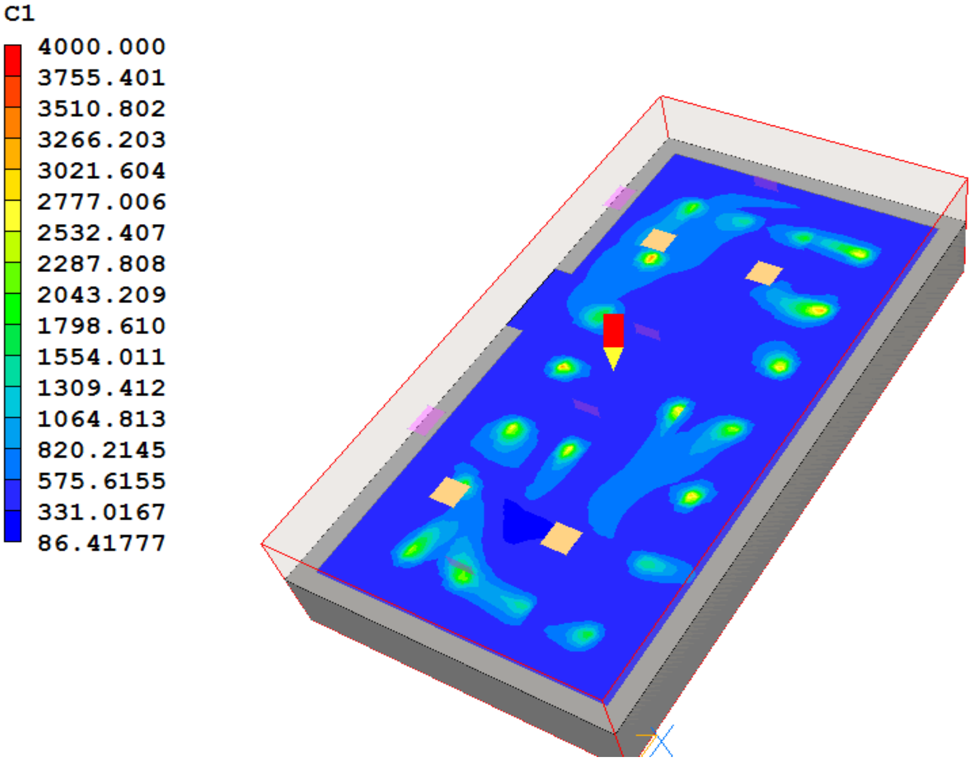
Numerical Scheme	Grid Size	Turbulence model	Computational time (24 GB RAM)
Hybrid	85,39,37	K-E	3:03

Velocity





Concentration



The average room concentration was **503.09 ppm**. This was calculated by taking 20 plane averages, nine in the Y-direction and 11 in the X-direction and averaging them together.

Residual Calculation		
Mass	P1 Res Sum	2.11E-02
	R1 Pos Sum	1.961443
	Residual	**1.1%**
Temperature	Tem1 Res Sum	1.59E+02
	Tem1 Pos Sum	5.77E+05
	Residual	**0.03%**
Concentration	C1 Res Sum	1.11E+02
	C1 Pos Sum	1.03E+03
	Residual	**10.7%**

Ventilation Rate and Load comparison for the Men's Locker Room

											Design Airflow		
Occupancy Category	Pz (Occ.)	Az (SF)	Rp (CFM/Occ.)	Ra (CFM/SF)	Vbz (CFM)	Vbz Occ	Vbz Area	Ez	Voz (CFM)	Load	Max (CFM)	Setback	Vpz (CFM)
102A Mens Coach Locker Room	4	188	5	0.5	114	20	94	1.0	114	143	143	80%	114
105A- Vedio study	4	330	5	0.06	40	20	20	1.0	40	106	106	40%	42
105B- Storage	0	76	0	0.12	9	0	9	1.0	9	9	9	100%	9
107- Mens Equipment	0	360	0	0.12	43.2	0	43	1.0	43	107	107	41%	44
105- Mens Team Lounge	10	600	5	0.06	86	50	36	1.0	86	406	406	30%	122
100A-Dry Lockers	10	240	5	0.5	170	50	120	1.0	170	94	170	100%	170
110B-Restrooms	4	205	70	0	280	280	0	1.0	280	66	280	100%	280
110C-Shower Rooms	16	305	50	0	800	800	0	1.0	800	115	800	100%	800
F101-Vestibule	0	216	5	0.06	13	0	13	1.0	13	26	26	50%	13
111B- Restroom	1	61	70	0	70	70	0	1.0	70	43	70	100%	70
111A-Exam Room	3	161	10	0.12	49	30	19	1.0	49	131	131	38%	50
111C- Office	2	125	5	0.06	18	10	8	1.0	18	107	107	30%	32
Q103- Cooridor	0	650	0	0.06	39	0	39	1.0	39	78	78	50%	39
110D Mens Ice Hockey Locker Room	30	1,332	0	2.5	3330	0	3330	1.0	3330	433	3,330	100%	3,330
110- Corridor	0	640	0	0.06	38	0	38	1.0	38	78	78	50%	39
102 Mens Coaches Longe	4	186	5	0.06	31	20	11	1.0	31	193	193	30%	58
109-Main Communication Room	1	100	5	0.12	17	5	12	1.0	17	68	68	30%	20
Q104- Corridor	0	112	0	0.06	7	0	7	1.0	7	14	14	50%	7

Event Level Raising Cost Impact

Table 39: Event Level Raising Overall Cost Breakdown

Overhead & Profit Markup = 24.8%

	Baseline				Redesign				Difference (+/-)				
Item - Cost	Material Cost	Labor/Equip	O&P	Total Cost	Material Cost	Labor/Equip	O&P	Total Cost	Material	Labor/Equip	O&P	Total (%)	
Excavation/Backfill	$105,668.16	$787,599.26	$221,530.32	$1,114,797.74	$55,224.00	$587,299.27	$159,345.77	$801,869.04	$50,444.16	$200,299.99	$62,184.55	$312,928.70	28.07%
Foundation Walls	$256,157.73	$631,332.51	$220,097.58	$1,107,587.82	$218,614.13	$538,784.60	$187,834.89	$945,233.62	$37,543.60	$92,547.91	$32,262.69	$162,354.20	14.66%
Evt Level Int Walls	$258,577.16	$354,392.30	$152,016.43	$764,985.89	$219,989.17	$294,671.71	$127,635.90	$642,296.78	$38,587.99	$59,720.59	$24,380.53	$122,689.11	16.04%
Concrete Columns	$26,390.66	$100,879.10	$31,562.90	$158,832.66	$22,227.34	$81,531.06	$25,732.08	$129,490.48	$4,163.32	$19,348.04	$5,830.82	$29,342.18	18.47%
Main Arena Bowl Stadia	$72,175.16	$18,764.16	$22,552.95	$113,492.27	$83,470.28	$27,755.32	$27,583.95	$138,809.55	-$11,295.12	-$8,991.16	-$5,031.00	-$25,317.28	-22.31%
Main Arena Bowl Seating	$16,757.71	$1,910.19	$4,629.64	$23,297.54	$27,785.87	$4,182.70	$7,928.21	$39,896.78	-$11,028.16	-$2,272.51	-$3,298.57	-$16,599.24	-71.25%
Main Arena Bowl Steps	$6,843.69	$6,143.63	$3,220.86	$16,208.18	$4,524.55	$4,061.72	$2,129.39	$10,715.66	$2,319.14	$2,081.91	$1,091.46	$5,492.51	33.89%
Main Concourse Int Walls	$127,270.20	$134,588.62	$64,940.99	$326,799.81	$164,774.13	$161,008.68	$80,794.14	$406,576.95	-$37,503.93	-$26,420.06	-$15,853.15	-$79,777.14	-24.41%
Club Level Int Walls	$35,304.61	$71,614.31	$26,515.89	$133,434.81	$39,790.35	$82,974.77	$30,445.75	$153,210.87	-$4,485.74	-$11,360.46	-$3,929.86	-$19,776.06	-14.82%
Exterior Glazing w/ Mullions (not including East Façade)	$65,769.31	$10,276.56	$18,859.38	$94,905.25	$81,582.24	$12,743.59	$23,392.81	$117,718.64	-$15,812.93	-$2,467.03	-$4,533.43	-$22,813.39	-24.04%
Shaft & Column Walls	$31,082.55	$40,558.12	$17,766.89	$89,407.56	$29,754.19	$37,335.66	$16,638.28	$83,728.13	$1,328.36	$3,222.46	$1,128.60	$5,679.42	6.35%
Exterior Walls (not Including East Façade)	$475,102.63	$531,049.55	$249,525.74	$1,255,677.92	$530,146.89	$586,559.93	$276,943.29	$1,393,650.11	-$55,044.26	-$55,510.38	-$27,417.55	-$137,972.19	-10.99%
Steel Columns	$365,211.00	$131,900.20	$123,283.58	$620,394.78	$388,387.44	$131,311.27	$128,885.28	$648,583.99	-$23,176.44	$588.93	-$5,601.70	-$28,189.21	-4.54%
Shaft & Lobby Stairs	$103,363.68	$13,516.19	$28,986.21	$145,866.08	$98,988.33	$12,891.59	$27,746.22	$139,626.14	$4,375.35	$624.60	$1,239.99	$6,239.94	4.28%
Steel Beams & Concrete Footings	$591,835.66	$213,722.56	$199,778.44	$1,005,336.66	$619,143.70	$210,264.09	$205,693.13	$1,035,100.92	-$27,308.04	$3,458.47	-$5,914.69	-$29,764.26	-2.96%
Remaining Steel	$1,713,342.96	$574,665.90	$567,426.20	$2,855,435.06	$1,713,342.96	$537,895.65	$558,307.18	$2,809,545.79	$0.00	$36,770.25	$9,119.02	$45,889.27	1.61%
Total	**$4,250,852.87**	**$3,622,913.16**	**$1,952,693.98**	**$9,826,460.01**	**$4,297,745.57**	**$3,311,271.61**	**$1,887,036.26**	**$9,496,053.44**	**-$46,892.70**	**$311,641.55**	**$65,657.71**	**$330,406.56**	**3.36%**

Table 40: Event Level Current Design Excavation Costs

Overhead & Profit Markup = 24.8%

Drilling and Blasting of Bedrock	Size/Amt	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
Rock Excavation (drilling) Most work	10596	25	LF	$0.00	$8.51	$0.00	$90,171.96	$22,362.65	$112,534.61
Blasting 12' x 12' pattern	25401	108	CY	$4.16	$2.87	$105,668.16	$72,900.87	$44,285.12	$222,854.15
243 HP Excavator w/ 3 CY bucket ave cond (rock)	25401	181	CY	$0.00	$0.88	$0.00	$22,352.88	$5,543.51	$27,896.39
25 CY Dump Truck Hauling 3 miles at 30 mph (rock)	41912	79	CY	$0.00	$3.24	$0.00	$135,794.88	$33,677.13	$169,472.01
243 HP Excavator w/ 3 CY Bucket Ave Cond. (soil)	73207	278	CY	$0.00	$0.57	$0.00	$41,727.99	$10,348.54	$52,076.53
25 CY Dump Truck Hauling 3 miles at 30 mph (soil)	90703	79	CY	$0.00	$3.24	$0.00	$293,877.72	$72,881.67	$366,759.39
Front Loader (3 1/4 CY bucket)	91509	125	CY	$0.00	$1.42	$0.00	$129,942.78	$32,225.81	$162,168.59
12-ton 3-wheel Compactor for Backfill	806	100	CY	$0.00	$1.03	$0.00	$830.18	$205.88	$1,036.06
					Total	**$105,668.16**	**$787,599.26**		**$1,114,797.74**

Table 41: Event Level Raising Excavation Costs

Overhead & Profit Markup = 24.8%

Drilling and Blasting of Bedrock	Size/Amt	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
Rock Excavation (drilling) Most work	4584	25	LF	$0.00	$8.51	$0.00	$39,009.84	$9,674.44	$48,684.28
Blasting 12' x 12' pattern	13275	108	CY	$4.16	$2.87	$55,224.00	$38,099.25	$23,144.17	$116,467.42
243 HP Excavator w/ 3 CY bucket ave cond (rock)	13275	181	CY	$0.00	$0.88	$0.00	$11,682.00	$2,897.14	$14,579.14
25 CY Dump Truck Hauling 3 miles at 30 mph (rock)	21904	79	CY	$0.00	$3.24	$0.00	$70,968.96	$17,600.30	$88,569.26
243 HP Excavator w/ 3 CY Bucket Ave Cond. (soil)	67061	278	CY	$0.00	$0.57	$0.00	$38,224.77	$9,479.74	$47,704.51
25 CY Dump Truck Hauling 3 miles at 30 mph (soil)	83230	79	CY	$0.00	$3.24	$0.00	$269,665.20	$66,876.97	$336,542.17
Front Loader (3 1/4 CY bucket)	83827	125	CY	$0.00	$1.42	$0.00	$119,034.34	$29,520.52	$148,554.86
12-ton 3-wheel Compactor for Backfill	597	100	CY	$0.00	$1.03	$0.00	$614.91	$152.50	$767.41
					Total	**$55,224.00**	**$587,299.27**	**$159,345.77**	**$801,869.04**

Table 42: Event Level Current Design Steel Columns

Equipment costs based on same crane used by Current Project Team - 200 Ton Hydraulic Crane

Overhead & Profit Markup = 24.8%

Steel Columns	Size	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
W24x176	45	5/8	Ton	$1,724.31	$607.75	$77,593.95	$27,348.53	$26,025.74	$130,968.22
W14x61	19	5/11	Ton	$2,045.61	$835.72	$38,866.59	$15,878.77	$13,576.85	$68,322.20
W14x74	8	25/47	Ton	$1,884.96	$714.68	$15,079.68	$5,717.45	$5,157.69	$25,954.82
W18x119	34	5/8	Ton	$1,724.31	$607.75	$58,626.54	$20,663.33	$19,663.89	$98,953.76
W12x136	2	5/8	Ton	$1,724.31	$607.75	$3,448.62	$1,215.49	$1,156.70	$5,820.81
W14x120	7	5/8	Ton	$1,724.31	$607.75	$12,070.17	$4,254.22	$4,048.45	$20,372.83
W14x145	13	5/8	Ton	$1,724.31	$607.75	$22,416.03	$7,900.69	$7,518.55	$37,835.26
W14x53	1	5/11	Ton	$2,045.61	$835.72	$2,045.61	$835.72	$714.57	$3,595.91
W14x68	2	25/47	Ton	$1,884.96	$714.68	$3,769.92	$1,429.36	$1,289.42	$6,488.70
W14x90	47	25/47	Ton	$1,884.96	$714.68	$88,593.12	$33,590.02	$30,301.42	$152,484.56
W24x146	13	5/8	Ton	$1,724.31	$607.75	$22,416.03	$7,900.69	$7,518.55	$37,835.26
HSS8x8x1/2	6	5/8	Ton	$2,559.69	$607.75	$15,358.14	$3,646.47	$4,713.14	$23,717.75
HSS6x6x3/8	1	1/2	Ton	$2,463.30	$759.73	$2,463.30	$759.73	$799.31	$4,022.34
HSS4x4x3/8	1	1/2	Ton	$2,463.30	$759.73	$2,463.30	$759.73	$799.31	$4,022.34
					Total	**$365,211.00**	**$131,900.20**	**$123,283.58**	**$620,394.78**

Table 43: Event Level Redesign Steel Columns

Equipment costs based on HPR's crane analysis (see Table 68 and 69 in Appendix G)

– 150 Ton Hydraulic Crane

Overhead & Profit Markup = 24.8%

Steel Columns	Size	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
W24x176	46	5/8	Ton	$1,724.31	$566.89	$79,318.26	$26,077.11	$26,138.05	$131,533.43
W14x61	18	5/11	Ton	$2,045.61	$779.55	$36,820.98	$14,031.97	$12,611.53	$63,464.48
W14x74	10	25/47	Ton	$1,884.96	$666.37	$18,849.60	$6,663.67	$6,327.29	$31,840.56
W18x119	33	5/8	Ton	$1,724.31	$566.89	$56,902.23	$18,707.49	$18,751.21	$94,360.94
W12x136	2	5/8	Ton	$1,724.31	$566.89	$3,448.62	$1,133.79	$1,136.44	$5,718.84
W14x120	6	5/8	Ton	$1,724.31	$566.89	$10,345.86	$3,401.36	$3,409.31	$17,156.53
W14x145	12	5/8	Ton	$1,724.31	$566.89	$20,691.72	$6,802.73	$6,818.62	$34,313.07
W14x53	8	5/11	Ton	$2,045.61	$779.55	$16,364.88	$6,236.43	$5,605.13	$28,206.44
W14x68	2	25/47	Ton	$1,884.96	$666.37	$3,769.92	$1,332.73	$1,265.46	$6,368.11
W14x90	48	25/47	Ton	$1,884.96	$666.37	$90,478.08	$31,985.60	$30,370.99	$152,834.67
W14x99	2	25/47	Ton	$1,884.96	$666.37	$3,769.92	$1,332.73	$1,265.46	$6,368.11
W24x146	13	5/8	Ton	$1,724.31	$566.89	$22,416.03	$7,369.62	$7,386.84	$37,172.49
HSS8x8x1/2	6	5/8	Ton	$2,559.69	$566.89	$15,358.14	$3,401.36	$4,652.36	$23,411.86
HSS6x6x3/8	2	1/2	Ton	$2,463.30	$708.67	$4,926.60	$1,417.33	$1,573.30	$7,917.23
HSS4x4x3/8	2	1/2	Ton	$2,463.30	$708.67	$4,926.60	$1,417.33	$1,573.30	$7,917.23
					Total	**$388,387.44**	**$131,311.27**	**$128,885.28**	**$648,583.99**

Table 44: Event Level Current Design Steel Beams

Equipment costs based on same crane used by Current Project Team - 200 Ton Hydraulic Crane

Overhead & Profit Markup = 24.8%

Steel & Concrete	Size	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
W30x108	8	5/8	Ton	$1,724.31	$607.75	$13,794.48	$4,861.96	$4,626.80	$23,283.24
W10x22	1	5/14	Ton	$3,105.90	$1,065.51	$3,105.90	$1,065.51	$1,034.51	$5,205.92
W10x33	6	5/11	Ton	$2,045.61	$835.72	$12,273.66	$5,014.35	$4,287.43	$21,575.43
W12x19	1	5/14	Ton	$3,105.90	$1,065.51	$3,105.90	$1,065.51	$1,034.51	$5,205.92
W12x30	2	5/11	Ton	$2,045.61	$835.72	$4,091.22	$1,671.45	$1,429.14	$7,191.81
W12x53	8	5/11	Ton	$2,045.61	$835.72	$16,364.88	$6,685.80	$5,716.57	$28,767.24
W16x40	3	5/11	Ton	$2,045.61	$835.72	$6,136.83	$2,507.17	$2,143.71	$10,787.72
W16x45	1	5/11	Ton	$2,045.61	$835.72	$2,045.61	$835.72	$714.57	$3,595.91
W16x67	1	25/47	Ton	$1,884.96	$715.68	$1,884.96	$715.68	$644.96	$3,245.60
W18x35	72	5/11	Ton	$2,045.61	$835.72	$147,283.92	$60,172.17	$51,449.11	$258,905.20
W30x148	43	5/8	Ton	$1,724.31	$607.75	$74,145.33	$26,133.04	$24,869.04	$125,147.41
W30x173	129	5/8	Ton	$1,724.31	$607.75	$222,435.99	$78,399.12	$74,607.11	$375,442.22
2L6x6x3/4x3/4	5	64/91	Ton	$2,848.86	$540.69	$14,244.30	$2,703.43	$4,203.04	$21,150.77
HSS8x8x1/2	9	5/8	Ton	$2,559.69	$607.75	$23,037.21	$5,469.71	$7,069.72	$35,576.63
HSS10x10x1/2	2	5/6	Ton	$2,559.69	$456.23	$5,119.38	$912.47	$1,495.90	$7,527.74
HSS8x8x5/8	16	5/8	Ton	$2,559.69	$607.75	$40,955.04	$9,723.92	$12,568.38	$63,247.34
					Total	**$590,024.61**	**$207,937.01**	**$197,894.48**	**$995,856.10**

Table 45: Event Level Redesign Steel Beams

Equipment costs based on HPR's crane analysis (see Tables 68 and 69 in Appendix G)

– 150 Ton Hydraulic Crane

Overhead & Profit Markup = 24.8%

Steel & Concrete	Size	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
W30x108	8	5/8	Ton	$1,724.31	$566.89	$13,794.48	$4,535.15	$4,545.75	$22,875.38
W10x22	5	5/14	Ton	$3,105.90	$993.63	$15,529.50	$4,968.14	$5,083.42	$25,581.06
W10x33	8	5/11	Ton	$2,045.61	$779.55	$16,364.88	$6,236.43	$5,605.13	$28,206.44
W16x31	3	5/11	Ton	$2,045.61	$779.55	$6,136.83	$2,338.66	$2,101.92	$10,577.41
W16x40	3	5/11	Ton	$2,045.61	$779.55	$6,136.83	$2,338.66	$2,101.92	$10,577.41
W16x45	1	5/11	Ton	$2,045.61	$779.55	$2,045.61	$779.55	$700.64	$3,525.80
W24x94	5	25/47	Ton	$1,884.96	$667.37	$9,424.80	$3,336.83	$3,164.89	$15,926.52
W18x35	72	5/11	Ton	$2,045.61	$779.55	$147,283.92	$56,127.88	$50,446.13	$253,857.93
W30x148	43	5/8	Ton	$1,724.31	$566.89	$74,145.33	$24,376.43	$24,433.40	$122,955.16
W30x173	129	5/8	Ton	$1,724.31	$566.89	$222,435.99	$73,129.30	$73,300.19	$368,865.48
2L6x6x3/4x3/4	5	64/91	Ton	$2,848.86	$504.28	$14,244.30	$2,521.38	$4,157.89	$20,923.57
HSS8x8x1/2	9	5/8	Ton	$2,559.69	$566.89	$23,037.21	$5,102.04	$6,978.54	$35,117.79
HSS10x10x1/2	2	5/6	Ton	$2,559.69	$425.52	$5,119.38	$851.03	$1,480.66	$7,451.08
HSS8x8x5/8	16	5/8	Ton	$2,559.69	$566.89	$40,955.04	$9,070.30	$12,406.28	$62,431.63
W8x31	7	5/11	Ton	$2,045.61	$779.55	$14,319.27	$5,456.88	$4,904.48	$24,680.63
W16x57	3	5/11	Ton	$2,045.61	$779.55	$6,136.83	$2,338.66	$2,101.92	$10,577.41
					Total	**$617,110.20**	**$203,507.35**	**$203,513.15**	**$1,024,130.70**

Table 46: Event Level Current Design of "To be Modified" Precast Stadia Dimensions

Dimensions based on 12' Sections of Precast Stadia

	Area (L x Rise)	Thick	PSF	Wt	Tons	Ton/Section
General Public - Riser 14	18	0.5	78	34723 1/8	17 1/3	1
General Public - Riser Wall	44 1/2	0.75	118.5	56702 4/9	28 1/3	1
General Public -14 Riser NE	12	0.5	78	2856 3/4	1 3/7	1
General Public - 14 NE Wall	44 3/4	0.5	78	2184	1	1
Lower Student - Riser 9	57	1	159	20399 5/7	10 1/5	1

Table 47: Event Level Current Design of "To be Modified" Precast Stadia Cost

Equipment costs based on using a 10,000 lb telehandler with 55'/42' reach

Overhead & Profit Markup = 24.8%

Baseline Stadia	# 12' Sect	Unit/Hr	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
Lower Gen Public Bowl - Riser 14	38	2.72	$396.90	$195.46	$15,082.20	$7,427.48	$5,582.40	$28,092.08
Lower Gen Public Bowl - Riser Wall	40	2.72	$981.23	$195.46	$39,249.00	$7,818.40	$11,672.72	$58,740.12
Lower Gen Public Bowl - Riser 14 NE	4	2.72	$264.60	$195.46	$1,058.40	$781.84	$456.38	$2,296.62
Lower Gen Public Bowl - 14 NE Wall	3	2.72	$986.74	$195.46	$2,960.21	$586.38	$879.55	$4,426.15
Lower Student Section - Riser 9	11	2.72	$1,256.85	$195.46	$13,825.35	$2,150.06	$3,961.90	$19,937.31
				Total	**$72,175.16**	**$18,764.16**	**$22,552.95**	**$113,492.27**

Table 48: Event Level Redesign of "Modified" Precast Stadia Dimensions

Dimensions based on 12' Sections of Precast Stadia

	Area (L x Rise)	Thick	PSF	Wt	Tons	Ton/Section
Basic Riser	2 1/3					
General Public - Riser 14	28	0.5	78	30662 5/6	15 1/3	1
General Public - Riser 15	28 1/4	0.5	78	26080 2/3	13	1
General Public - Riser 16	28 1/2	0.5	78	26441 3/8	13 2/9	1
General Public - Riser 17	18	0.5	78	26872 1/7	13 3/7	1
Lower Student Riser 9 L&R	57	1	159	14712 1/4	7 1/3	1
Lower Student Riser 9 Mid	22	1	78	2790 2/3	1 2/5	1
Lower Student Riser 10	22	1	78	3634 4/5	1 4/5	1
Lower Student Riser 11	22	1	78	3691 3/4	1 5/6	1
Lower Student Riser 12	6	1	78	3753 3/4	1 7/8	1

Table 49: Event Level Redesign of "Modified" Precast Stadia Cost

Equipment costs based on using a 10,000 lb telehandler with 55'/42' reach

Overhead & Profit Markup = 24.8%

Redesign Stadia	Quantity	Unit/Hr	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
Lower Gen Public Bowl - Riser 14	33	2.72	$617.40	$195.46	$20,374.20	$6,450.18	$6,652.45	$33,476.83
Lower Gen Public Bowl - Riser 15	28	2.72	$622.91	$195.46	$17,441.55	$5,472.88	$5,682.78	$28,597.21
Lower Gen Public Bowl - Riser 16	29	2.72	$628.43	$195.46	$18,224.33	$5,668.34	$5,925.38	$29,818.05
Lower Gen Public Bowl - Riser 17	29	2.72	$396.90	$195.46	$11,510.10	$5,668.34	$4,260.25	$21,438.69
Lower Student Section - Riser 9 L & R	8	2.72	$1,256.85	$195.46	$10,054.80	$1,563.68	$2,881.38	$14,499.86
Lower Student Section - Riser 9 Mid	3	2.72	$485.10	$195.46	$1,455.30	$586.38	$506.34	$2,548.02
Lower Student Section - Riser 10	4	2.72	$485.10	$195.46	$1,940.40	$781.84	$675.12	$3,397.36
Lower Student Section - Riser 11	4	2.72	$485.10	$195.46	$1,940.40	$781.84	$675.12	$3,397.36
Lower Student Section - Riser 12	4	2.72	$132.30	$195.46	$529.20	$781.84	$325.14	$1,636.18
				Total	**$83,470.28**	**$27,755.32**	**$27,583.95**	**$138,809.54**

Table 50: Event Level Current Design of "To be Modified" Arena Seating

Overhead & Profit Markup = 24.8%

Baseline Seating	Seats	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
10" Student Bleacher Bench Per 18" Seat	23	22 2/9	Each	$16.49	$4.38	$379.27	$100.74	$119.04	$599.05
36" Loge Suite Seat - Economy	73	4 38/53	Each	$196.88	$20.65	$14,372.24	$1,507.45	$3,938.16	$19,817.85
19" Molded Plastic Chair - Wheel chair Companion	20	6 14/31	Each	$100.31	$15.10	$2,006.20	$302.00	$572.43	$2,880.63
					Total	**$16,757.71**	**$1,910.19**	**$4,629.64**	**$23,297.54**

Table 51: Event Level Redesign of "Modified" Arena Seating

Overhead & Profit Markup = 24.8%

Redesign Seating	Seats	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
19" Molded Plastic Chair - Arena	277	6 14/31	Each	$100.31	$15.10	$27,785.87	$4,182.70	$7,928.21	$39,896.78
					Total	**$27,785.87**	**$4,182.70**	**$7,928.21**	**$39,896.78**

Table 52: Event Level Current Design Concrete Arena Steps

Overhead & Profit Markup = 24.8%

Baseline Arena Steps	Concrete Vol (CY)	Concrete Material	Concrete Labor	Synth Fibers (lbs)	Syn Fibers Material	Formwork (SF)	Formwork Labor	Total Material	Total Labor	O&P	Total
Gen Pub - Lower Bowl Stairs	54.498	$84.36	$8.95	81.7	$8.02	490.5	$8.62	$5,253.06	$4,715.71	$2,472.26	$12,441.03
Gen Pub - NE Entry Lobby Stair	7.842	$84.36	$8.95	11.8	$8.02	70.6	$8.62	$755.89	$678.57	$355.75	$1,790.20
Student - Lower Bowl Stairs	8.66	$84.36	$8.95	13.0	$8.02	77.9	$8.62	$834.74	$749.35	$392.85	$1,976.94
							Total	**$6,843.69**	**$6,143.63**	**$3,220.86**	**$16,208.18**

Table 53: Event Level Redesign Concrete Arena Steps

Overhead & Profit Markup = 24.8%

Redesign Arena Steps	Concrete Vol (CY)	Concrete Material	Concrete Labor	Synth Fibers (lbs)	Syn Fibers Material	Formwork (SF)	Formwork Labor	Total Material	Total Labor	O&P	Total
Gen Pub - Lower Bowl Stairs	32.307	$84.36	$8.95	48.5	$8.02	290.8	$8.62	$3,114.07	$2,795.52	$1,465.58	$7,375.18
Gen Pub - Upper Bowl Stairs	9.8	$84.36	$8.95	14.7	$8.02	88.2	$8.62	$944.62	$847.99	$444.57	$2,237.18
Student - Lower Bowl Stairs	4.833	$84.36	$8.95	7.2	$8.02	43.5	$8.62	$465.85	$418.20	$219.24	$1,103.30
							Total	**$4,524.55**	**$4,061.72**	**$2,129.39**	**$10,715.66**

Event Level Raising Schedule Impact

Table 54: Current Design Excavation Workdays

Overall Days (44,000 CY Rock)	356
Schedule Event Lvl Only (based on 35 days)	25

Drilling and Blasting of Bedrock	Size/Amt	Unit/Hr	Unit	Crew	Hours	Hrs/Shift	Daily Output	Shifts/Day	Days
Rock Excavation (drilling) Most work	10596	25	LF	S1	424	8	200	2	26 1/2
Blasting 12' x 12' pattern	25401	108	CY	C1	236	5	540	1	47 1/5
243 HP Excavator w/ 3 CY bucket ave cond (rock)	25401	181	CY	OE	141	8	1448	2	8 13/16
25 CY Dump Truck Hauling 3 miles at 30 mph (rock)	41912	79	CY	TD	531	8	632	2	33 3/16
243 HP Excavator w/ 3 CY Bucket Ave Cond. (soil)	73207	278	CY	OE	264	8	2224	2	16 1/2
25 CY Dump Truck Hauling 3 miles at 30 mph (soil)	90703	79	CY	TD	1149	8	632	2	71 13/16
Front Loader (3 1/4 CY bucket)	91509	125	CY	S1	733	8	1000	2	45 13/16
12-ton 3-wheel Compactor for Backfill	806	100	CY	HX	8	8	800	2	1/2
Grading & Compacting w/ 300 HP Dozer	6702	167	CY	GK	41	8	1336	2	2 9/16
								Total	**253**

Table 55: Event Level Raising Excavation Workdays

Overall Days (44,000 CY Rock)	356
Schedule Event Lvl Only (based on 35 days)	18

Drilling and Blasting of Bedrock - Everything	Size/Amt	Unit/Hr	Unit	Crew	Hours	Hours/Shift	Daily Output	Shifts/Day	Days
Rock Excavation (drilling) Most work	4584	25	LF	S1	184	8	200	2	11 1/2
Blasting 12' x 12' pattern	13275	108	CY	C1	123	5	540	1	24 3/5
243 HP Excavator w/ 3 CY bucket ave cond (rock)	13275	181	CY	OE	74	8	1448	2	4 5/8
25 CY Dump Truck Hauling 3 miles at 30 mph (rock)	21904	79	CY	TD	278	8	632	2	17 3/8
243 HP Excavator w/ 3 CY Bucket Ave Cond. (soil)	67061	278	CY	OE	242	8	2224	2	15 1/8
25 CY Dump Truck Hauling 3 miles at 30 mph (soil)	83230	79	CY	TD	1054	8	632	2	65 7/8
Front Loader (3 1/4 CY bucket)	83827	125	CY	S1	671	8	1000	2	41 15/16
12-ton 3-wheel Compactor for Backfill	597	100	CY	HX	8	8	800	2	1/2
Grading & Compacting w/ 300 HP Dozer	6702	167	CY	GK	41	8	1336	2	2 9/16
								Total	**185**

APPENDIX G: Main Arena Roof System

Structural Loads

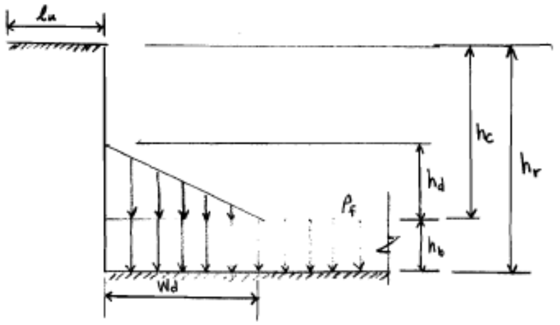
Snow Loads – Flat Roof Snow Load and Drifting

Table 56: Flat Roof Snow Load Calculations

Flat Roof Snow Load Calculations		
Variable	**Value**	**Code**
Ground Snow Load - p_g (psf)	40.0	Adopted per State College Amendment A, Section 103
Exposure Factor - C_e	1.0	ASCE 7-10 Table 7-2 - Fully Exposed
Temperature Factor - C_t	1.1	ASCE 7-10 Table 7-3 - Struct. Kept Right Above Freezing
Importance Factor - I	1.1	ASCE 7-10 Table 7-4 - Building Category III
Flat Roof Snow Load - p_f (psf)	**36.0**	Used per FM Global Plan Review No. 122327 dated 4/13/11

DRIFTING ON LOWER ROOFS:

ROOF HEIGHT: 53'-6" (LOW ROOF)



$h_r = 9.76'$
$h_b = P_f/\gamma \quad \gamma = 0.13P_g + 14 = 0.13(40)+14 = 19.2 < 40$ PCF ∴ OK ✓

$h_c = h_r - h_b = 9.76' - 40/19.2 = 7.68'$

$\frac{h_c}{h_b} = \frac{7.68'}{2.08'} = 3.69 >> 0.2$ ∴ DRIFT MUST BE CALCULATED ✓

WINDWARD: $l_u = 196' \approx 200'$ (LEEWARD) → HIGH ROOF
$l_u = 28'$ (WINDWARD) → LOW ROOF

$\left.\begin{array}{l} hd = 1'\text{-}6" \\ Wd = 4hd = 6'\text{-}0" \end{array}\right\}$ FIGURE 7-9 ASCE 7-05 $\quad P_d = 1.5'(19.2) = \underline{29}$ PSF

LEEWARD: $l_u \approx 200'$

$h_d = 5'\text{-}0"$
$W_d = 20'\text{-}0"$
$P_d = h_d\gamma = 5'(19.2) = \underline{\underline{96}}$ PSF

Table 57: Summary of Snow Drift Load Calculations

Snow Drift Load Calculations								
Roof Level	Windward				Leeward			
	L_u (ft)	h_d (ft)	p_d (psf)	w_d (ft)	L_u (ft)	h_d (ft)	p_d (psf)	w_d (ft)
Low	28.00	1.50	29.00	6.00	28.00	5.00	96.00	20.00

Wind Calculations

Table 58: General Wind Load Design Criteria

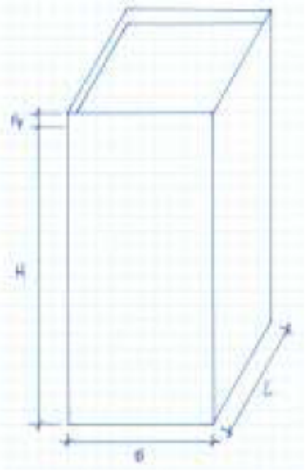
General Wind Load Design Criteria		
Design Wind Speed	120 mph	ASCE 7-10 (Fig. 26.5.1)
Exposure Category	C	ASCE 7-10 (Fig. 26.7.3)
Importance Factor (Iw)	1.15	ASCE 7-10 (Table 1.5-2)
Topographic Factor (K_{zt})	1.00	ASCE 7-10 (26.8 & Table 2.8-1)
Internal Pressure Coefficient (Gc_{pi})	±0.18	ASCE 7-10 - Enclosed

Table 59: Velocity Pressure Coefficients

Velocity Pressure Coefficients (K_z) and Velocity Pressure (q_z)			
Level	Elevation (ft)	K_z	q_z (psf)
Event Level	0.00	0.85	26.63
Main Concourse	17.65	0.877	27.46
Club Level	37.31	1.02	32.08
Low Roof	53.52	1.1	34.59
High Roof	67.52	1.16	36.44

WIND ANALYSIS FOR HIGH-RISE BUILDINGS (> 60 FT)

Calculates MWFRS and C&C Loads as per ASCE 7-10



DESCRIPTION:

INPUT DATA

Exposure Category (ASCE 7-10, 26.7.3)		C	
Importance Factor (ASCE 7-10, Table 1.5-2)	I_w =	1.15	
Basic Wind Speed (ASCE 7-10, 26.5.1)	V =	120	mph
Topographic Factor (ASCE 7-10, 26.8 & Table 26.8-1)	K_{zt} =	1.00	
Enclosure Classifications (ASCE 7-10,		Enclosed	
Building Height to Roof	H =	81.52	ft
Parapet Height	H_p =	0	ft
Roof Slope	θ =	<10°	
Roof Ridge Orientation (Parallel to)		L	
Building Length	L =	360	ft
Building Width	B =	252	ft
Effective Area of Mullion	A_m =	0	ft²
Effective Area of Panel	A_p =	0	ft²
Structural System:		Structural Steel Moment Frames	
Natural Frequency (ASCE 7-10, 26.9)	n1 =	0.6567	Hz or (1/T)

ANALYSIS

<u>Velocity Pressures</u>

$q_z = 0.00256\ K_z\ K_{zt}\ K_d\ V^2$

where: q_z = velocity pressure at height, z (ASCE 7-10, Eq. 27.3-1 & Eq. 30.3-1)
K_z = velocity pressure exposure coefficient evaluated at height, z. (ASCE 7-10, Table 27.3-1)
K_d = wind directionality factor. (ASCE 7-10, Table26.6-1)
z = height above the ground

pmin = 16 psf (ASCE 7-10, 27.47)

Kd = 0.85

z (ft)	**0-15**	**20**	**25**	**30**	**40**	**50**	**60**	**70**	**80**	**81.52**
K_z	0.85	0.90	0.94	0.98	1.04	1.09	1.13	1.17	1.21	1.21
q_z (psf)	26.63	28.20	29.45	30.71	32.59	34.15	35.41	36.79	37.84	37.99
z (ft)										**81.52**
K_z										1.21
q_z (psf)										37.99

<u>Design Pressures for MWFRS</u>

$p = q\ G\ C_p - q_h\ (G\ C_{pi})$

where: p = pressure on surface of rigid building with height, h (ASCE 7-10, Eq. 27.4-1)
q = q_z for windward wall at height z above the ground, see table above
G C_{pi} = +/- 0.18 = internal pressure coefficient (ASCE 7-10, Table 26.11-1)
q_h = q_z value at the mean roof height, h, for leeward wall, side walls, and roof
Cp = external pressure coefficient (ASCE 7-10, Table 27.4-1)
G = gust effect factor (ASCE 7-10, 26.9) = **0.923**

$$G = \begin{cases} 0.925\left(\dfrac{1+1.7 I_{\bar{z}}\sqrt{g_Q^2 Q^2 + g_R^2 R^2}}{1+1.7 g_v I_{\bar{z}}}\right), & for\ \ n_1 < 1.0 \\ 0.925\left(\dfrac{1+1.7 g_Q I_{\bar{z}} Q}{1+1.7 g_v I_{\bar{z}}}\right), & for\ \ n_1 \geq 1.0 \end{cases}$$

I_z = 0.187	z = 48.912	Q = 0.826
z_{min} = 15	g_Q = 3.4	L_z = 540.94
c = 0.2	g_R = 4.088	β = 0.01
R_h = 0.374	R_B = 0.147	R_L = 0.033
N_1 = 2.923	R_n = 0.071	R = 0.461
h = 81.52	g_v = 3.4	V_z = 121.54

Wall Pressure Coefficients, Cp (ASCE 7-10, Figure 27.4-1)

Wall	Wind Direction	L/B	C_p
Windward	All	All	0.80
Leeward	Perp to L	0.70	-0.50
Leeward	Perp to B	1.43	-0.41
Side Walls	All	All	-0.70

Roof Pressure Coefficients, Cp Normal to Ridge (θ≥10°) (ASCE 7-10, Figure 27.4-1)

h/L		Windward	Leeward
0.226	Positive	N/A	N/A
	Negative	N/A	N/A
h/B		**Windward**	**Leeward**
0.323	Positive	N/A	N/A
	Negative	N/A	N/A

Roof Pressure Coefficients, Cp Parallel to Ridge (ASCE 7-10, Figure 27.4-1)

Roof	h/B	Distance	Cp
To L Face	0.323	40.76	-0.900
To L Face	0.323	81.52	-0.900
To L Face	0.323	163.04	-0.500
To L Face	0.323	252	-0.300
Roof	**h/L**	**Distance**	**Cp**
To B Face	0.226	40.76	-0.900
To B Face	0.226	81.52	-0.900
To B Face	0.226	163.04	-0.500
To B Face	0.226	360	-0.300

Roof Pressure Coefficients, Cp Normal to Ridge (θ<10°) (ASCE 7-10, Figure 27.4-1)

Roof	h/B	Distance	Cp
To L Face	0.323	40.76	-0.900
To L Face	0.323	81.52	-0.900
To L Face	0.323	163.04	-0.500
To L Face	0.323	252	-0.300
Roof	**h/L**	**Distance**	**Cp**
To B Face	0.226	40.76	-0.900
To B Face	0.226	81.52	-0.900
To B Face	0.226	163.04	-0.500
To B Face	0.226	360	-0.300

MWFRS Net Pressures are Given by the Following Tables

Surface	z (ft)	P (psf) with GCpi	P (psf) with -GCpi
Windward Wall	0-15	12.82	26.50
	20	13.98	27.65
	25	14.90	28.58
	30	15.83	29.50
	40	17.22	30.89
	50	18.37	32.05
	60	19.30	32.97
	70	20.32	33.99
	80	21.09	34.77
	81.52	21.20	34.88

Surface	z(ft)	P (psf) with GCpi	P (psf) with -Gcpi
Side Wall	All	-31.37	-17.70

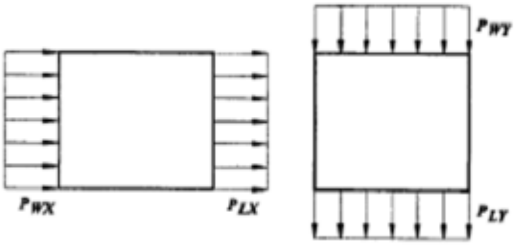
Normal to L Face		P (psf) with		Normal to B Face		P (psf) with	
Surface	z (ft)	GCpi	-Gcpi	Surface	z (ft)	GCpi	-Gcpi
Leeward	All	-24.36	-10.69	Leeward	All	-21.36	-7.68

Normal to L Face		P (psf) with		Normal to B Face		P (psf) with	
Surface	z (ft)	GCpi	-Gcpi	Surface	z (ft)	GCpi	-Gcpi
Roof	0 - 40.76	-38.38	-24.71	Roof	0 - 40.76	-38.38	-24.71
	81.52	-38.38	-24.71		81.52	-38.38	-24.71
	163.04	-24.36	-10.69		163.04	-24.36	-10.69
	252	-17.35	-3.68		360	-17.35	-3.68

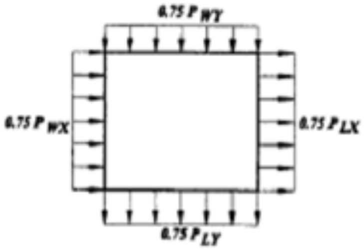
Windward		P (psf) with		Leeward		P (psf) with	
Surface	Sign	GCpi	-Gcpi	Surface	Sign	GCpi	-Gcpi
Roof Normal to	Positive	N/A	N/A	Roof Normal to	Positive	N/A	N/A
	Negative	N/A	N/A		Negative	N/A	N/A

Normal to L Face		P (psf) with		Normal to B Face		P (psf) with	
Surface	z (ft)	GCpi	-Gcpi	Surface	z (ft)	GCpi	-Gcpi
Roof Parallel to Ridge	0 - 40.76	N/A	N/A	Roof Parallel to Ridge	0 - 40.76	N/A	N/A
	81.52	N/A	N/A		81.52	N/A	N/A
	163.04	N/A	N/A		163.04	N/A	N/A
	252	N/A	N/A		360	N/A	N/A

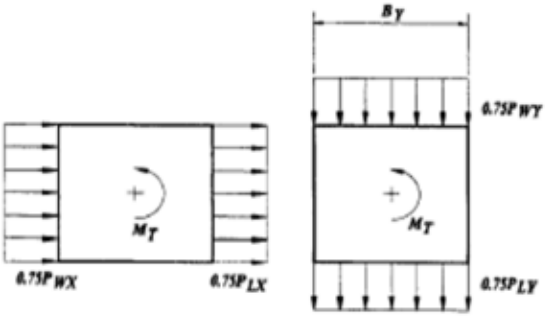
Base Forces		Normal to L Face		Normal to B Face		Wind at Angle		ASCE 7-10
		Case 1	Case 2	Case 1	Case 2	Case 3	Case 4	
V_{Base}	(kips)	1624	1218	1137	853	2071	1166	ASCE 7-10 Fig 27.4-8 (Shown Below)
M_{Base}	(ft-kips)	76155	57116	53308	39981	97097	72888	
M_T	(ft-kips)	0	65783	0	32234	0	73578	
V_{min}	(kips)	470	470	329	329	599	449	ASCE 7-10 27.4.7



CASE 1



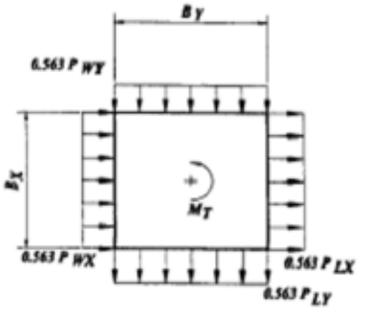
CASE 3



$M_T = 0.75\ (P_{WX}+P_{LX})B_X e_X$ $\quad$ $M_T = 0.75\ (P_{WY}+P_{LY})B_Y e_Y$

$e_X = \pm\ 0.15\ B_X$ $\quad$ $e_Y = \pm\ 0.15\ B_Y$

CASE 2

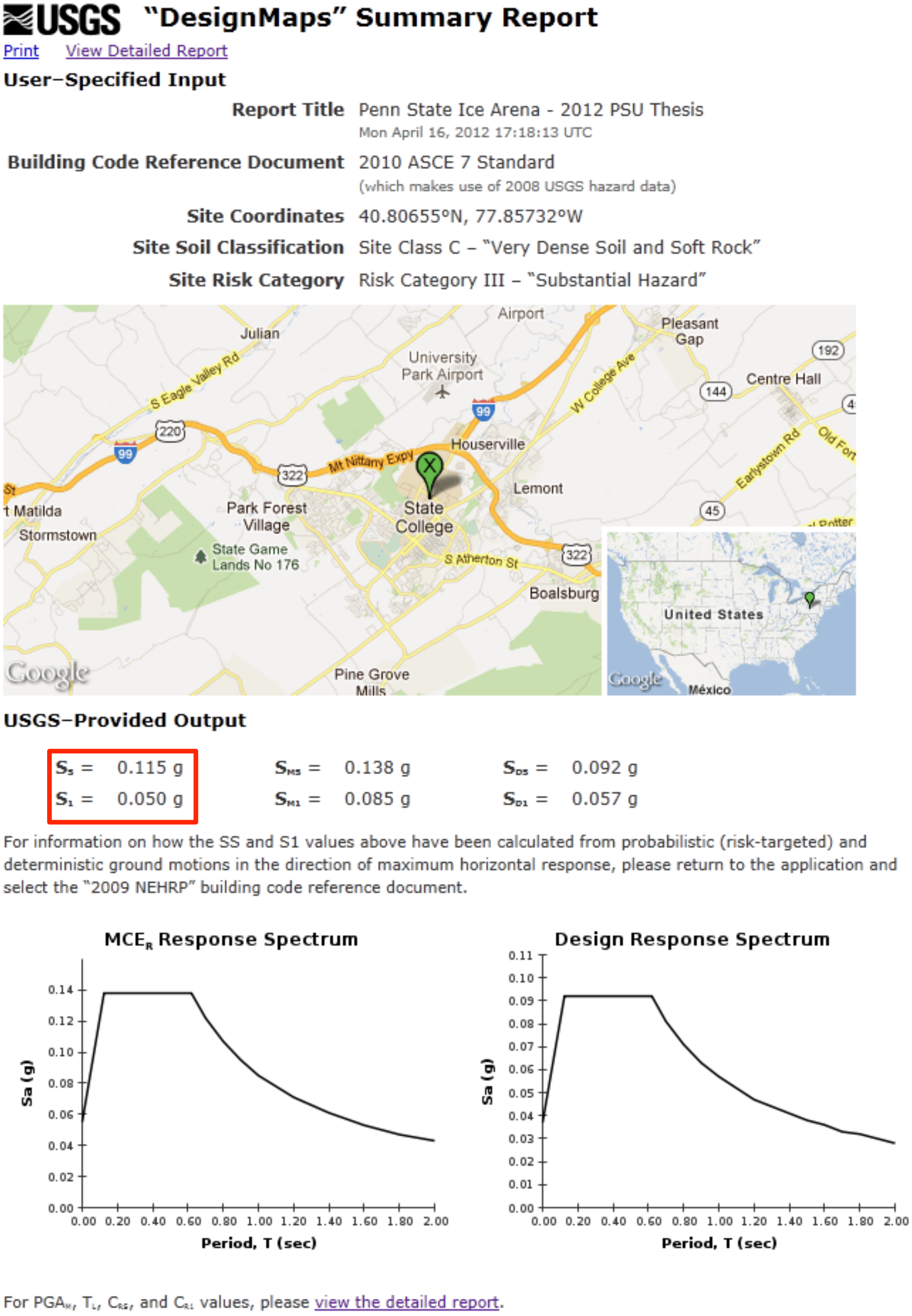


$M_T = 0.563\ (P_{WX}+P_{LX})B_X e_X + 0.563\ (P_{WY}+P_{LY})B_Y e_Y$

$e_X = \pm\ 0.15\ B_X$ $\quad$ $e_Y = \pm\ 0.15\ B_Y$

CASE 4

Seismic Design Loads & Results



"DesignMaps" Summary Report

Print View Detailed Report

User–Specified Input

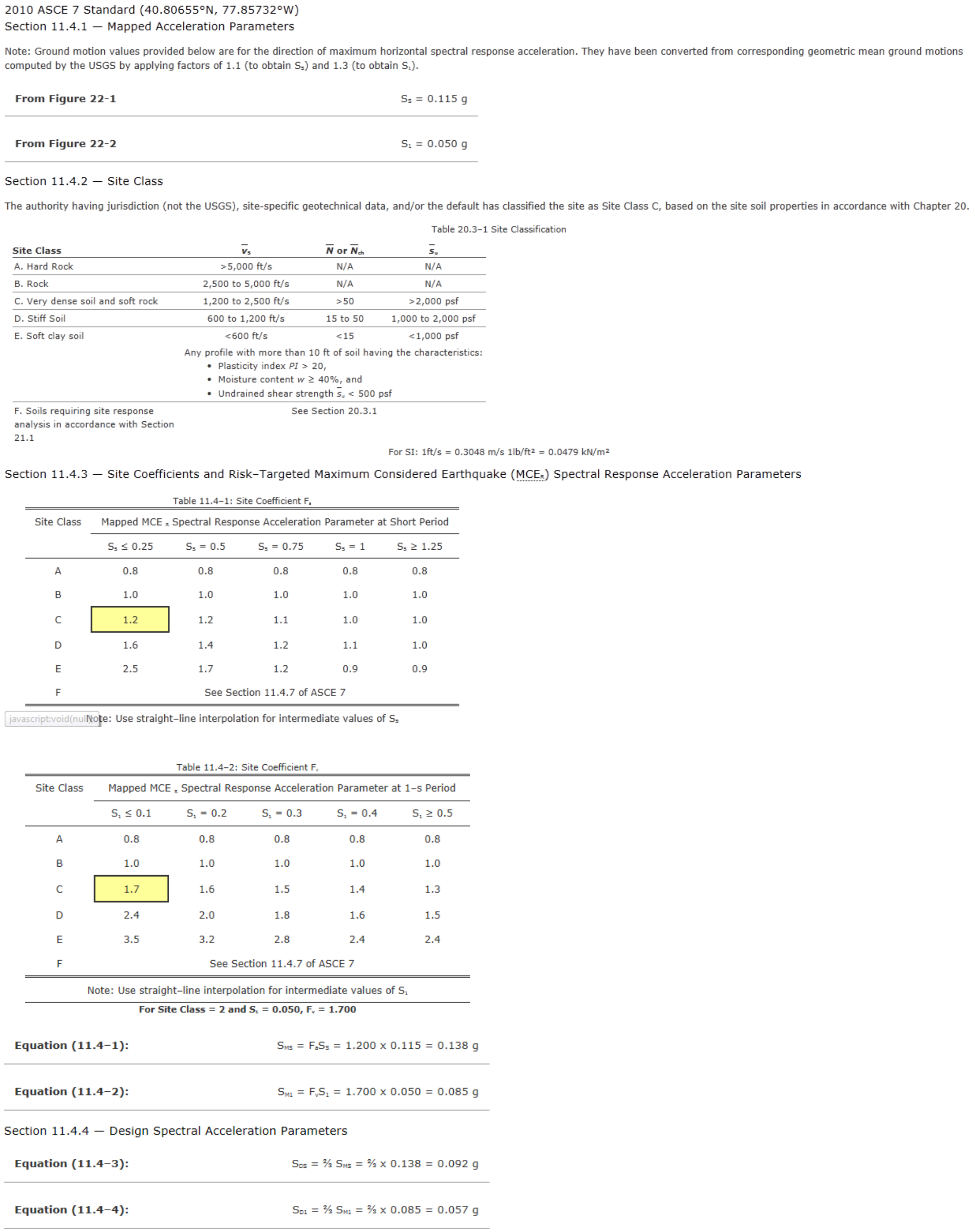
Report Title	Penn State Ice Arena - 2012 PSU Thesis Mon April 16, 2012 17:18:13 UTC
Building Code Reference Document	2010 ASCE 7 Standard (which makes use of 2008 USGS hazard data)
Site Coordinates	40.80655°N, 77.85732°W
Site Soil Classification	Site Class C – "Very Dense Soil and Soft Rock"
Site Risk Category	Risk Category III – "Substantial Hazard"

USGS–Provided Output

$S_S =$ 0.115 g　$S_{MS} =$ 0.138 g　$S_{DS} =$ 0.092 g
$S_1 =$ 0.050 g　$S_{M1} =$ 0.085 g　$S_{D1} =$ 0.057 g

For information on how the SS and S1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the "2009 NEHRP" building code reference document.

For PGA_M, T_L, C_{RS}, and C_{R1} values, please view the detailed report.



2010 ASCE 7 Standard (40.80655°N, 77.85732°W)

Section 11.4.1 — Mapped Acceleration Parameters

Note: Ground motion values provided below are for the direction of maximum horizontal spectral response acceleration. They have been converted from corresponding geometric mean ground motions computed by the USGS by applying factors of 1.1 (to obtain S_S) and 1.3 (to obtain S_1).

From Figure 22-1	S_S = 0.115 g
From Figure 22-2	S_1 = 0.050 g

Section 11.4.2 — Site Class

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the default has classified the site as Site Class C, based on the site soil properties in accordance with Chapter 20.

Table 20.3–1 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard Rock	>5,000 ft/s	N/A	N/A
B. Rock	2,500 to 5,000 ft/s	N/A	N/A
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff Soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the characteristics: • Plasticity index *PI* > 20, • Moisture content *w* ≥ 40%, and • Undrained shear strength $\bar{s}_u$ < 500 psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

For SI: 1ft/s = 0.3048 m/s 1lb/ft² = 0.0479 kN/m²

Section 11.4.3 — Site Coefficients and Risk–Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters

Table 11.4–1: Site Coefficient F_a

Site Class	Mapped MCE $_R$ Spectral Response Acceleration Parameter at Short Period				
	$S_S \le 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 of ASCE 7				

javascript:void(nul Note: Use straight–line interpolation for intermediate values of S_S

Table 11.4–2: Site Coefficient F_v

Site Class	Mapped MCE $_R$ Spectral Response Acceleration Parameter at 1–s Period				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7 of ASCE 7				

Note: Use straight–line interpolation for intermediate values of S_1

For Site Class = 2 and S_1 = 0.050, F_v = 1.700

Equation (11.4–1):	$S_{MS} = F_aS_S = 1.200 \times 0.115 = 0.138$ g
Equation (11.4–2):	$S_{M1} = F_vS_1 = 1.700 \times 0.050 = 0.085$ g

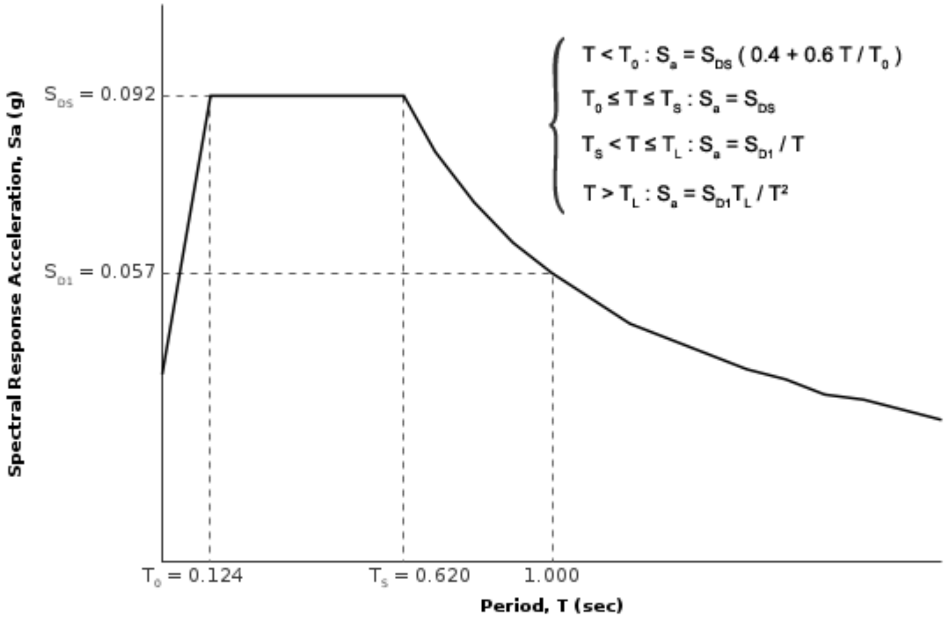
Section 11.4.4 — Design Spectral Acceleration Parameters

Equation (11.4–3):	$S_{DS} = ⅔\ S_{MS} = ⅔ \times 0.138 = 0.092$ g
Equation (11.4–4):	$S_{D1} = ⅔\ S_{M1} = ⅔ \times 0.085 = 0.057$ g

Section 11.4.5 — Design Response Spectrum

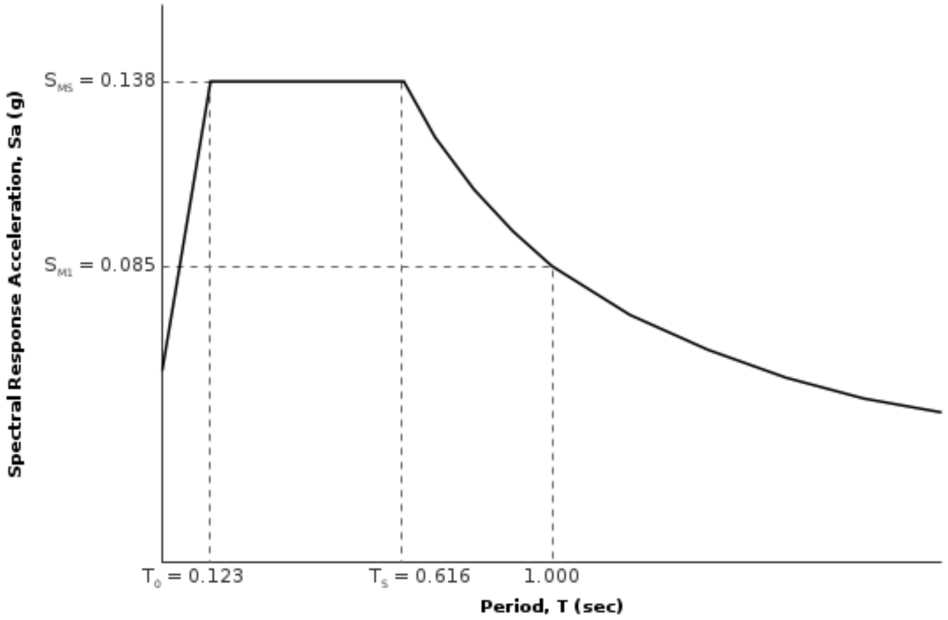
From Figure 22-12 T_L = 6 seconds

Figure 11.4-1: Design Response Spectrum



Section 11.4.6 — Risk-Targeted Maximum Considered Earthquake (MCE_R) Response Spectrum

The MCE_R Response Spectrum is determined by multiplying the design response spectrum above by 1.5.



Section 11.6 — Seismic Design Category

Table 11.6-1 Seismic Design Category Based on Short Period Response Acceleration Parameter

VALUE OF S_{DS}	**RISK CATEGORY**		
	I or II	**III**	**IV**
$S_{DS} < 0.167g$	A	A	A
$0.167g \le S_{DS} < 0.33g$	B	B	C
$0.33g \le S_{DS} < 0.50g$	C	C	D
$0.50g \le S_{DS}$	D	D	D

For Risk Category = III and S_{DS} = 0.092, Seismic Design Category = A

Table 11.6-2 Seismic Design Category Based on 1-S Period Response Acceleration Parameter

VALUE OF S_{D1}	**RISK CATEGORY**		
	I or II	**III**	**IV**
$S_{D1} < 0.067g$	A	A	A
$0.067g \le S_{D1} < 0.133g$	B	B	C
$0.133g \le S_{D1} < 0.20g$	C	C	D
$0.20g \le S_{D1}$	D	D	D

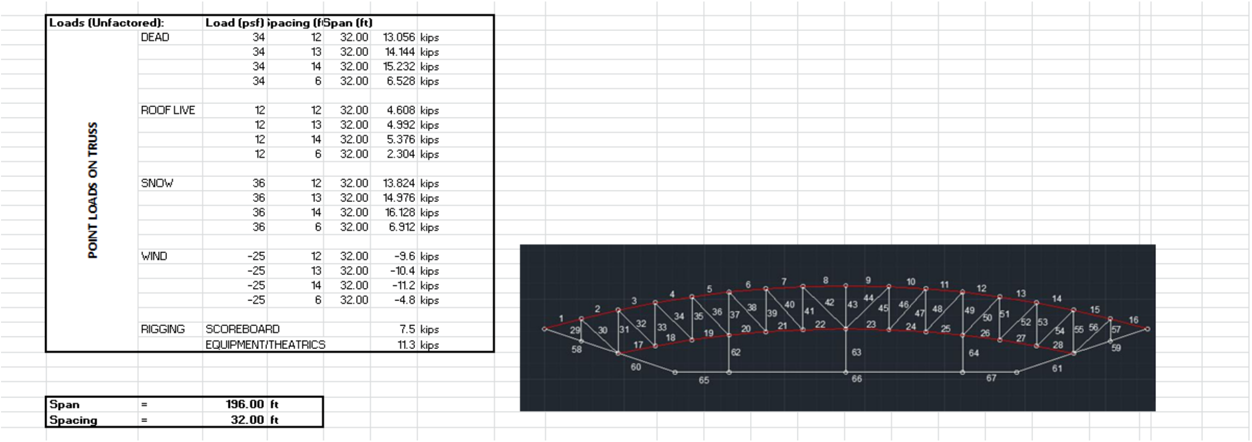
For Risk Category = III and S_{D1} = 0.057, Seismic Design Category = A

Note: When S_1 is greater than 0.75g, the Seismic Design Category is **E** for buildings in Risk Categories I, II, and III, and **F** for those in Risk Category IV, irrespective of the above.

Seismic Design Category ≡ "the more severe design category in accordance with Table 11.6-1 or 11.6-2" = A

Long Span Truss Design

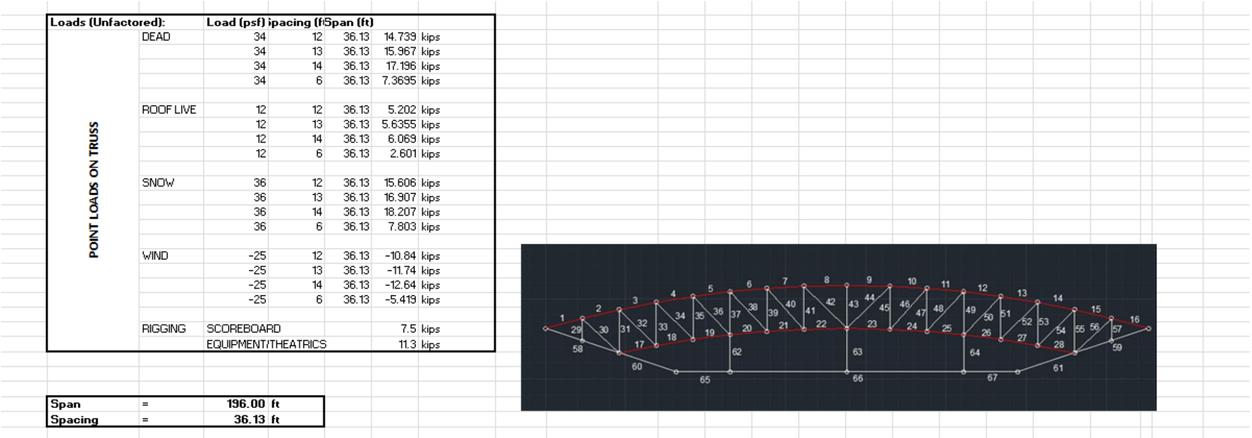
Table 60: Design Criteria for Trusses X8 & X9 - Scoreboard Rigging



Loads (Unfactored):		Load (psf)	ipacing (f	Span (ft)		
POINT LOADS ON TRUSS	DEAD	34	12	32.00	13.056	kips
		34	13	32.00	14.144	kips
		34	14	32.00	15.232	kips
		34	6	32.00	6.528	kips
	ROOF LIVE	12	12	32.00	4.608	kips
		12	13	32.00	4.992	kips
		12	14	32.00	5.376	kips
		12	6	32.00	2.304	kips
	SNOW	36	12	32.00	13.824	kips
		36	13	32.00	14.976	kips
		36	14	32.00	16.128	kips
		36	6	32.00	6.912	kips
	WIND	-25	12	32.00	-9.6	kips
		-25	13	32.00	-10.4	kips
		-25	14	32.00	-11.2	kips
		-25	6	32.00	-4.8	kips
	RIGGING	SCOREBOARD			7.5	kips
		EQUIPMENT/THEATRICS			11.3	kips

Span	=	**196.00**	**ft**
Spacing	=	**32.00**	**ft**

Table 61: Design Criteria for Trusses X4 & X13 - Worse Case Span (End)



Loads (Unfactored):		Load (psf)	ipacing (f	Span (ft)		
POINT LOADS ON TRUSS	DEAD	34	12	36.13	14.739	kips
		34	13	36.13	15.967	kips
		34	14	36.13	17.196	kips
		34	6	36.13	7.3695	kips
	ROOF LIVE	12	12	36.13	5.202	kips
		12	13	36.13	5.6355	kips
		12	14	36.13	6.069	kips
		12	6	36.13	2.601	kips
	SNOW	36	12	36.13	15.606	kips
		36	13	36.13	16.907	kips
		36	14	36.13	18.207	kips
		36	6	36.13	7.803	kips
	WIND	-25	12	36.13	-10.84	kips
		-25	13	36.13	-11.74	kips
		-25	14	36.13	-12.64	kips
		-25	6	36.13	-5.419	kips
	RIGGING	SCOREBOARD			7.5	kips
		EQUIPMENT/THEATRICS			11.3	kips

Span	=	**196.00**	**ft**
Spacing	=	**36.13**	**ft**

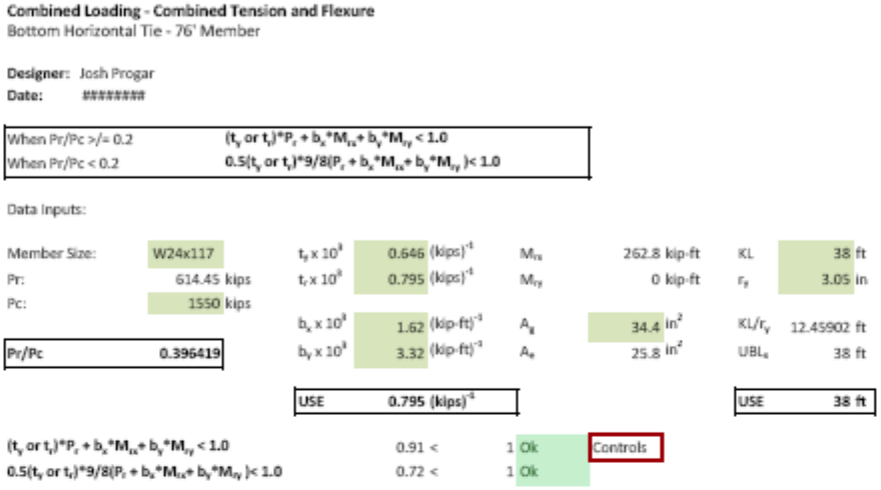
Table 62: Member Sizing - Trusses Along X8 & X9 - Scoreboard Rigging

SECTION PROPERTIES							LOADING			COMPRESSION					TENSION		BENDING		DEFLECTION			
Member	Member Location	Member Size	K Value	Length (ft)	I_x (in^4)	E (ksi)	Controlling LC	Load (k)	Tension/Compression?	P_u (k)	KL	r_y	KL/r_y	ΦP_n (k)	P_u (k)	ΦP_n (k)	M_u (ft-k)	Neglected?	Δ (in)	<	ΔT (=L/120	
1	Top Chord	W14x43	1.00	12.438	428	29000	1.2D+1.6S+0.5W	419.99	Compression	419.99	12.438	2.46	5.056098	562	0	567	37.75	Yes	0.024		1.244	Ok
2	Top Chord	W14x43	1.00	12.328	428	29000	1.2D+1.6S+0.5W	426.68	Compression	426.68	12.328	2.46	5.011382	562	0	567	25.58	Yes	0.029		1.233	Ok
3	Top Chord	W14x43	1.00	12.234	428	29000	1.2D+1.6S+0.5W	461.5	Compression	461.5	12.234	2.46	4.973171	562	0	567	14.81	Yes	0.010		1.223	Ok
4	Top Chord	W14x43	1.00	12.156	428	29000	1.2D+1.6S+0.5W	488.48	Compression	488.48	12.156	2.46	4.941463	562	0	567	9.81	Yes	0.021		1.216	Ok
5	Top Chord	W14x43	1.00	12.094	428	29000	1.2D+1.6S+0.5W	494.74	Compression	494.74	12.094	2.46	4.91626	562	0	567	5.23	Yes	0.006		1.209	Ok
6	Top Chord	W14x53	1.00	12.052	541	29000	1.2D+1.6S+0.5W	534.68	Compression	534.68	12.052	2.46	4.899187	663	0	702	17.35	Yes	0.012		1.205	Ok
7	Top Chord	W14x53	1.00	12.021	541	29000	1.2D+1.6S+0.5W	569.09	Compression	569.09	12.021	2.46	4.886585	663	0	702	11.72	Yes	0.019		1.202	Ok
8	Top Chord	W14x53	1.00	14.000	541	29000	1.2D+1.6S+0.5W	582.83	Compression	582.83	14.000	2.46	5.691057	663	0	702	33.46	Yes	0.055		1.400	Ok
9	Top Chord	W14x53	1.00	14.000	541	29000	1.2D+1.6S+0.5W	582.83	Compression	582.83	14.000	2.46	5.691057	663	0	702	33.46	Yes	0.054		1.400	Ok
10	Top Chord	W14x53	1.00	12.021	541	29000	1.2D+1.6S+0.5W	568.47	Compression	568.47	12.021	2.46	4.886585	663	0	702	11.81	Yes	0.019		1.202	Ok
11	Top Chord	W14x53	1.00	12.052	541	29000	1.2D+1.6S+0.5W	533.46	Compression	533.46	12.052	2.46	4.899187	663	0	702	17.34	Yes	0.012		1.205	Ok
12	Top Chord	W14x43	1.00	12.094	428	29000	1.2D+1.6S+0.5W	492.88	Compression	492.88	12.094	2.46	4.91626	562	0	567	5.12	Yes	0.006		1.209	Ok
13	Top Chord	W14x43	1.00	12.156	428	29000	1.2D+1.6S+0.5W	486.11	Compression	486.11	12.156	2.46	4.941463	562	0	567	9.79	Yes	0.021		1.216	Ok
14	Top Chord	W14x43	1.00	12.234	428	29000	1.2D+1.6S+0.5W	458.45	Compression	458.45	12.234	2.46	4.973171	562	0	567	14.81	Yes	0.009		1.223	Ok
15	Top Chord	W14x43	1.00	12.328	428	29000	1.2D+1.6S+0.5W	422.96	Compression	422.96	12.328	2.46	5.011382	562	0	567	25.48	Yes	0.028		1.233	Ok
16	Top Chord	W14x43	1.00	12.438	428	29000	1.2D+1.6S+0.5W	416.73	Compression	416.73	12.438	2.46	5.056098	562	0	567	37.47	Yes	0.025		1.244	Ok
17	Bottom Chord	W14x43	1.00	12.233	428	29000	1.2D+1.6S+0.5W	156.46	Compression	156.46	12.233	2.46	4.972764	562	0	567	66.29	Yes	0.045		1.223	Ok
18	Bottom Chord	W14x43	1.00	12.159	428	29000	1.2D+1.6S+0.5W	115.6	Compression	115.6	12.159	2.46	4.942683	562	0	567	18.01	Yes	0.028		1.216	Ok
19	Bottom Chord	W14x43	1.00	12.093	428	29000	1.2D+1.6S+0.5W	86.14	Compression	86.14	12.093	2.46	4.915854	562	0	567	50.05	Yes	0.058		1.209	Ok
20	Bottom Chord	W14x43	1.00	12.052	428	29000	1.2D+1.6S+0.5W	111.3	Compression	111.3	12.052	2.46	4.899187	562	0	567	68.66	Yes	0.046		1.205	Ok
21	Bottom Chord	W14x43	1.00	12.019	428	29000	1.2D+1.6S+0.5W	67.6	Compression	67.6	12.019	2.46	4.885772	562	0	567	16.5	Yes	0.032		1.202	Ok
22	Bottom Chord	W14x43	1.00	14.000	428	29000	1.2D+1.6S+0.5W	31.98	Compression	31.98	14.000	2.46	5.691057	562	0	567	31.18	Yes	0.054		1.400	Ok
23	Bottom Chord	W14x43	1.00	14.000	428	29000	1.2D+1.6S+0.5W	32.46	Compression	32.46	14.000	2.46	5.691057	562	0	567	31.88	Yes	0.055		1.400	Ok
24	Bottom Chord	W14x43	1.00	12.019	428	29000	1.2D+1.6S+0.5W	68.69	Compression	68.69	12.019	2.46	4.885772	562	0	567	16.53	Yes	0.032		1.202	Ok
25	Bottom Chord	W14x43	1.00	12.052	428	29000	1.2D+1.6S+0.5W	112.94	Compression	112.94	12.052	2.46	4.899187	562	0	567	69.33	Yes	0.047		1.205	Ok
26	Bottom Chord	W14x43	1.00	12.093	428	29000	1.2D+1.6S+0.5W	88.11	Compression	88.11	12.093	2.46	4.915854	562	0	567	50.62	Yes	0.059		1.209	Ok
27	Bottom Chord	W14x43	1.00	12.159	428	29000	1.2D+1.6S+0.5W	118.25	Compression	118.25	12.159	2.46	4.942683	562	0	567	17.89	Yes	0.028		1.216	Ok
28	Bottom Chord	W14x43	1.00	12.233	428	29000	1.2D+1.6S+0.5W	159.77	Compression	159.77	12.233	2.46	4.972764	562	0	567	66.59	Yes	0.046		1.223	Ok
29	Vertical Web	W8x18	1.00	7.229	61.9	29000	1.2D+1.6S+0.5W	27.06	Compression	27.06	7.229	1.23	5.877236	374	0	237	12.87	Yes	0.005		0.723	Ok
30	Diagonal Web	W8x18	1.00	16.406	61.9	29000	1.2D+1.6S+0.5W	12.21	Tension	0	16.406	1.23	13.33821	265	12.21	237	4.05	Yes	0.092		1.641	Ok
31	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	70.33	Compression	70.33	14.000	1.23	11.38211	300	0	237	2.6	Yes	0.046		1.400	Ok
32	Diagonal Web	W8x18	1.00	16.708	61.9	29000	1.2D+1.6S+0.5W	50.58	Tension	0	16.708	1.23	13.58374	248	50.58	237	3.16	Yes	0.007		1.671	Ok
33	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	54.8	Compression	54.8	14.000	1.23	11.38211	283	0	237	9.05	Yes	0.017		1.400	Ok
34	Diagonal Web	W8x18	1.00	16.999	61.9	29000	1.2D+1.6S+0.5W	40.29	Tension	0	16.999	1.23	13.82033	248	40.29	237	1.99	Yes	0.018		1.700	Ok
35	Vertical Web	W8x18	1.00	13.999	61.9	29000	1.2D+1.6S+0.5W	29.63	Compression	29.63	13.999	1.23	11.3813	283	0	237	6.51	Yes	0.009		1.400	Ok
36	Diagonal Web	W8x18	1.00	17.328	61.9	29000	1.2D+1.6S+0.5W	12.13	Tension	0	17.328	1.23	14.0878	230	12.13	237	4.44	Yes	0.072		1.733	Ok
37	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	73.19	Compression	73.19	14.000	1.23	11.38211	283	0	237	2.84	Yes	0.052		1.400	Ok
38	Diagonal Web	W8x18	1.00	17.608	61.9	29000	1.2D+1.6S+0.5W	60.07	Tension	0	17.608	1.23	14.31545	230	60.07	237	4.12	Yes	0.003		1.761	Ok
39	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	58.2	Compression	58.2	14.000	1.23	11.38211	283	0	237	10.23	Yes	0.016		1.400	Ok
40	Diagonal Web	W8x18	1.00	17.931	61.9	29000	1.2D+1.6S+0.5W	51.57	Tension	0	17.931	1.23	14.57805	230	51.57	237	2.56	Yes	0.035		1.793	Ok
41	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	37.28	Compression	37.28	14.000	1.23	11.38211	283	0	237	7.07	Yes	0.001		1.400	Ok
42	Diagonal Web	W8x18	1.00	19.594	61.9	29000	1.2D+1.6S+0.5W	19.09	Tension	0	19.594	1.23	15.93008	212	19.09	237	1.62	Yes	0.074		1.959	Ok
43	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	16.78	Compression	16.78	14.000	1.23	11.38211	283	0	237	0	Yes	0.000		1.400	Ok
44	Diagonal Web	W8x18	1.00	19.594	61.9	29000	1.2D+1.6S+0.5W	19.95	Tension	0	19.594	1.23	15.93008	212	19.95	237	1.67	Yes	0.075		1.959	Ok
45	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	37.9	Compression	37.9	14.000	1.23	11.38211	283	0	237	7.16	Yes	0.001		1.400	Ok
46	Diagonal Web	W8x18	1.00	17.931	61.9	29000	1.2D+1.6S+0.5W	52.44	Tension	0	17.931	1.23	14.57805	230	52.44	237	2.6	Yes	0.027		1.793	Ok
47	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	58.93	Compression	58.93	14.000	1.23	11.38211	283	0	237	10.32	Yes	0.016		1.400	Ok
48	Diagonal Web	W8x18	1.00	17.608	61.9	29000	1.2D+1.6S+0.5W	60.84	Tension	0	17.608	1.23	14.31545	230	60.84	237	4.18	Yes	0.003		1.761	Ok
49	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	73.86	Compression	73.86	14.000	1.23	11.38211	283	0	237	2.87	Yes	0.052		1.400	Ok
50	Diagonal Web	W8x18	1.00	17.328	61.9	29000	1.2D+1.6S+0.5W	12.95	Tension	0	17.328	1.23	14.0878	230	12.95	237	4.46	Yes	0.073		1.733	Ok
51	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	30.39	Compression	30.39	14.000	1.23	11.38211	283	0	237	6.6	Yes	0.009		1.400	Ok
52	Diagonal Web	W8x18	1.00	16.999	61.9	29000	1.2D+1.6S+0.5W	41.21	Tension	0	16.999	1.23	13.82033	248	41.21	237	2.04	Yes	0.018		1.700	Ok
53	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	55.64	Compression	55.64	14.000	1.23	11.38211	283	0	237	9.13	Yes	0.017		1.400	Ok
54	Diagonal Web	W8x18	1.00	16.708	61.9	29000	1.2D+1.6S+0.5W	51.44	Tension	0	16.708	1.23	13.58374	248	51.44	237	3.21	Yes	0.008		1.671	Ok
55	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	71.22	Compression	71.22	14.000	1.23	11.38211	283	0	237	2.56	Yes	0.046		1.400	Ok
56	Diagonal Web	W8x18	1.00	16.406	61.9	29000	1.2D+1.6S+0.5W	11.6	Tension	0	16.406	1.23	13.33821	248	11.6	237	4	Yes	0.091		1.641	Ok
57	Vertical Web	W8x18	1.00	7.229	61.9	29000	1.2D+1.6S+0.5W	26.73	Compression	26.73	7.229	1.23	5.877236	374	0	237	12.63	Yes	0.005		0.723	Ok
58	Diagonal Tie	W27x146	1.00	25.272	4020	29000	1.2D+1.6S+0.5W	477.64	Tension	0	25.272	1.95	12.96	-	529.02	1940	445.3	No	0.283		2.527	Ok
59	Diagonal Tie	W27x146	1.00	25.272	4020	29000	1.2D+1.6S+0.5W	479.94	Tension	0	25.272	1.95	12.96	-	531.41	1940	438.89	No	0.284		2.527	Ok
60	Diagonal Tie	W27x146	1.00	19.435	4020	29000	1.2D+1.6S+0.5W	514.85	Tension	0	19.435	1.95	9.966667	-	514.85	1940	818.35	No	0.038		1.944	Ok
61	Diagonal Tie	W27x146	1.00	19.435	4020	29000	1.2D+1.6S+0.5W	514.5	Tension	0	19.435	1.95	9.966667	-	514.5	1940	818.82	No	0.039		1.944	Ok
62	Vertical Tie	W14x68	1.00	11.917	722	29000	1.2D+1.6S+0.5W	69.37	Compression	69.37	11.917	3.7	3.220811	844	0	905	272.53	No	0.108		1.192	Ok
63	Vertical Tie	W14x68	1.00	14	722	29000	1.2D+1.6S+0.5W	15.3	Tension	0	14.000	3.7	3.783784	844	15.3	905	1.01	Yes	0.002		1.400	Ok
64	Vertical Tie	W14x68	1.00	11.917	722	29000	1.2D+1.6S+0.5W	69.35	Compression	69.35	11.917	3.7	3.220811	844	0	905	274.24	Yes	0.109		1.192	Ok
65	Horizontal Tie	W27x146	1.00	17.542	4020	29000	1.2D+1.6S+0.5W	512.21	Tension	0	17.542	1.95	8.995897	-	512.21	1940	818.35	No	0.084		1.754	Ok
66	Horizontal Tie	W24x117	1.00	76	4020	29000	1.2D+1.6S+0.5W	540.24	Tension	0	76.000	3.27	23.24159	-	540.24	1550	214.94	No	1.800		7.600	Ok
67	Horizontal Tie	W27x146	1.00	17.542	4020	29000	1.2D+1.6S+0.5W	511.83	Tension	0	17.542	1.95	8.995897	-	511.83	1940	818.82	No	0.084		1.754	Ok

Table 63: Member Sizing - Worst Case Scenario Truss

SECTION PROPERTIES							LOADING			COMPRESSION					TENSION		BENDING		DEFLECTION			
Member	Member Location	Member Size	K Value	Length (ft)	$I_x (in^4)$	E (ksi)	Controlling LC	Load (k)	Tension/Compression?	P_u (k)	KL	r_y	KL/r_y	ϕP_n (k)	P_u (k)	ϕP_n (k)	M_u (ft-k)	Neglected?	Δ (in)	<	ΔTL=L/120	
1	Top Chord	W14x43	1.00	12.438	428	29000	1.2D+1.6S+0.5W	463.03	Compression	463.03	12.438	2.46	5.056098	562	0	567	42.24	Yes	0.027		1.244	Ok
2	Top Chord	W14x43	1.00	12.328	428	29000	1.2D+1.6S+0.5W	468.03	Compression	468.03	12.328	2.46	5.011382	562	0	567	29.14	Yes	0.031		1.233	Ok
3	Top Chord	W14x43	1.00	12.234	428	29000	1.2D+1.6S+0.5W	509.06	Compression	509.06	12.234	2.46	4.973171	562	0	567	16.91	Yes	0.010		1.223	Ok
4	Top Chord	W14x43	1.00	12.156	428	29000	1.2D+1.6S+0.5W	542.08	Compression	542.08	12.156	2.46	4.941463	562	0	567	10.3	Yes	0.022		1.216	Ok
5	Top Chord	W14x43	1.00	12.094	428	29000	1.2D+1.6S+0.5W	550.84	Compression	550.84	12.094	2.46	4.91626	562	0	567	4.77	Yes	0.009		1.209	Ok
6	Top Chord	W14x53	1.00	12.052	541	29000	1.2D+1.6S+0.5W	600.33	Compression	600.33	12.052	2.46	4.899187	663	0	702	19.52	Yes	0.014		1.205	Ok
7	Top Chord	W14x53	1.00	12.021	541	29000	1.2D+1.6S+0.5W	643.83	Compression	643.83	12.021	2.46	4.886585	663	0	702	13.91	Yes	0.021		1.202	Ok
8	Top Chord	W14x53	1.00	14.000	541	29000	1.2D+1.6S+0.5W	664.58	Compression	664.58	14.000	2.46	5.691057	663	0	702	40.35	Yes	0.063		1.400	Ok
9	Top Chord	W14x53	1.00	14.000	541	29000	1.2D+1.6S+0.5W	664.58	Compression	664.58	14.000	2.46	5.691057	663	0	702	40.35	Yes	0.063		1.400	Ok
10	Top Chord	W14x53	1.00	12.021	541	29000	1.2D+1.6S+0.5W	643.18	Compression	643.18	12.021	2.46	4.886585	663	0	702	14	Yes	0.021		1.202	Ok
11	Top Chord	W14x53	1.00	12.052	541	29000	1.2D+1.6S+0.5W	599.06	Compression	599.06	12.052	2.46	4.899187	663	0	702	19.51	Yes	0.014		1.205	Ok
12	Top Chord	W14x43	1.00	12.094	428	29000	1.2D+1.6S+0.5W	549.01	Compression	549.01	12.094	2.46	4.91626	562	0	567	4.67	Yes	0.009		1.209	Ok
13	Top Chord	W14x43	1.00	12.156	428	29000	1.2D+1.6S+0.5W	539.62	Compression	539.62	12.156	2.46	4.941463	562	0	567	10.29	Yes	0.022		1.216	Ok
14	Top Chord	W14x43	1.00	12.234	428	29000	1.2D+1.6S+0.5W	505.89	Compression	505.89	12.234	2.46	4.973171	562	0	567	16.91	Yes	0.009		1.223	Ok
15	Top Chord	W14x43	1.00	12.328	428	29000	1.2D+1.6S+0.5W	464.15	Compression	464.15	12.328	2.46	5.011382	562	0	567	29.04	Yes	0.030		1.233	Ok
16	Top Chord	W14x43	1.00	12.438	428	29000	1.2D+1.6S+0.5W	459.64	Compression	459.64	12.438	2.46	5.056098	562	0	567	41.94	Yes	0.028		1.244	Ok
17	Bottom Chord	W14x43	1.00	12.233	428	29000	1.2D+1.6S+0.5W	187.57	Compression	187.57	12.233	2.46	4.972764	562	0	567	79.92	Yes	0.057		1.223	Ok
18	Bottom Chord	W14x43	1.00	12.159	428	29000	1.2D+1.6S+0.5W	139.59	Compression	139.59	12.159	2.46	4.942683	562	0	567	20.92	Yes	0.031		1.216	Ok
19	Bottom Chord	W14x43	1.00	12.093	428	29000	1.2D+1.6S+0.5W	103.86	Compression	103.86	12.093	2.46	4.915854	562	0	567	62.86	Yes	0.071		1.209	Ok
20	Bottom Chord	W14x43	1.00	12.052	428	29000	1.2D+1.6S+0.5W	133.06	Compression	133.06	12.052	2.46	4.899187	562	0	567	79.94	Yes	0.054		1.205	Ok
21	Bottom Chord	W14x43	1.00	12.019	428	29000	1.2D+1.6S+0.5W	79.29	Compression	79.29	12.019	2.46	4.885772	562	0	567	18.5	Yes	0.036		1.202	Ok
22	Bottom Chord	W14x43	1.00	14.000	428	29000	1.2D+1.6S+0.5W	34.44	Compression	34.44	14.000	2.46	5.691057	562	0	567	38.38	Yes	0.064		1.400	Ok
23	Bottom Chord	W14x43	1.00	14.000	428	29000	1.2D+1.6S+0.5W	34.94	Compression	34.94	14.000	2.46	5.691057	562	0	567	39.12	Yes	0.065		1.400	Ok
24	Bottom Chord	W14x43	1.00	12.019	428	29000	1.2D+1.6S+0.5W	80.41	Compression	80.41	12.019	2.46	4.885772	562	0	567	18.54	Yes	0.036		1.202	Ok
25	Bottom Chord	W14x43	1.00	12.052	428	29000	1.2D+1.6S+0.5W	134.76	Compression	134.76	12.052	2.46	4.899187	562	0	567	80.65	Yes	0.055		1.205	Ok
26	Bottom Chord	W14x43	1.00	12.093	428	29000	1.2D+1.6S+0.5W	105.91	Compression	105.91	12.093	2.46	4.915854	562	0	567	63.46	Yes	0.071		1.209	Ok
27	Bottom Chord	W14x43	1.00	12.159	428	29000	1.2D+1.6S+0.5W	142.34	Compression	142.34	12.159	2.46	4.942683	562	0	567	20.8	Yes	0.030		1.216	Ok
28	Bottom Chord	W14x43	1.00	12.233	428	29000	1.2D+1.6S+0.5W	191	Compression	191	12.233	2.46	4.972764	562	0	567	80.23	Yes	0.057		1.223	Ok
29	Vertical Web	W8x18	1.00	7.229	61.9	29000	1.2D+1.6S+0.5W	27.94	Compression	27.94	7.229	1.23	5.877236	374	0	237	14.06	Yes	0.006		0.723	Ok
30	Diagonal Web	W8x18	1.00	16.406	61.9	29000	1.2D+1.6S+0.5W	10.45	Tension	0	16.406	1.23	13.33821	265	10.45	237	4.99	Yes	0.107		1.641	Ok
31	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	81.81	Compression	81.81	14.000	1.23	11.38211	300	0	237	3.49	Yes	0.056		1.400	Ok
32	Diagonal Web	W8x18	1.00	16.708	61.9	29000	1.2D+1.6S+0.5W	59.29	Tension	0	16.708	1.23	13.58374	248	59.29	237	3.77	Yes	0.011		1.671	Ok
33	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	64.81	Compression	64.81	14.000	1.23	11.38211	283	0	237	10.54	Yes	0.020		1.400	Ok
34	Diagonal Web	W8x18	1.00	16.999	61.9	29000	1.2D+1.6S+0.5W	48.91	Tension	0	16.999	1.23	13.82033	248	48.91	237	2.46	Yes	0.019		1.700	Ok
35	Vertical Web	W8x18	1.00	13.999	61.9	29000	1.2D+1.6S+0.5W	35.77	Compression	35.77	13.999	1.23	11.3813	283	0	237	7.81	Yes	0.010		1.400	Ok
36	Diagonal Web	W8x18	1.00	17.328	61.9	29000	1.2D+1.6S+0.5W	15.93	Tension	0	17.328	1.23	14.0878	230	15.93	237	5.61	Yes	0.089		1.733	Ok
37	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	87.23	Compression	87.23	14.000	1.23	11.38211	283	0	237	3.82	Yes	0.061		1.400	Ok
38	Diagonal Web	W8x18	1.00	17.608	61.9	29000	1.2D+1.6S+0.5W	74.06	Tension	0	17.608	1.23	14.31545	230	74.06	237	5.04	Yes	0.002		1.761	Ok
39	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	71.14	Compression	71.14	14.000	1.23	11.38211	283	0	237	12.13	Yes	0.018		1.400	Ok
40	Diagonal Web	W8x18	1.00	17.931	61.9	29000	1.2D+1.6S+0.5W	64.93	Tension	0	17.931	1.23	14.57805	230	64.93	237	3.23	Yes	0.030		1.793	Ok
41	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	47.09	Compression	47.09	14.000	1.23	11.38211	283	0	237	8.66	Yes	0.001		1.400	Ok
42	Diagonal Web	W8x18	1.00	19.594	61.9	29000	1.2D+1.6S+0.5W	28.75	Tension	0	19.594	1.23	15.93008	212	28.75	237	1.95	Yes	0.088		1.959	Ok
43	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	18.13	Compression	18.13	14.000	1.23	11.38211	283	0	237	0	Yes	0.000		1.400	Ok
44	Diagonal Web	W8x18	1.00	19.594	61.9	29000	1.2D+1.6S+0.5W	29.64	Tension	0	19.594	1.23	15.93008	212	29.64	237	2	Yes	0.089		1.959	Ok
45	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	47.72	Compression	47.72	14.000	1.23	11.38211	283	0	237	8.75	Yes	0.001		1.400	Ok
46	Diagonal Web	W8x18	1.00	17.931	61.9	29000	1.2D+1.6S+0.5W	65.84	Tension	0	17.931	1.23	14.57805	230	65.84	237	3.28	Yes	0.030		1.793	Ok
47	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	71.9	Compression	71.9	14.000	1.23	11.38211	283	0	237	12.22	Yes	0.018		1.400	Ok
48	Diagonal Web	W8x18	1.00	17.608	61.9	29000	1.2D+1.6S+0.5W	74.87	Tension	0	17.608	1.23	14.31545	230	74.87	237	5.1	Yes	0.002		1.761	Ok
49	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	87.93	Compression	87.93	14.000	1.23	11.38211	283	0	237	3.86	Yes	0.062		1.400	Ok
50	Diagonal Web	W8x18	1.00	17.328	61.9	29000	1.2D+1.6S+0.5W	16.79	Tension	0	17.328	1.23	14.0878	230	16.79	237	5.63	Yes	0.090		1.733	Ok
51	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	36.55	Compression	36.55	14.000	1.23	11.38211	283	0	237	7.9	Yes	0.010		1.400	Ok
52	Diagonal Web	W8x18	1.00	16.999	61.9	29000	1.2D+1.6S+0.5W	49.86	Tension	0	16.999	1.23	13.82033	248	49.86	237	2.51	Yes	0.018		1.700	Ok
53	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	65.68	Compression	65.68	14.000	1.23	11.38211	283	0	237	10.61	Yes	0.020		1.400	Ok
54	Diagonal Web	W8x18	1.00	16.708	61.9	29000	1.2D+1.6S+0.5W	60.19	Tension	0	16.708	1.23	13.58374	248	60.19	237	3.82	Yes	0.111		1.671	Ok
55	Vertical Web	W8x18	1.00	14	61.9	29000	1.2D+1.6S+0.5W	82.44	Compression	82.44	14.000	1.23	11.38211	283	0	237	3.45	Yes	0.056		1.400	Ok
56	Diagonal Web	W8x18	1.00	16.406	61.9	29000	1.2D+1.6S+0.5W	9.81	Tension	0	16.406	1.23	13.33821	248	9.81	237	4.94	Yes	0.106		1.641	Ok
57	Vertical Web	W8x18	1.00	7.229	61.9	29000	1.2D+1.6S+0.5W	27.6	Compression	27.6	7.229	1.23	5.877236	374	0	237	13.82	Yes	0.006		0.723	Ok
58	Diagonal Tie	W27x146	1.00	25.272	4020	29000	1.2D+1.6S+0.5W	531.69	Tension	0	25.272	1.95	12.96	-	529.02	1940	526.39	No	0.352		2.527	Ok
59	Diagonal Tie	W27x146	1.00	25.272	4020	29000	1.2D+1.6S+0.5W	533.92	Tension	0	25.272	1.95	12.96	-	531.41	1940	519.71	No	0.353		2.527	Ok
60	Diagonal Tie	W27x146	1.00	19.435	4020	29000	1.2D+1.6S+0.5W	560.67	Tension	0	19.435	1.95	9.966667	-	575.32	1940	992.8	No	0.072		1.944	Ok
61	Diagonal Tie	W27x146	1.00	19.435	4020	29000	1.2D+1.6S+0.5W	558.41	Tension	0	19.435	1.95	9.966667	-	574.96	1940	993.29	No	0.112		1.944	Ok
62	Vertical Tie	W14x68	1.00	11.917	722	29000	1.2D+1.6S+0.5W	82.12	Compression	82.12	11.917	3.7	3.220811	844	0	905	356	No	0.138		1.192	Ok
63	Vertical Tie	W14x68	1.00	14	722	29000	1.2D+1.6S+0.5W	31.23	Tension	0	14.000	3.7	3.783784	844	31.23	905	1.07	Yes	0.000		1.400	Ok
64	Vertical Tie	W14x68	1.00	11.917	722	29000	1.2D+1.6S+0.5W	82.06	Compression	82.06	11.917	3.7	3.220811	844	0	905	357.72	Yes	0.139		1.192	Ok
65	Horizontal Tie	W27x146	1.00	17.542	4020	29000	1.2D+1.6S+0.5W	574.34	Tension	0	17.542	1.95	8.995897	-	574.34	1940	992.8	No	0.112		1.754	Ok
66	Horizontal Tie	W24x117	1.00	76	4020	29000	1.2D+1.6S+0.5W	614.45	Tension	0	76.000	3.27	23.24159	-	614.45	1550	262.8	No	2.161		7.600	Ok
67	Horizontal Tie	W27x146	1.00	17.542	4020	29000	1.2D+1.6S+0.5W	573.95	Tension	0	17.542	1.95	8.995897	-	573.95	1940	993.29	No	0.112		1.754	Ok

Combined Loading Calculations



Combined Loading - Combined Tension and Flexure
Bottom Horizontal Tie - 76' Member

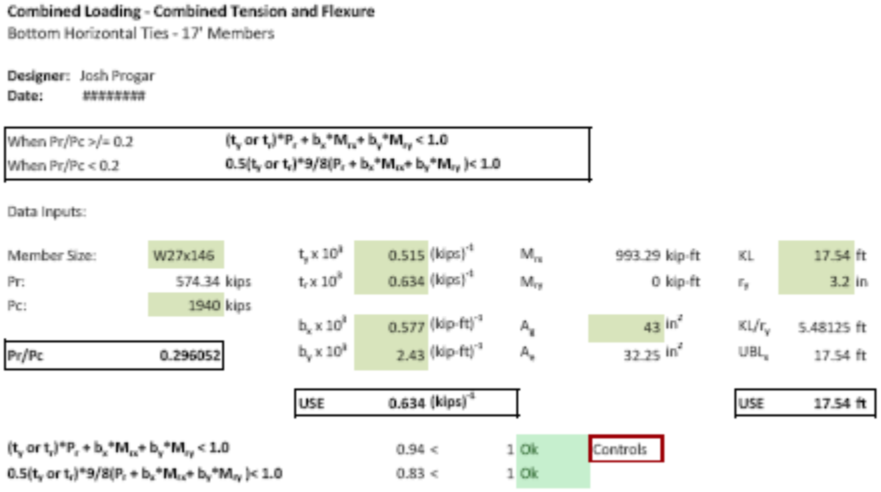
Designer: Josh Progar
Date: ########

When Pr/Pc >/= 0.2	**$(t_y \text{ or } t_r)*P_r + b_x*M_{rx} + b_y*M_{ry} < 1.0$**
When Pr/Pc < 0.2	**$0.5(t_y \text{ or } t_r)*9/8(P_r + b_x*M_{rx} + b_y*M_{ry}) < 1.0$**

Data Inputs:

Member Size:	W24x117		$t_y \times 10^3$	0.646	$(\text{kips})^{-1}$	M_{rx}	262.8	kip-ft	KL	38	ft
Pr:	614.45	kips	$t_r \times 10^3$	0.795	$(\text{kips})^{-1}$	M_{ry}	0	kip-ft	r_y	3.05	in
Pc:	1550	kips									
			$b_x \times 10^3$	1.62	$(\text{kip-ft})^{-1}$	A_g	34.4	in^2	KL/r_y	12.45902	ft
Pr/Pc	**0.396419**		$b_y \times 10^3$	3.32	$(\text{kip-ft})^{-1}$	A_e	25.8	in^2	UBL_x	38	ft
			USE	**0.795**	**$(\text{kips})^{-1}$**				**USE**	**38**	**ft**

$(t_y \text{ or } t_r)*P_r + b_x*M_{rx} + b_y*M_{ry} < 1.0$	0.91 <	1	Ok	Controls
$0.5(t_y \text{ or } t_r)*9/8(P_r + b_x*M_{rx} + b_y*M_{ry}) < 1.0$	0.72 <	1	Ok	



Combined Loading - Combined Tension and Flexure
Bottom Horizontal Ties - 17' Members

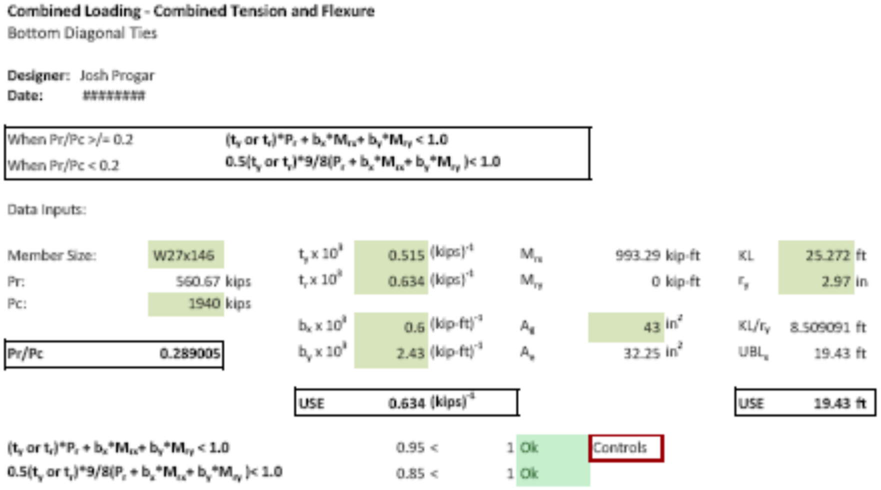
Designer: Josh Progar
Date: ########

When Pr/Pc >/= 0.2	**$(t_y \text{ or } t_r)*P_r + b_x*M_{rx} + b_y*M_{ry} < 1.0$**
When Pr/Pc < 0.2	**$0.5(t_y \text{ or } t_r)*9/8(P_r + b_x*M_{rx} + b_y*M_{ry}) < 1.0$**

Data Inputs:

Member Size:	W27x146		$t_y \times 10^3$	0.515	$(\text{kips})^{-1}$	M_{rx}	993.29	kip-ft	KL	17.54	ft
Pr:	574.34	kips	$t_r \times 10^3$	0.634	$(\text{kips})^{-1}$	M_{ry}	0	kip-ft	r_y	3.2	in
Pc:	1940	kips									
			$b_x \times 10^3$	0.577	$(\text{kip-ft})^{-1}$	A_g	43	in^2	KL/r_y	5.48125	ft
Pr/Pc	**0.296052**		$b_y \times 10^3$	2.43	$(\text{kip-ft})^{-1}$	A_e	32.25	in^2	UBL_x	17.54	ft
			USE	**0.634**	**$(\text{kips})^{-1}$**				**USE**	**17.54**	**ft**

$(t_y \text{ or } t_r)*P_r + b_x*M_{rx} + b_y*M_{ry} < 1.0$	0.94 <	1	Ok	Controls
$0.5(t_y \text{ or } t_r)*9/8(P_r + b_x*M_{rx} + b_y*M_{ry}) < 1.0$	0.83 <	1	Ok	



Combined Loading - Combined Tension and Flexure
Bottom Diagonal Ties

Designer: Josh Progar
Date: ########

When Pr/Pc >/= 0.2	**$(t_y \text{ or } t_r)*P_r + b_x*M_{rx} + b_y*M_{ry} < 1.0$**
When Pr/Pc < 0.2	**$0.5(t_y \text{ or } t_r)*9/8(P_r + b_x*M_{rx} + b_y*M_{ry}) < 1.0$**

Data Inputs:

Member Size:	W27x146		$t_y \times 10^3$	0.515	$(\text{kips})^{-1}$	M_{rx}	993.29	kip-ft	KL	25.272	ft
Pr:	560.67	kips	$t_r \times 10^3$	0.634	$(\text{kips})^{-1}$	M_{ry}	0	kip-ft	r_y	2.97	in
Pc:	1940	kips									
			$b_x \times 10^3$	0.6	$(\text{kip-ft})^{-1}$	A_g	43	in^2	KL/r_y	8.509091	ft
Pr/Pc	**0.289005**		$b_y \times 10^3$	2.43	$(\text{kip-ft})^{-1}$	A_e	32.25	in^2	UBL_x	19.43	ft
			USE	**0.634**	**$(\text{kips})^{-1}$**				**USE**	**19.43**	**ft**

$(t_y \text{ or } t_r)*P_r + b_x*M_{rx} + b_y*M_{ry} < 1.0$	0.95 <	1	Ok	Controls
$0.5(t_y \text{ or } t_r)*9/8(P_r + b_x*M_{rx} + b_y*M_{ry}) < 1.0$	0.85 <	1	Ok	

Combined Loading - Combined Compression and Flexure

Bottom Vertical Tie

Designer: Josh Progar
Date: 4/13/2012

When Pr/Pc >/= 0.2	**$p*P_r + b_x*M_{rx}+ b_y*M_{ry} < 1.0$**
When Pr/Pc < 0.2	**$0.5p*P_r*9/8(b_x*M_{rx}+ b_y*M_{ry})< 1.0$**

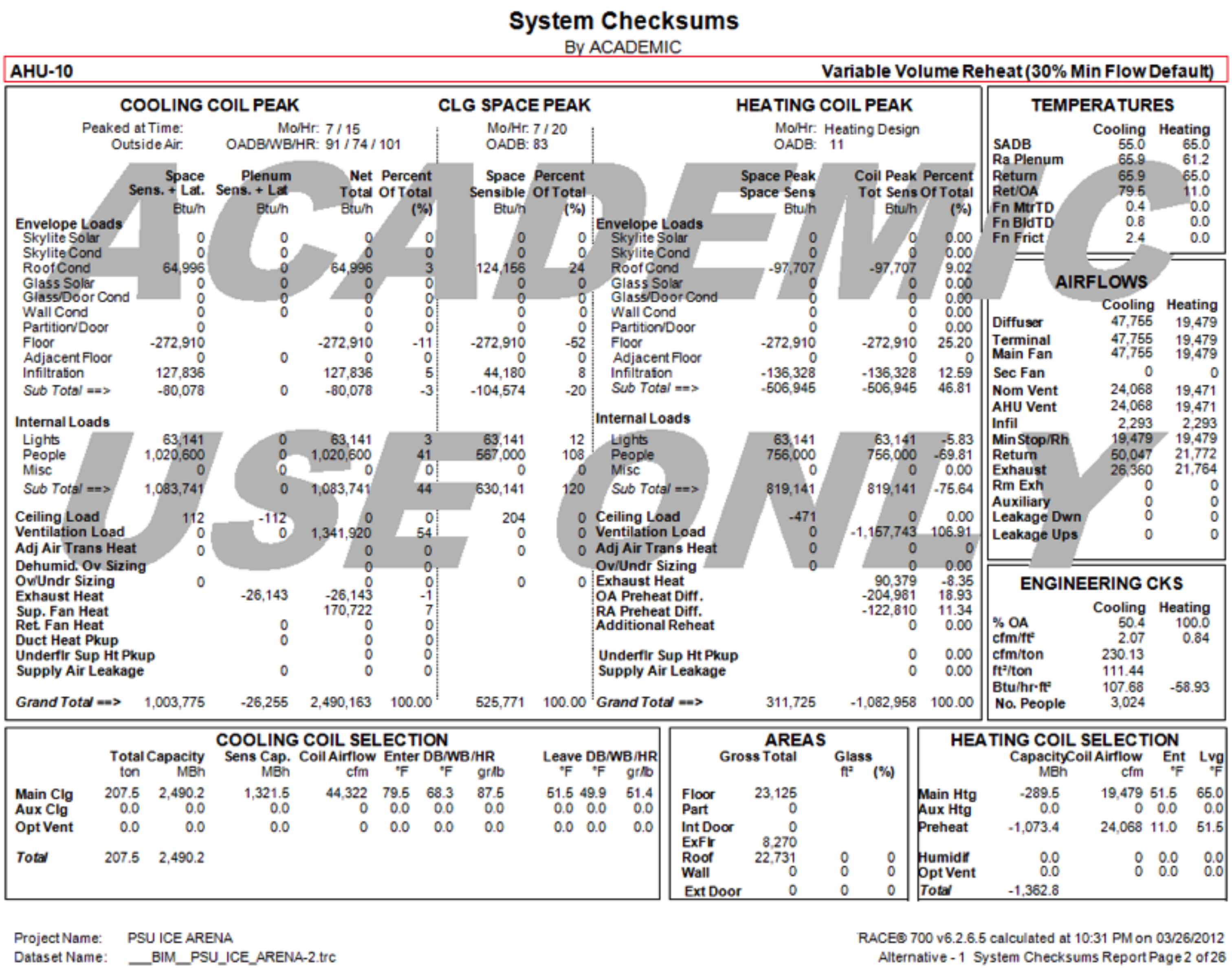
Data Inputs:

Member Size:	W14x68		$p \times 10^3$	1.43	$(\text{kips})^{-1}$	M_{rx}
Pr:	82.12	kips				M_{ry}
Pc:	700	kips				
			$b_x \times 10^3$	2.19	$(\text{kip-ft})^{-1}$	A_g
Pr/Pc	**0.117314**		$b_y \times 10^3$	6.42	$(\text{kip-ft})^{-1}$	A_e

USE	**1.43**	**$(\text{kips})^{-1}$**

$p*P_r + b_x*M_{rx}+ b_y*M_{ry} < 1.0$	0.901	<	1	Ok
$0.5p*P_r*9/8(b_x*M_{rx}+ b_y*M_{ry})< 1.0$	0.940	<	1	Ok

Mechanical Load



System Checksums

By ACADEMIC

AHU-10 **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK | CLG SPACE PEAK

Peaked at Time: Mo/Hr: 7 / 15
Outside Air: OADB/WB/HR: 91 / 74 / 101

CLG SPACE PEAK: Mo/Hr: 7 / 20
OADB: 83

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	64,996	0	64,996	3	124,156	24
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	0	0	0	0	0	0
Partition/Door	0		0	0	0	0
Floor	-272,910		-272,910	-11	-272,910	-52
Adjacent Floor	0	0	0	0	0	0
Infiltration	127,836		127,836	5	44,180	8
Sub Total ==>	-80,078	0	-80,078	-3	-104,574	-20
Internal Loads						
Lights	63,141	0	63,141	3	63,141	12
People	1,020,600	0	1,020,600	41	567,000	108
Misc	0	0	0	0	0	0
Sub Total ==>	1,083,741	0	1,083,741	44	630,141	120
Ceiling Load	112	-112	0	0	204	0
Ventilation Load	0	0	1,341,920	54	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-26,143	-26,143	-1		
Sup. Fan Heat			170,722	7		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	1,003,775	-26,255	2,490,163	100.00	525,771	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	-97,707	-97,707	9.02
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	-272,910	-272,910	25.20
Adjacent Floor	0	0	0
Infiltration	-136,328	-136,328	12.59
Sub Total ==>	-506,945	-506,945	46.81
Internal Loads			
Lights	63,141	63,141	-5.83
People	756,000	756,000	-69.81
Misc	0	0	0.00
Sub Total ==>	819,141	819,141	-75.64
Ceiling Load	-471	0	0.00
Ventilation Load	0	-1,157,743	106.91
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		90,379	-8.35
OA Preheat Diff.		-204,981	18.93
RA Preheat Diff.		-122,810	11.34
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	311,725	-1,082,958	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	65.0
Ra Plenum	65.9	61.2
Return	65.9	65.0
Ret/OA	79.5	11.0
Fn MtrTD	0.4	0.0
Fn BldTD	0.8	0.0
Fn Frict	2.4	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	47,755	19,479
Terminal	47,755	19,479
Main Fan	47,755	19,479
Sec Fan	0	0
Nom Vent	24,068	19,471
AHU Vent	24,068	19,471
Infil	2,293	2,293
Min Stop/Rh	19,479	19,479
Return	50,047	21,772
Exhaust	26,360	21,764
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	50.4	100.0
cfm/ft²	2.07	0.84
cfm/ton	230.13	
ft²/ton	111.44	
Btu/hr·ft²	107.68	-58.93
No. People	3,024	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	207.5	2,490.2	1,321.5	44,322	79.5	68.3	87.5	51.5	49.9	51.4
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	207.5	2,490.2								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	23,125		
Part	0		
Int Door	0		
ExFlr	8,270		
Roof	22,731	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-289.5	19,479	51.5	65.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-1,073.4	24,068	11.0	51.5
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-1,362.8			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA-2.trc

RACE® 700 v6.2.6.5 calculated at 10:31 PM on 03/26/2012
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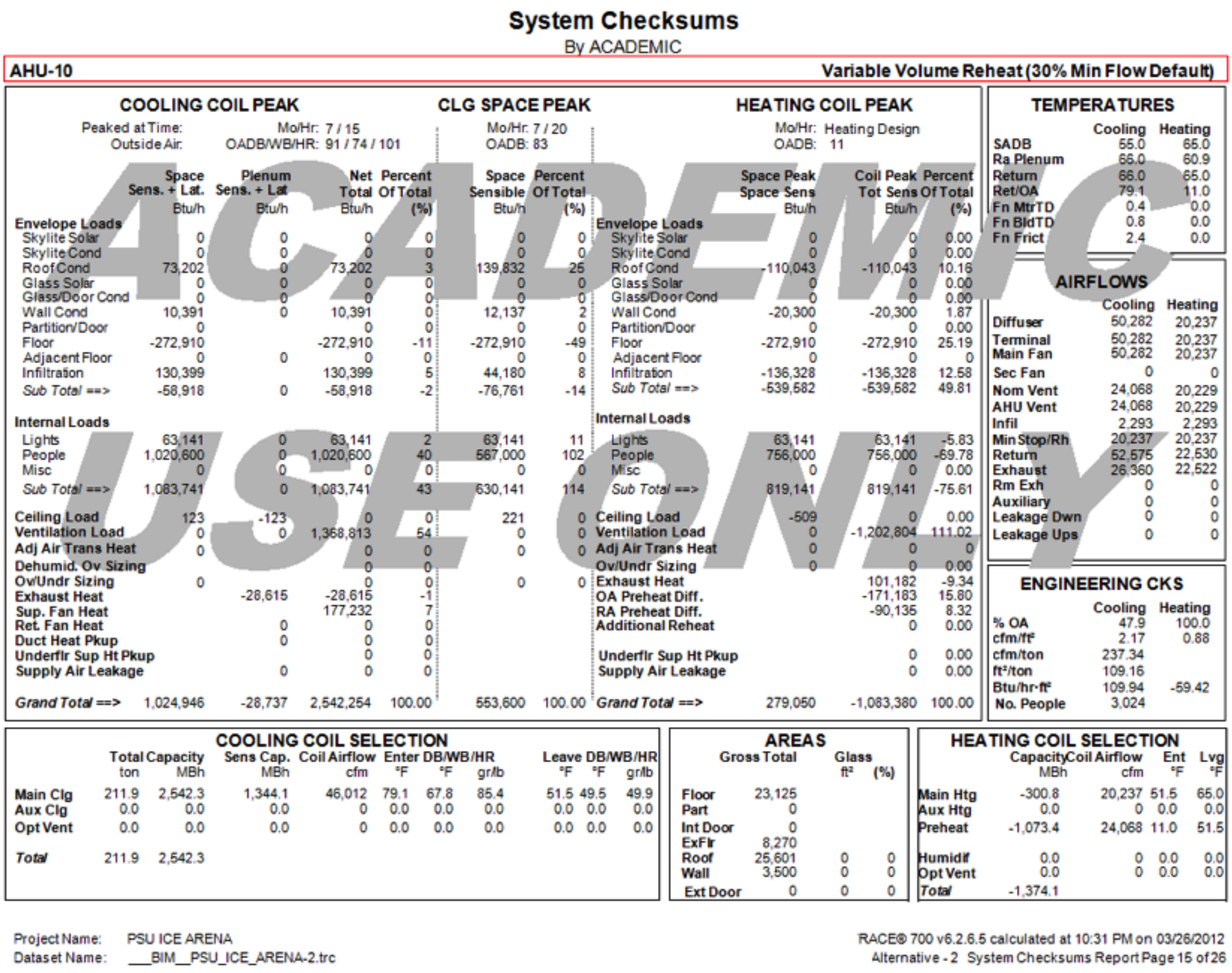

System Checksums

By ACADEMIC

AHU-10 **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK / **CLG SPACE PEAK**

Peaked at Time: Mo/Hr: 7 / 15 | Mo/Hr: 7 / 20
Outside Air: OADB/WB/HR: 91 / 74 / 101 | OADB: 83

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	73,202	0	73,202	3	139,832	25
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	10,391	0	10,391	0	12,137	2
Partition/Door	0		0	0	0	0
Floor	-272,910		-272,910	-11	-272,910	-49
Adjacent Floor	0	0	0	0	0	0
Infiltration	130,399		130,399	5	44,180	8
Sub Total ==>	-58,918	0	-58,918	-2	-76,761	-14
Internal Loads						
Lights	63,141	0	63,141	2	63,141	11
People	1,020,600	0	1,020,600	40	567,000	102
Misc	0	0	0	0	0	0
Sub Total ==>	1,083,741	0	1,083,741	43	630,141	114
Ceiling Load	123	-123	0	0	221	0
Ventilation Load	0	0	1,368,813	54	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-28,615	-28,615	-1		
Sup. Fan Heat			177,232	7		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	1,024,946	-28,737	2,542,254	100.00	553,600	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	-110,043	-110,043	10.16
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	-20,300	-20,300	1.87
Partition/Door	0	0	0.00
Floor	-272,910	-272,910	25.19
Adjacent Floor	0	0	0
Infiltration	-136,328	-136,328	12.58
Sub Total ==>	-539,582	-539,582	49.81
Internal Loads			
Lights	63,141	63,141	-5.83
People	756,000	756,000	-69.78
Misc	0	0	0.00
Sub Total ==>	819,141	819,141	-75.61
Ceiling Load	-509	0	0.00
Ventilation Load	0	-1,202,804	111.02
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		101,182	-9.34
OA Preheat Diff.		-171,183	15.80
RA Preheat Diff.		-90,135	8.32
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	279,050	-1,083,380	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	65.0
Ra Plenum	66.0	60.9
Return	66.0	65.0
Ret/OA	79.1	11.0
Fn MtrTD	0.4	0.0
Fn BldTD	0.8	0.0
Fn Frict	2.4	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	50,282	20,237
Terminal	50,282	20,237
Main Fan	50,282	20,237
Sec Fan	0	0
Nom Vent	24,068	20,229
AHU Vent	24,068	20,229
Infil	2,293	2,293
Min Stop/Rh	20,237	20,237
Return	52,575	22,530
Exhaust	26,360	22,522
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	47.9	100.0
cfm/ft²	2.17	0.88
cfm/ton	237.34	
ft²/ton	109.16	
Btu/hr·ft²	109.94	-59.42
No. People	3,024	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	211.9	2,542.3	1,344.1	46,012	79.1	67.8	85.4	51.5	49.5	49.9
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	211.9	2,542.3								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	23,125		
Part	0		
Int Door	0		
ExFlr	8,270		
Roof	25,601	0	0
Wall	3,500	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-300.8	20,237	51.5	65.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-1,073.4	24,068	11.0	51.5
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-1,374.1			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA-2.trc

RACE® 700 v6.2.6.5 calculated at 10:31 PM on 03/26/2012
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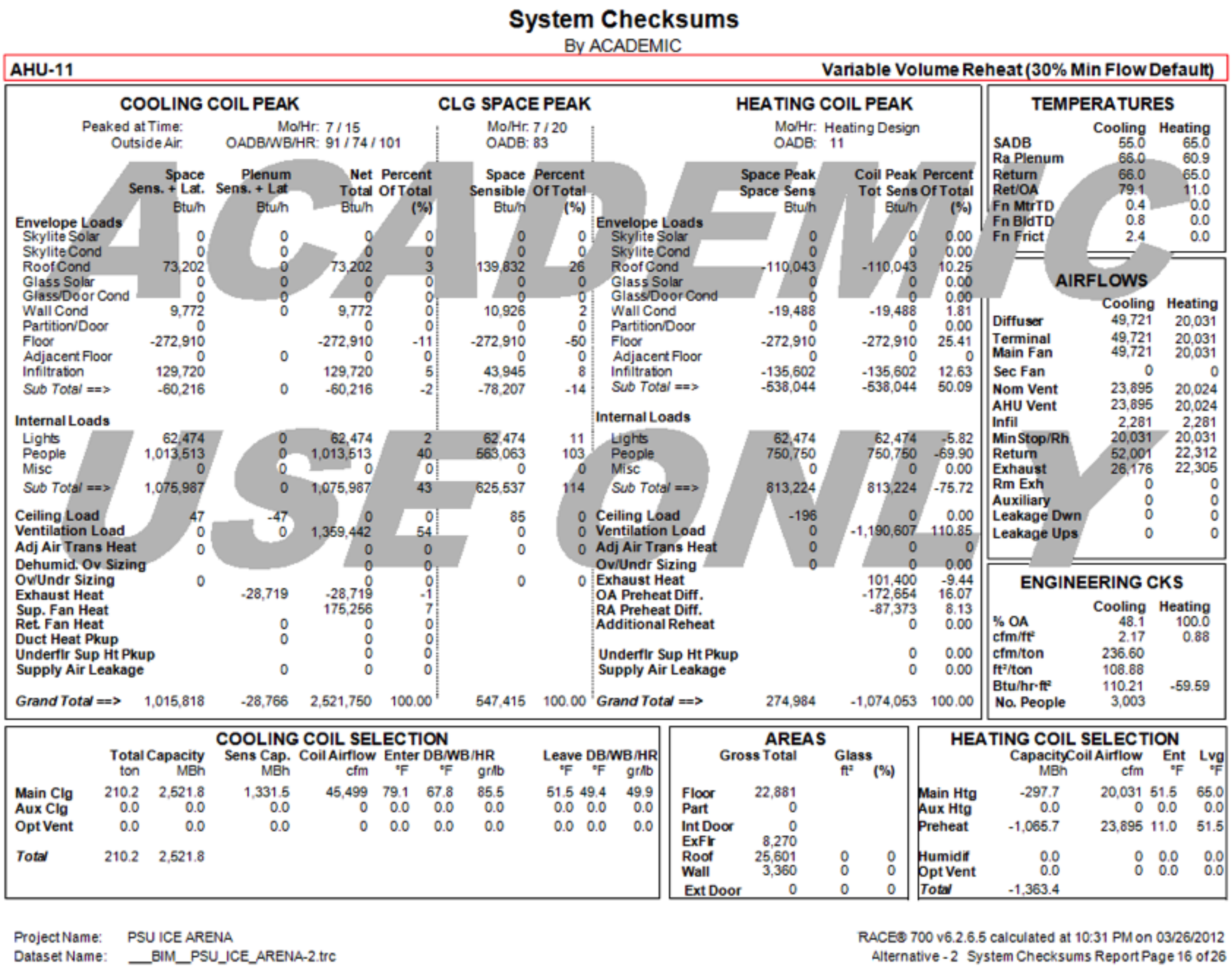


System Checksums

By ACADEMIC

AHU-11 **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling coil peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 91 / 74 / 101

Clg space peak — Mo/Hr: 7 / 20; OADB: 83

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	73,202	0	73,202	3	139,832	26
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	9,772	0	9,772	0	10,926	2
Partition/Door	0		0	0	0	0
Floor	-272,910		-272,910	-11	-272,910	-50
Adjacent Floor	0	0	0	0	0	0
Infiltration	129,720		129,720	5	43,945	8
Sub Total ==>	-60,216	0	-60,216	-2	-78,207	-14
Internal Loads						
Lights	62,474	0	62,474	2	62,474	11
People	1,013,513	0	1,013,513	40	563,063	103
Misc	0	0	0	0	0	0
Sub Total ==>	1,075,987	0	1,075,987	43	625,537	114
Ceiling Load	47	-47	0	0	85	0
Ventilation Load	0	0	1,359,442	54	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-28,719	-28,719	-1		
Sup. Fan Heat			175,256	7		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	1,015,818	-28,766	2,521,750	100.00	547,415	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 11

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	-110,043	-110,043	10.25
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	-19,488	-19,488	1.81
Partition/Door	0	0	0.00
Floor	-272,910	-272,910	25.41
Adjacent Floor	0	0	0
Infiltration	-135,602	-135,602	12.63
Sub Total ==>	-538,044	-538,044	50.09
Internal Loads			
Lights	62,474	62,474	-5.82
People	750,750	750,750	-69.90
Misc	0	0	0.00
Sub Total ==>	813,224	813,224	-75.72
Ceiling Load	-196	0	0.00
Ventilation Load	0	-1,190,607	110.85
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		101,400	-9.44
OA Preheat Diff.		-172,654	16.07
RA Preheat Diff.		-87,373	8.13
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	274,984	-1,074,053	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	65.0
Ra Plenum	66.0	60.9
Return	66.0	65.0
Ret/OA	79.1	11.0
Fn MtrTD	0.4	0.0
Fn BldTD	0.8	0.0
Fn Frict	2.4	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	49,721	20,031
Terminal	49,721	20,031
Main Fan	49,721	20,031
Sec Fan	0	0
Nom Vent	23,895	20,024
AHU Vent	23,895	20,024
Infil	2,281	2,281
Min Stop/Rh	20,031	20,031
Return	52,001	22,312
Exhaust	26,176	22,305
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	48.1	100.0
cfm/ft²	2.17	0.88
cfm/ton	236.60	
ft²/ton	108.88	
Btu/hr·ft²	110.21	-59.59
No. People	3,003	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	210.2	2,521.8	1,331.5	45,499	79.1	67.8	85.5	51.5	49.4	49.9
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	210.2	2,521.8								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	22,881		
Part	0		
Int Door	0		
ExFlr	8,270		
Roof	25,601	0	0
Wall	3,360	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

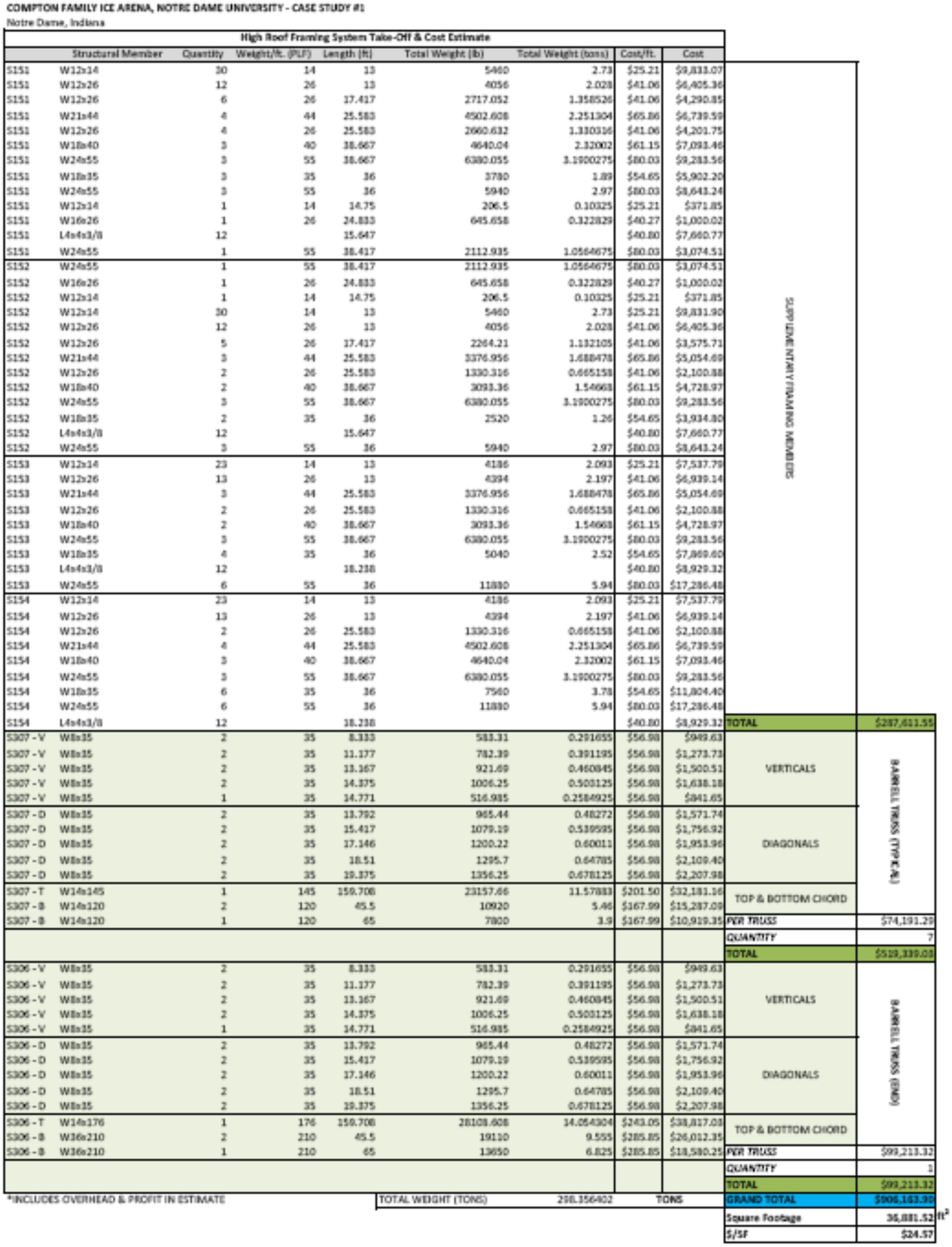
	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-297.7	20,031	51.5	65.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-1,065.7	23,895	11.0	51.5
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-1,363.4			

Project Name: PSU ICE ARENA
Dataset Name: ___BIM__PSU_ICE_ARENA-2.trc

RACE® 700 v6.2.6.5 calculated at 10:31 PM on 03/26/2012
Alternative - 2 System Checksums Report Page 16 of 26

Structural Detailed Cost Estimates – High Roof System Members Only

Table 64: Notre Dame Case Study - Truss System Estimate

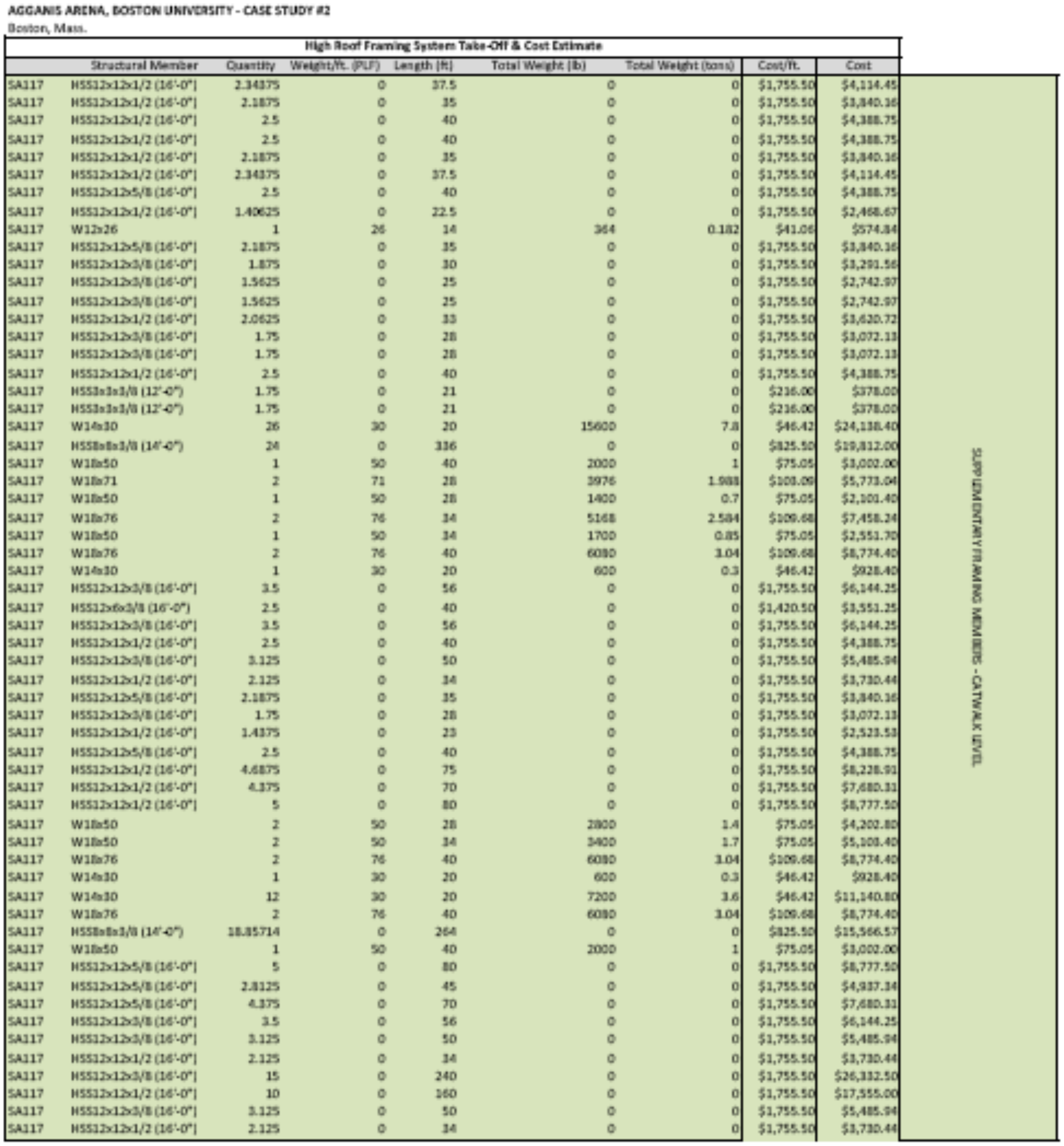


COMPTON FAMILY ICE ARENA, NOTRE DAME UNIVERSITY - CASE STUDY #1
Notre Dame, Indiana

High Roof Framing System Take-Off & Cost Estimate

	Structural Member	Quantity	Weight/ft. (PLF)	Length (ft)	Total Weight (lb)	Total Weight (tons)	Cost/ft.	Cost		
S151	W12x14	30	14	13	5460	2.73	$25.21	$9,833.07	SUPPLEMENTARY FRAMING MEMBERS	
S151	W12x26	12	26	13	4056	2.028	$41.06	$6,405.36		
S151	W12x26	6	26	17.417	2717.052	1.358526	$41.06	$4,290.85		
S151	W21x44	4	44	25.583	4502.608	2.251304	$65.86	$6,739.59		
S151	W12x26	4	26	25.583	2660.632	1.330316	$41.06	$4,201.75		
S151	W18x40	3	40	38.667	4640.04	2.32002	$61.15	$7,093.46		
S151	W24x55	3	55	38.667	6380.055	3.1900275	$80.03	$9,283.56		
S151	W18x35	3	35	36	3780	1.89	$54.65	$5,902.20		
S151	W24x55	3	55	36	5940	2.97	$80.03	$8,643.24		
S151	W12x14	1	14	14.75	206.5	0.10325	$25.21	$371.85		
S151	W16x26	1	26	24.833	645.658	0.322829	$40.27	$1,000.02		
S151	L4x4x3/8	12		15.647			$40.80	$7,660.77		
S151	W24x55	1	55	38.417	2112.935	1.0564675	$80.03	$3,074.51		
S152	W24x55	1	55	38.417	2112.935	1.0564675	$80.03	$3,074.51		
S152	W16x26	1	26	24.833	645.658	0.322829	$40.27	$1,000.02		
S152	W12x14	1	14	14.75	206.5	0.10325	$25.21	$371.85		
S152	W12x14	30	14	13	5460	2.73	$25.21	$9,831.90		
S152	W12x26	12	26	13	4056	2.028	$41.06	$6,405.36		
S152	W12x26	5	26	17.417	2264.21	1.132105	$41.06	$3,575.71		
S152	W21x44	3	44	25.583	3376.956	1.688478	$65.86	$5,054.69		
S152	W12x26	2	26	25.583	1330.316	0.665158	$41.06	$2,100.88		
S152	W18x40	2	40	38.667	3093.36	1.54668	$61.15	$4,728.97		
S152	W24x55	3	55	38.667	6380.055	3.1900275	$80.03	$9,283.56		
S152	W18x35	2	35	36	2520	1.26	$54.65	$3,934.80		
S152	L4x4x3/8	12		15.647			$40.80	$7,660.77		
S152	W24x55	3	55	36	5940	2.97	$80.03	$8,643.24		
S153	W12x14	23	14	13	4186	2.093	$25.21	$7,537.79		
S153	W12x26	13	26	13	4394	2.197	$41.06	$6,939.14		
S153	W21x44	3	44	25.583	3376.956	1.688478	$65.86	$5,054.69		
S153	W12x26	2	26	25.583	1330.316	0.665158	$41.06	$2,100.88		
S153	W18x40	2	40	38.667	3093.36	1.54668	$61.15	$4,728.97		
S153	W24x55	3	55	38.667	6380.055	3.1900275	$80.03	$9,283.56		
S153	W18x35	4	35	36	5040	2.52	$54.65	$7,869.60		
S153	L4x4x3/8	12		18.238			$40.80	$8,929.32		
S153	W24x55	6	55	36	11880	5.94	$80.03	$17,286.48		
S154	W12x14	23	14	13	4186	2.093	$25.21	$7,537.79		
S154	W12x26	13	26	13	4394	2.197	$41.06	$6,939.14		
S154	W12x26	2	26	25.583	1330.316	0.665158	$41.06	$2,100.88		
S154	W21x44	4	44	25.583	4502.608	2.251304	$65.86	$6,739.59		
S154	W18x40	3	40	38.667	4640.04	2.32002	$61.15	$7,093.46		
S154	W24x55	3	55	38.667	6380.055	3.1900275	$80.03	$9,283.56		
S154	W18x35	6	35	36	7560	3.78	$54.65	$11,804.40		
S154	W24x55	6	55	36	11880	5.94	$80.03	$17,286.48		
S154	L4x4x3/8	12		18.238			$40.80	$8,929.32	TOTAL	$287,611.55
S307 - V	W8x35	2	35	8.333	583.31	0.291655	$56.98	$949.63	VERTICALS	BARRELL TRUSS (TYPICAL)
S307 - V	W8x35	2	35	11.177	782.39	0.391195	$56.98	$1,273.73		
S307 - V	W8x35	2	35	13.167	921.69	0.460845	$56.98	$1,500.51		
S307 - V	W8x35	2	35	14.375	1006.25	0.503125	$56.98	$1,638.18		
S307 - V	W8x35	1	35	14.771	516.985	0.2584925	$56.98	$841.65		
S307 - D	W8x35	2	35	13.792	965.44	0.48272	$56.98	$1,571.74	DIAGONALS	
S307 - D	W8x35	2	35	15.417	1079.19	0.539595	$56.98	$1,756.92		
S307 - D	W8x35	2	35	17.146	1200.22	0.60011	$56.98	$1,953.96		
S307 - D	W8x35	2	35	18.51	1295.7	0.64785	$56.98	$2,109.40		
S307 - D	W8x35	2	35	19.375	1356.25	0.678125	$56.98	$2,207.98		
S307 - T	W14x145	1	145	159.708	23157.66	11.57883	$201.50	$32,181.16	TOP & BOTTOM CHORD	
S307 - B	W14x120	2	120	45.5	10920	5.46	$167.99	$15,287.09		
S307 - B	W14x120	1	120	65	7800	3.9	$167.99	$10,919.35	PER TRUSS	$74,191.29
									QUANTITY	7
									TOTAL	$519,339.03
S306 - V	W8x35	2	35	8.333	583.31	0.291655	$56.98	$949.63	VERTICALS	BARRELL TRUSS (END)
S306 - V	W8x35	2	35	11.177	782.39	0.391195	$56.98	$1,273.73		
S306 - V	W8x35	2	35	13.167	921.69	0.460845	$56.98	$1,500.51		
S306 - V	W8x35	2	35	14.375	1006.25	0.503125	$56.98	$1,638.18		
S306 - V	W8x35	1	35	14.771	516.985	0.2584925	$56.98	$841.65		
S306 - D	W8x35	2	35	13.792	965.44	0.48272	$56.98	$1,571.74	DIAGONALS	
S306 - D	W8x35	2	35	15.417	1079.19	0.539595	$56.98	$1,756.92		
S306 - D	W8x35	2	35	17.146	1200.22	0.60011	$56.98	$1,953.96		
S306 - D	W8x35	2	35	18.51	1295.7	0.64785	$56.98	$2,109.40		
S306 - D	W8x35	2	35	19.375	1356.25	0.678125	$56.98	$2,207.98		
S306 - T	W14x176	1	176	159.708	28108.608	14.054304	$243.05	$38,817.03	TOP & BOTTOM CHORD	
S306 - B	W36x210	2	210	45.5	19110	9.555	$285.85	$26,012.35		
S306 - B	W36x210	1	210	65	13650	6.825	$285.85	$18,580.25	PER TRUSS	$99,213.32
									QUANTITY	1
									TOTAL	$99,213.32
*INCLUDES OVERHEAD & PROFIT IN ESTIMATE				TOTAL WEIGHT (TONS)		298.356402		TONS	GRAND TOTAL	$906,163.90
									Square Footage	36,881.52 ft²
									$/SF	$24.57

Table 65: Boston University Case Study - Truss System Estimate



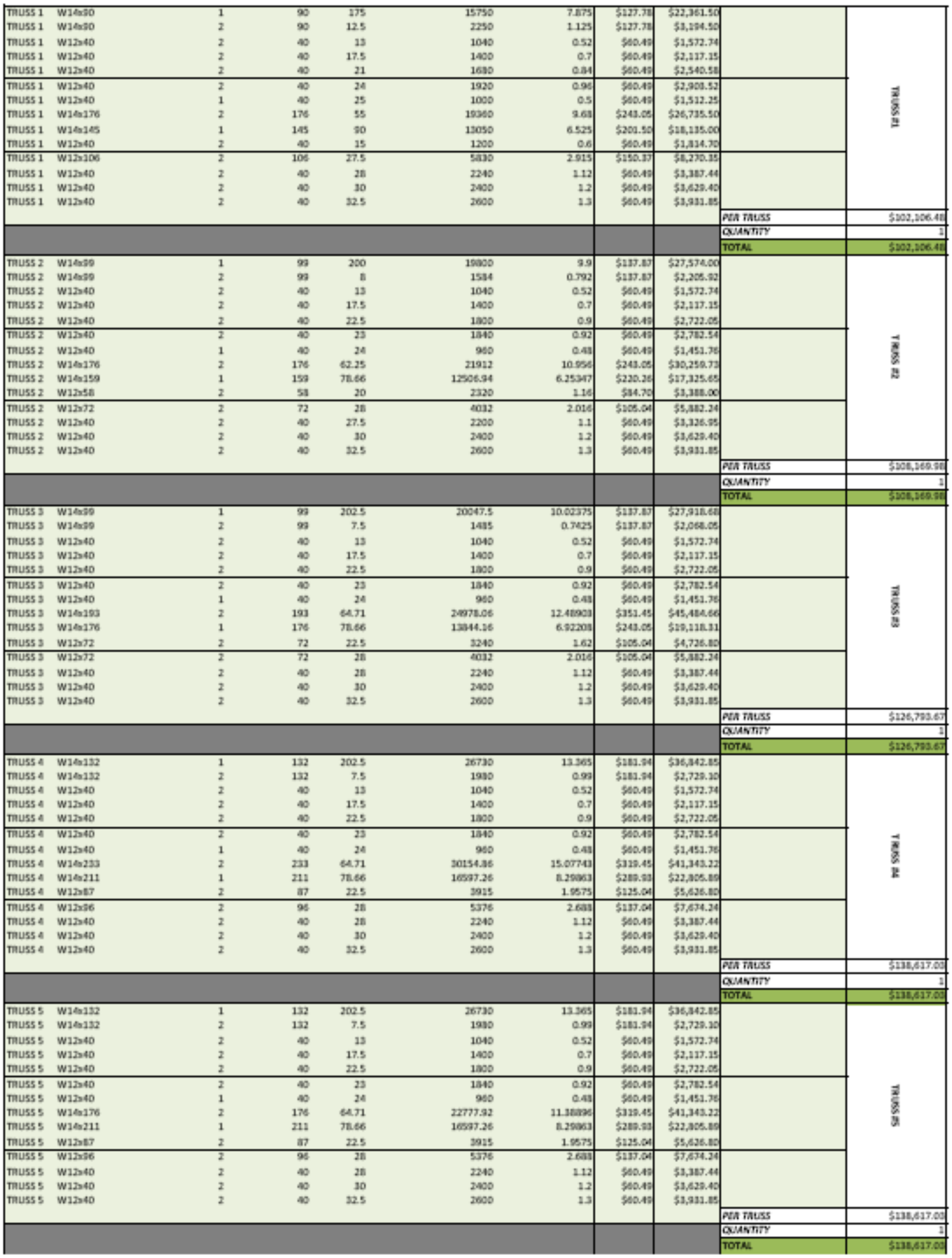
AGGANIS ARENA, BOSTON UNIVERSITY - CASE STUDY #2

Boston, Mass.

High Roof Framing System Take-Off & Cost Estimate

	Structural Member	Quantity	Weight/ft. (PLF)	Length (ft)	Total Weight (lb)	Total Weight (tons)	Cost/ft.	Cost	
SA117	HSS12x12x1/2 (16'-0")	2.34375	0	37.5	0	0	$1,755.50	$4,114.45	SUPPLEMENTARY FRAMING MEMBERS - CATWALK LEVEL
SA117	HSS12x12x1/2 (16'-0")	2.1875	0	35	0	0	$1,755.50	$3,840.16	
SA117	HSS12x12x1/2 (16'-0")	2.5	0	40	0	0	$1,755.50	$4,388.75	
SA117	HSS12x12x1/2 (16'-0")	2.5	0	40	0	0	$1,755.50	$4,388.75	
SA117	HSS12x12x1/2 (16'-0")	2.1875	0	35	0	0	$1,755.50	$3,840.16	
SA117	HSS12x12x1/2 (16'-0")	2.34375	0	37.5	0	0	$1,755.50	$4,114.45	
SA117	HSS12x12x5/8 (16'-0")	2.5	0	40	0	0	$1,755.50	$4,388.75	
SA117	HSS12x12x1/2 (16'-0")	1.40625	0	22.5	0	0	$1,755.50	$2,468.67	
SA117	W12x26	1	26	14	364	0.182	$41.06	$574.84	
SA117	HSS12x12x5/8 (16'-0")	2.1875	0	35	0	0	$1,755.50	$3,840.16	
SA117	HSS12x12x3/8 (16'-0")	1.875	0	30	0	0	$1,755.50	$3,291.56	
SA117	HSS12x12x3/8 (16'-0")	1.5625	0	25	0	0	$1,755.50	$2,742.97	
SA117	HSS12x12x3/8 (16'-0")	1.5625	0	25	0	0	$1,755.50	$2,742.97	
SA117	HSS12x12x1/2 (16'-0")	2.0625	0	33	0	0	$1,755.50	$3,620.72	
SA117	HSS12x12x3/8 (16'-0")	1.75	0	28	0	0	$1,755.50	$3,072.13	
SA117	HSS12x12x3/8 (16'-0")	1.75	0	28	0	0	$1,755.50	$3,072.13	
SA117	HSS12x12x1/2 (16'-0")	2.5	0	40	0	0	$1,755.50	$4,388.75	
SA117	HSS3x3x3/8 (12'-0")	1.75	0	21	0	0	$216.00	$378.00	
SA117	HSS3x3x3/8 (12'-0")	1.75	0	21	0	0	$216.00	$378.00	
SA117	W14x30	26	30	20	15600	7.8	$46.42	$24,138.40	
SA117	HSS8x8x3/8 (14'-0")	24	0	336	0	0	$825.50	$19,812.00	
SA117	W18x50	1	50	40	2000	1	$75.05	$3,002.00	
SA117	W18x71	2	71	28	3976	1.988	$103.09	$5,773.04	
SA117	W18x50	1	50	28	1400	0.7	$75.05	$2,101.40	
SA117	W18x76	2	76	34	5168	2.584	$109.68	$7,458.24	
SA117	W18x50	1	50	34	1700	0.85	$75.05	$2,551.70	
SA117	W18x76	2	76	40	6080	3.04	$109.68	$8,774.40	
SA117	W14x30	1	30	20	600	0.3	$46.42	$928.40	
SA117	HSS12x12x3/8 (16'-0")	3.5	0	56	0	0	$1,755.50	$6,144.25	
SA117	HSS12x6x3/8 (16'-0")	2.5	0	40	0	0	$1,420.50	$3,551.25	
SA117	HSS12x12x3/8 (16'-0")	3.5	0	56	0	0	$1,755.50	$6,144.25	
SA117	HSS12x12x1/2 (16'-0")	2.5	0	40	0	0	$1,755.50	$4,388.75	
SA117	HSS12x12x3/8 (16'-0")	3.125	0	50	0	0	$1,755.50	$5,485.94	
SA117	HSS12x12x1/2 (16'-0")	2.125	0	34	0	0	$1,755.50	$3,730.44	
SA117	HSS12x12x5/8 (16'-0")	2.1875	0	35	0	0	$1,755.50	$3,840.16	
SA117	HSS12x12x3/8 (16'-0")	1.75	0	28	0	0	$1,755.50	$3,072.13	
SA117	HSS12x12x1/2 (16'-0")	1.4375	0	23	0	0	$1,755.50	$2,523.53	
SA117	HSS12x12x5/8 (16'-0")	2.5	0	40	0	0	$1,755.50	$4,388.75	
SA117	HSS12x12x1/2 (16'-0")	4.6875	0	75	0	0	$1,755.50	$8,228.91	
SA117	HSS12x12x1/2 (16'-0")	4.375	0	70	0	0	$1,755.50	$7,680.31	
SA117	HSS12x12x1/2 (16'-0")	5	0	80	0	0	$1,755.50	$8,777.50	
SA117	W18x50	2	50	28	2800	1.4	$75.05	$4,202.80	
SA117	W18x50	2	50	34	3400	1.7	$75.05	$5,103.40	
SA117	W18x76	2	76	40	6080	3.04	$109.68	$8,774.40	
SA117	W14x30	1	30	20	600	0.3	$46.42	$928.40	
SA117	W14x30	12	30	20	7200	3.6	$46.42	$11,140.80	
SA117	W18x76	2	76	40	6080	3.04	$109.68	$8,774.40	
SA117	HSS8x8x3/8 (14'-0")	18.85714	0	264	0	0	$825.50	$15,566.57	
SA117	W18x50	1	50	40	2000	1	$75.05	$3,002.00	
SA117	HSS12x12x5/8 (16'-0")	5	0	80	0	0	$1,755.50	$8,777.50	
SA117	HSS12x12x5/8 (16'-0")	2.8125	0	45	0	0	$1,755.50	$4,937.34	
SA117	HSS12x12x5/8 (16'-0")	4.375	0	70	0	0	$1,755.50	$7,680.31	
SA117	HSS12x12x3/8 (16'-0")	3.5	0	56	0	0	$1,755.50	$6,144.25	
SA117	HSS12x12x3/8 (16'-0")	3.125	0	50	0	0	$1,755.50	$5,485.94	
SA117	HSS12x12x1/2 (16'-0")	2.125	0	34	0	0	$1,755.50	$3,730.44	
SA117	HSS12x12x3/8 (16'-0")	15	0	240	0	0	$1,755.50	$26,332.50	
SA117	HSS12x12x1/2 (16'-0")	10	0	160	0	0	$1,755.50	$17,555.00	
SA117	HSS12x12x3/8 (16'-0")	3.125	0	50	0	0	$1,755.50	$5,485.94	
SA117	HSS12x12x1/2 (16'-0")	2.125	0	34	0	0	$1,755.50	$3,730.44	

SA118	W14x22	2	22	6	264	0.132	$34.24	$410.88	SUPPLEMENTARY FRAMING MEMBERS - HIGH ROOF LEVEL	
SA118	W16x26	1	26	27	702	0.351	$40.27	$1,087.29		
SA118	W16x26	2	26	33	1716	0.858	$40.27	$2,657.82		
SA118	W16x40	2	40	37	2960	1.48	$60.20	$4,454.80		
SA118	W21x50	6	50	40	12000	6	$73.86	$17,726.40		
SA118	W14x22	1	22	27	594	0.297	$34.24	$924.48		
SA118	W16x45	2	45	28	2520	1.26	$66.95	$3,749.20		
SA118	W10x12	4	12	12	576	0.288	$25.57	$1,227.36		
SA118	W10x12	14	12	10	1680	0.84	$25.57	$3,579.80		
SA118	HSS6x6x3/8 (12'-0")	18.33333	0	220	0	0	$432.00	$7,920.00		
SA118	40LH09	2	20	21	840	0.42	$22.92	$962.64		
SA118	W24x68	3	68	28	5712	2.856	$97.53	$8,192.52		
SA118	40LH09	2	20	28	1120	0.56	$22.92	$1,283.52		
SA118	40LH13	2	0	28	0	0	$31.14	$1,743.84		
SA118	40LH11	2	0	28	0	0	$25.66	$1,436.96		
SA118	40LH08	6	0	28	0	0	$22.92	$3,850.56		
SA118	40LH09	8	20	32.5	5200	2.6	$22.92	$5,959.20		
SA118	40LH13	1	0	32.5	0	0	$31.14	$1,012.05		
SA118	40LH12	4	0	32.5	0	0	$28.40	$3,692.00		
SA118	40LH11	1	0	32.5	0	0	$25.66	$833.95		
SA118	W27x84	2	84	32.5	5460	2.73	$118.56	$7,706.40		
SA118	W30x99	1	99	32.5	3217.5	1.60875	$138.51	$4,501.58		
SA118	40LH12	3	0	40	0	0	$28.40	$3,408.00		
SA118	40LH13	1	0	40	0	0	$31.14	$1,245.60		
SA118	40LH10	2	0	40	0	0	$22.92	$1,833.60		
SA118	40LH11	4	0	40	0	0	$25.66	$4,105.60		
SA118	40LH15	2	0	40	0	0	$36.62	$2,929.60		
SA118	40LH14	2	0	40	0	0	$33.88	$2,710.40		
SA118	W30x132	2	132	40	10560	5.28	$182.71	$14,616.80		
SA118	W33x152	1	152	40	6080	3.04	$209.51	$8,380.40		
SA118	40LH13	3	0	40	0	0	$31.14	$3,736.80		
SA118	40LH14	1	0	40	0	0	$33.88	$1,355.20		
SA118	40LH10	2	0	40	0	0	$22.92	$1,833.60		
SA118	40LH11	2	0	40	0	0	$25.66	$2,052.80		
SA118	44LH16	1	0	40	0	0	$42.12	$1,684.80		
SA118	52DLH17	1	0	40	0	0	$47.98	$1,919.20		
SA118	44LH15	1	0	40	0	0	$42.12	$1,684.80		
SA118	40LH16	1	0	40	0	0	$36.62	$1,464.80		
SA118	W24x55	2	55	40	4400	2.2	$80.03	$6,402.40		
SA118	W27x84	2	84	40	6720	3.36	$118.56	$9,484.80		
SA118	W30x90	1	90	40	3600	1.8	$132.83	$5,313.20		
SA118	W10x12	4	12	7	336	0.168	$25.57	$715.96		
SA118	40LH13	3	0	40	0	0	$31.14	$3,736.80		
SA118	40LH14	2	0	40	0	0	$33.88	$2,710.40		
SA118	40LH12	3	0	40	0	0	$28.40	$3,408.00		
SA118	40LH11	3	0	40	0	0	$25.66	$3,079.20		
SA118	40LH16	1	0	40	0	0	$36.62	$1,464.80		
SA118	44LH17	1	0	40	0	0	$45.82	$1,832.80		
SA118	40LH15	1	0	40	0	0	$36.62	$1,464.80		
SA118	W30x148	1	0	40	0	0	$203.71	$8,148.40		
SA118	W33x141	1	0	40	0	0	$194.90	$7,796.00		
SA118	W33x152	1	0	40	0	0	$209.51	$8,380.40		
SA118	40LH10	2	0	34	0	0	$22.92	$1,558.56		
SA118	40LH13	1	0	34	0	0	$31.14	$1,058.76		
SA118	40LH12	4	0	34	0	0	$28.40	$3,862.40		
SA118	40LH9	4	0	34	0	0	$22.92	$3,117.12		
SA118	40LH11	2	0	34	0	0	$25.66	$1,744.88		
SA118	40LH14	1	0	34	0	0	$33.88	$1,151.92		
SA118	W27x84	2	84	34	5712	2.856	$118.56	$8,062.08		
SA118	W27x94	1	94	34	3196	1.598	$131.56	$4,473.04		
SA118	40LH10	1	0	21	0	0	$22.92	$481.32		
SA118	40LH10	9	0	28	0	0	$22.92	$5,775.84		
SA118	40LH13	2	0	28	0	0	$31.14	$1,743.84		
SA118	40LH12	1	0	28	0	0	$28.40	$795.20		
SA118	40LH12	1	0	21	0	0	$28.40	$596.40		
SA118	W24x76	1	76	28	2128	1.064	$108.03	$3,024.84		
SA118	W24x68	1	68	28	1904	0.952	$97.53	$2,730.84		
SA118	W24x84	1	84	28	2352	1.176	$119.23	$3,338.44		
SA118	W14x22	2	22	6	264	0.132	$34.24	$410.88		
SA118	W16x31	1	31	27.5	852.5	0.42625	$47.92	$1,317.80		
SA118	W16x31	1	31	33	1023	0.5115	$47.92	$1,581.36		
SA118	W16x57	1	57	37	2109	1.0545	$83.14	$3,076.18		
SA118	W21x68	1	68	40	2720	1.36	$98.05	$3,922.00		
SA118	W21x62	1	62	40	2480	1.24	$90.05	$3,602.00		
SA118	W21x57	4	57	40	9120	4.56	$83.30	$13,328.00		
SA118	W16x50	1	50	37	1850	0.925	$73.70	$2,726.90		
SA118	W16x36	1	36	33	1188	0.594	$54.74	$1,806.42		
SA118	W14x22	1	22	27.5	605	0.3025	$34.24	$941.60		
SA118	W16x45	2	45	27.5	2475	1.2375	$66.95	$3,682.25		
SA118	W10x12	4	12	12	576	0.288	$25.57	$1,227.36		
SA118	W10x12	14	12	7	1176	0.588	$25.57	$2,505.86		
SA118	HSS6x6x3/8 (12'-0")	18.33333	0	220	0	0	$432.00	$7,920.00		
									TOTAL	$644,871.81



TRUSS 1	W14x90	1	90	175	15750	7.875	$127.78	$22,361.50		TRUSS #1
TRUSS 1	W14x90	2	90	12.5	2250	1.125	$127.78	$3,194.50		
TRUSS 1	W12x40	2	40	13	1040	0.52	$60.49	$1,572.74		
TRUSS 1	W12x40	2	40	17.5	1400	0.7	$60.49	$2,117.15		
TRUSS 1	W12x40	2	40	21	1680	0.84	$60.49	$2,540.58		
TRUSS 1	W12x40	2	40	24	1920	0.96	$60.49	$2,903.52		
TRUSS 1	W12x40	1	40	25	1000	0.5	$60.49	$1,512.25		
TRUSS 1	W14x176	2	176	55	19360	9.68	$243.05	$26,735.50		
TRUSS 1	W14x145	1	145	90	13050	6.525	$201.50	$18,135.00		
TRUSS 1	W12x40	2	40	15	1200	0.6	$60.49	$1,814.70		
TRUSS 1	W12x106	2	106	27.5	5830	2.915	$150.37	$8,270.35		
TRUSS 1	W12x40	2	40	28	2240	1.12	$60.49	$3,387.44		
TRUSS 1	W12x40	2	40	30	2400	1.2	$60.49	$3,629.40		
TRUSS 1	W12x40	2	40	32.5	2600	1.3	$60.49	$3,931.85		
									PER TRUSS	$102,106.48
									QUANTITY	1
									TOTAL	$102,106.48
TRUSS 2	W14x99	1	99	200	19800	9.9	$137.87	$27,574.00		TRUSS #2
TRUSS 2	W14x99	2	99	8	1584	0.792	$137.87	$2,205.92		
TRUSS 2	W12x40	2	40	13	1040	0.52	$60.49	$1,572.74		
TRUSS 2	W12x40	2	40	17.5	1400	0.7	$60.49	$2,117.15		
TRUSS 2	W12x40	2	40	22.5	1800	0.9	$60.49	$2,722.05		
TRUSS 2	W12x40	2	40	23	1840	0.92	$60.49	$2,782.54		
TRUSS 2	W12x40	1	40	24	960	0.48	$60.49	$1,451.76		
TRUSS 2	W14x176	2	176	62.25	21912	10.956	$243.05	$30,259.73		
TRUSS 2	W14x159	1	159	78.66	12506.94	6.25347	$220.26	$17,325.65		
TRUSS 2	W12x58	2	58	20	2320	1.16	$84.70	$3,388.00		
TRUSS 2	W12x72	2	72	28	4032	2.016	$105.04	$5,882.24		
TRUSS 2	W12x40	2	40	27.5	2200	1.1	$60.49	$3,326.95		
TRUSS 2	W12x40	2	40	30	2400	1.2	$60.49	$3,629.40		
TRUSS 2	W12x40	2	40	32.5	2600	1.3	$60.49	$3,931.85		
									PER TRUSS	$108,169.98
									QUANTITY	1
									TOTAL	$108,169.98
TRUSS 3	W14x99	1	99	202.5	20047.5	10.02375	$137.87	$27,918.68		TRUSS #3
TRUSS 3	W14x99	2	99	7.5	1485	0.7425	$137.87	$2,068.05		
TRUSS 3	W12x40	2	40	13	1040	0.52	$60.49	$1,572.74		
TRUSS 3	W12x40	2	40	17.5	1400	0.7	$60.49	$2,117.15		
TRUSS 3	W12x40	2	40	22.5	1800	0.9	$60.49	$2,722.05		
TRUSS 3	W12x40	2	40	23	1840	0.92	$60.49	$2,782.54		
TRUSS 3	W12x40	1	40	24	960	0.48	$60.49	$1,451.76		
TRUSS 3	W14x193	2	193	64.71	24978.06	12.48903	$351.45	$45,484.66		
TRUSS 3	W14x176	1	176	78.66	13844.16	6.92208	$243.05	$19,118.31		
TRUSS 3	W12x72	2	72	22.5	3240	1.62	$105.04	$4,726.80		
TRUSS 3	W12x72	2	72	28	4032	2.016	$105.04	$5,882.24		
TRUSS 3	W12x40	2	40	28	2240	1.12	$60.49	$3,387.44		
TRUSS 3	W12x40	2	40	30	2400	1.2	$60.49	$3,629.40		
TRUSS 3	W12x40	2	40	32.5	2600	1.3	$60.49	$3,931.85		
									PER TRUSS	$126,793.67
									QUANTITY	1
									TOTAL	$126,793.67
TRUSS 4	W14x132	1	132	202.5	26730	13.365	$181.94	$36,842.85		TRUSS #4
TRUSS 4	W14x132	2	132	7.5	1980	0.99	$181.94	$2,729.10		
TRUSS 4	W12x40	2	40	13	1040	0.52	$60.49	$1,572.74		
TRUSS 4	W12x40	2	40	17.5	1400	0.7	$60.49	$2,117.15		
TRUSS 4	W12x40	2	40	22.5	1800	0.9	$60.49	$2,722.05		
TRUSS 4	W12x40	2	40	23	1840	0.92	$60.49	$2,782.54		
TRUSS 4	W12x40	1	40	24	960	0.48	$60.49	$1,451.76		
TRUSS 4	W14x233	2	233	64.71	30154.86	15.07743	$319.45	$41,343.22		
TRUSS 4	W14x211	1	211	78.66	16597.26	8.29863	$289.93	$22,805.89		
TRUSS 4	W12x87	2	87	22.5	3915	1.9575	$125.04	$5,626.80		
TRUSS 4	W12x96	2	96	28	5376	2.688	$137.04	$7,674.24		
TRUSS 4	W12x40	2	40	28	2240	1.12	$60.49	$3,387.44		
TRUSS 4	W12x40	2	40	30	2400	1.2	$60.49	$3,629.40		
TRUSS 4	W12x40	2	40	32.5	2600	1.3	$60.49	$3,931.85		
									PER TRUSS	$138,617.00
									QUANTITY	1
									TOTAL	$138,617.00
TRUSS 5	W14x132	1	132	202.5	26730	13.365	$181.94	$36,842.85		TRUSS #5
TRUSS 5	W14x132	2	132	7.5	1980	0.99	$181.94	$2,729.10		
TRUSS 5	W12x40	2	40	13	1040	0.52	$60.49	$1,572.74		
TRUSS 5	W12x40	2	40	17.5	1400	0.7	$60.49	$2,117.15		
TRUSS 5	W12x40	2	40	22.5	1800	0.9	$60.49	$2,722.05		
TRUSS 5	W12x40	2	40	23	1840	0.92	$60.49	$2,782.54		
TRUSS 5	W12x40	1	40	24	960	0.48	$60.49	$1,451.76		
TRUSS 5	W14x176	2	176	64.71	22777.92	11.38896	$319.45	$41,343.22		
TRUSS 5	W14x211	1	211	78.66	16597.26	8.29863	$289.93	$22,805.89		
TRUSS 5	W12x87	2	87	22.5	3915	1.9575	$125.04	$5,626.80		
TRUSS 5	W12x96	2	96	28	5376	2.688	$137.04	$7,674.24		
TRUSS 5	W12x40	2	40	28	2240	1.12	$60.49	$3,387.44		
TRUSS 5	W12x40	2	40	30	2400	1.2	$60.49	$3,629.40		
TRUSS 5	W12x40	2	40	32.5	2600	1.3	$60.49	$3,931.85		
									PER TRUSS	$138,617.00
									QUANTITY	1
									TOTAL	$138,617.00

TRUSS 6	W14x90	1	90	202.5	18225	9.1125	$127.78	$25,875.45		TRUSS #6
TRUSS 6	W14x99	2	99	7.5	1485	0.7425	$137.87	$2,068.05		
TRUSS 6	W12x40	2	40	13	1040	0.52	$60.49	$1,572.74		
TRUSS 6	W12x40	2	40	17.5	1400	0.7	$60.49	$2,117.15		
TRUSS 6	W12x40	2	40	22.5	1800	0.9	$60.49	$2,722.05		
TRUSS 6	W12x40	2	40	23	1840	0.92	$60.49	$2,782.54		
TRUSS 6	W12x40	1	40	24	960	0.48	$60.49	$1,451.76		
TRUSS 6	W14x176	2	176	64.71	22777.92	11.38896	$243.05	$31,455.53		
TRUSS 6	W14x159	1	159	78.66	12506.94	6.25347	$220.26	$17,325.65		
TRUSS 6	W12x72	2	72	22.5	3240	1.62	$105.04	$4,726.80		
TRUSS 6	W12x65	2	65	28	3640	1.82	$93.94	$5,260.64		
TRUSS 6	W12x40	2	40	28	2240	1.12	$60.49	$3,387.44		
TRUSS 6	W12x40	2	40	30	2400	1.2	$60.49	$3,629.40		
TRUSS 6	W12x40	2	40	32.5	2600	1.3	$60.49	$3,931.85		
									PER TRUSS	$108,307.05
									QUANTITY	1
									TOTAL	$108,307.05
TRUSS 7	W14x90	1	90	200	18000	9	$127.78	$25,556.00		TRUSS #7
TRUSS 7	W14x90	2	90	8	1440	0.72	$127.78	$2,044.48		
TRUSS 7	W12x40	2	40	13	1040	0.52	$60.49	$1,572.74		
TRUSS 7	W12x40	2	40	17.5	1400	0.7	$60.49	$2,117.15		
TRUSS 7	W12x40	2	40	22.5	1800	0.9	$60.49	$2,722.05		
TRUSS 7	W12x40	2	40	23	1840	0.92	$60.49	$2,782.54		
TRUSS 7	W12x40	1	40	24	960	0.48	$60.49	$1,451.76		
TRUSS 7	W14x159	2	159	62.25	19795.5	9.89775	$220.26	$27,422.37		
TRUSS 7	W14x132	1	132	78.66	10383.12	5.19156	$181.94	$14,311.40		
TRUSS 7	W12x50	2	50	20	2000	1	$74.20	$2,968.00		
TRUSS 7	W12x65	2	65	28	3640	1.82	$94.87	$5,312.72		
TRUSS 7	W12x40	2	40	27.5	2200	1.1	$60.49	$3,326.95		
TRUSS 7	W12x40	2	40	30	2400	1.2	$60.49	$3,629.40		
TRUSS 7	W12x40	2	40	32.5	2600	1.3	$60.49	$3,931.85		
									PER TRUSS	$99,149.41
									QUANTITY	1
									TOTAL	$99,149.41
TRUSS 8	W14x90	1	90	175	15750	7.875	$127.78	$22,361.50		TRUSS #8
TRUSS 8	W14x90	2	90	12.5	2250	1.125	$127.78	$3,194.50		
TRUSS 8	W12x40	2	40	13	1040	0.52	$60.49	$1,572.74		
TRUSS 8	W12x40	2	40	17.5	1400	0.7	$60.49	$2,117.15		
TRUSS 8	W12x40	2	40	21	1680	0.84	$60.49	$2,540.58		
TRUSS 8	W12x40	2	40	24	1920	0.96	$60.49	$2,903.52		
TRUSS 8	W12x40	1	40	25	1000	0.5	$60.49	$1,512.25		
TRUSS 8	W14x159	2	159	55	17490	8.745	$220.26	$24,228.60		
TRUSS 8	W14x132	1	132	90	11880	5.94	$181.94	$16,374.60		
TRUSS 8	W12x40	2	40	15	1200	0.6	$60.49	$1,814.70		
TRUSS 8	W12x96	2	96	27.5	5280	2.64	$137.04	$7,537.20		
TRUSS 8	W12x40	2	40	28	2240	1.12	$60.49	$3,387.44		
TRUSS 8	W12x40	2	40	30	2400	1.2	$60.49	$3,629.40		
TRUSS 8	W12x40	2	40	32.5	2600	1.3	$60.49	$3,931.85		
									PER TRUSS	$97,106.03
									QUANTITY	1
									TOTAL	$97,106.03
TRUSS 9	W14x61	6	61	32.5	11895	5.9475	$88.53	$17,263.35		TRUSS #9
TRUSS 9	W14x74	2	74	27.5	4070	2.035	$106.12	$5,836.60		
TRUSS 9	W14x61	2	61	27.5	3355	1.6775	$88.53	$4,869.15		
TRUSS 9	W14x74	2	74	32.5	4810	2.405	$106.12	$6,897.80		
TRUSS 9	W14x74	3	74	40	8880	4.44	$106.12	$12,734.40		
TRUSS 9	W14x82	3	82	40	9840	4.92	$116.95	$14,034.00		
TRUSS 9	HSS8x8x3/8 (14'-0")	1.428571		20	0	0	$825.50	$1,179.28		
TRUSS 9	HSS10x10x3/8 (16'-0")	3.214286		45	0	0	$1,445.50	$4,646.25		
TRUSS 9	HSS10x10x3/8 (16'-0")	4.285714		60	0	0	$1,445.50	$6,195.00		
TRUSS 9	HSS10x10x3/8 (16'-0")	5		70	0	0	$1,445.50	$7,227.50		
TRUSS 9	HSS10x10x3/8 (16'-0")	7.428571		104	0	0	$1,445.50	$10,738.00		
TRUSS 9	HSS10x10x3/8 (16'-0")	12.85714		180	0	0	$1,445.50	$18,585.00		
									PER TRUSS	$110,206.34
									QUANTITY	1
									TOTAL	$110,206.34
TRUSS 10	W14x61	6	61	32.5	11895	5.9475	$88.53	$17,263.35		TRUSS #10
TRUSS 10	W14x74	2	74	27.5	4070	2.035	$106.12	$5,836.60		
TRUSS 10	W14x61	2	61	27.5	3355	1.6775	$88.53	$4,869.15		
TRUSS 10	W14x74	2	74	32.5	4810	2.405	$106.12	$6,897.80		
TRUSS 10	W14x74	3	74	40	8880	4.44	$106.12	$12,734.40		
TRUSS 10	W14x82	3	82	40	9840	4.92	$116.95	$14,034.00		
TRUSS 10	HSS8x8x3/8 (14'-0")	1.428571		20	0	0	$825.50	$1,179.28		
TRUSS 10	HSS10x10x3/8 (16'-0")	3.214286		45	0	0	$1,445.50	$4,646.25		
TRUSS 10	HSS10x10x3/8 (16'-0")	4.285714		60	0	0	$1,445.50	$6,195.00		
TRUSS 10	HSS10x10x3/8 (16'-0")	5		70	0	0	$1,445.50	$7,227.50		
TRUSS 10	HSS10x10x3/8 (16'-0")	7.428571		104	0	0	$1,445.50	$10,738.00		
TRUSS 10	HSS10x10x3/8 (16'-0")	12.85714		180	0	0	$1,445.50	$18,585.00		
									PER TRUSS	$110,206.34
									QUANTITY	1
									TOTAL	$110,206.34

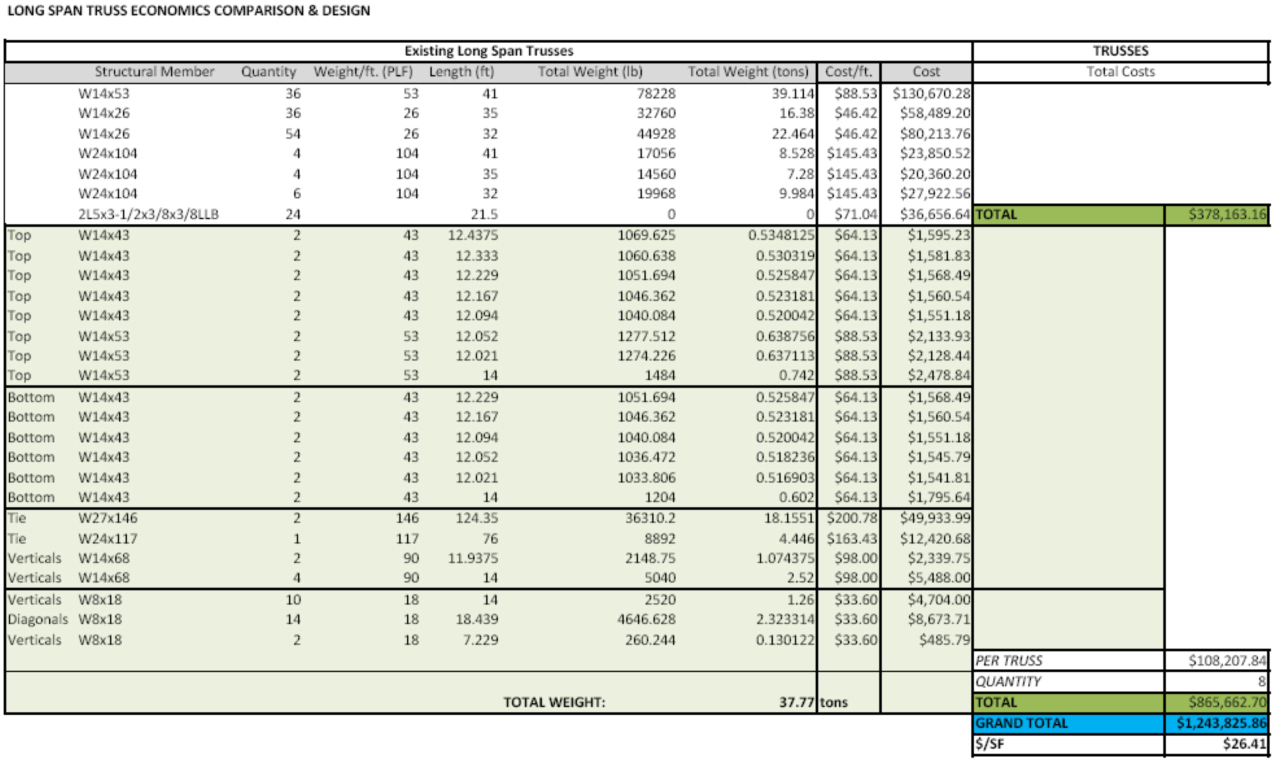
TRUSS 11	W21x50	1	50	32.5	1625	0.8125	$73.86	$2,400.45		TRUSS #11 & 12
TRUSS 11	HSS12x12x5/8 (16'-0")	2.03125		32.5	0	0	$1,755.50	$3,565.86		
TRUSS 11	HSS10x10x3/8 (16'-0")	1.875		30	0	0	$1,445.50	$2,710.31		
TRUSS 11	HSS8x8x3/8 (14'-0")	1.5		21	0	0	$825.50	$1,238.25		
TRUSS 11	HSS8x8x3/8 (14'-0")	1.607143		22.5	0	0	$825.50	$1,326.70		
TRUSS 12	W21x57	1	57	32.5	1852.5	0.92625	$83.30	$2,707.25		
TRUSS 12	HSS12x12x5/8 (16'-0")	2.03125		32.5	0	0	$1,755.50	$3,565.86		
TRUSS 12	HSS10x10x3/8 (16'-0")	1.875		30	0	0	$1,445.50	$2,710.31		
TRUSS 12	HSS8x8x3/8 (14'-0")	1.5		21	0	0	$825.50	$1,238.25		
TRUSS 12	HSS8x8x3/8 (14'-0")	1.607143		22.5	0	0	$825.50	$1,326.70		
									PER TRUSS	$22,789.94
									QUANTITY	1
									TOTAL	$22,789.94
TRUSS 13	W24x68	1	68	40	2720	1.36	$97.53	$3,901.20		TRUSS #13 & 14
TRUSS 13	HSS12x12x5/8 (16'-0")	2.5		40	0	0	$1,755.50	$4,388.75		
TRUSS 13	HSS8x8x3/8 (14'-0")	4.285714		60	0	0	$825.50	$3,537.86		
TRUSS 14	W24x94	1	94	40	3760	1.88	$132.23	$5,289.20		
TRUSS 14	HSS12x12x5/8 (16'-0")	2.5		40	0	0	$1,755.50	$4,388.75		
TRUSS 14	HSS8x8x3/8 (14'-0")	4.285714		60	0	0	$825.50	$3,537.86		
									PER TRUSS	$25,043.61
									QUANTITY	1
									TOTAL	$25,043.61
*INCLUDES OVERHEAD & PROFIT IN ESTIMATE					TOTAL WEIGHT (TONS)	451.61522	TONS		**GRAND TOTAL**	**$1,831,984.72**
									Square Footage	**65,790.00 ft²**
									$/SF	**$27.85**

Table 66: Existing Design Penn State Ice Arena - Truss System Estimate

LONG SPAN TRUSS ECONOMICS COMPARISON & DESIGN

	Existing Long Span Trusses								TRUSSES	
	Structural Member	Quantity	Weight/ft. (PLF)	Length (ft)	Total Weight (lb)	Total Weight (tons)	Cost/ft.	Cost	Total Costs	
	W14x74	4	74	40.25	11914	5.957	$106.12	$17,085.32		
	W14x74	4	74	31.33	9273.68	4.63684	$106.12	$13,298.96		
	W14x74	6	74	32	14208	7.104	$106.12	$20,375.04		
	W14x38	12	38	41	18696	9.348	$57.74	$28,408.08		
	W14x43	6	43	41	10578	5.289	$64.13	$15,775.98		
	W14x30	8	40	41	13120	6.56	$46.42	$15,225.76		
	W14x38	12	38	31.25	14250	7.125	$57.74	$21,652.50		
	W14x43	6	43	31.25	8062.5	4.03125	$64.13	$12,024.38		
	W14x30	8	30	31.25	7500	3.75	$46.42	$11,605.00		
	W14x38	18	38	32	21888	10.944	$57.74	$33,258.24		
	W14x43	9	43	32	12384	6.192	$64.13	$18,469.44		
	W14x30	12	30	32	11520	5.76	$46.42	$17,825.28	**TOTAL**	$225,003.97
T-1	W14x132	2	132	60	15840	7.92	$181.94	$21,832.80		
T-1	W14x132	2	132	37.5	9900	4.95	$181.94	$13,645.50		
T-1	W14x99	2	99	59	11682	5.841	$137.87	$16,268.66		
T-1	W14x99	1	99	76	7524	3.762	$137.87	$10,478.12	*PER TRUSS*	$102,072.98
T-1	W14x61	13	61	11.33	8984.69	4.492345	$88.53	$13,039.58	*QUANTITY*	6
T-1	2L8x8x1/2	14	52.8	17.6	13009.92	6.50496	$108.80	$26,808.32	**TOTAL**	$612,437.90
T-2	W14x132	2	132	60	15840	7.92	$181.94	$21,832.80		
T-2	W14x132	2	132	38	10032	5.016	$181.94	$13,827.44		
T-2	W14x109	2	109	59.5	12971	6.4855	$153.25	$18,236.75		
T-2	W14x132	1	132	76	10032	5.016	$181.94	$13,827.44		
T-2	W14x61	3	61	11.33	2073.39	1.036695	$88.53	$3,009.13		
T-2	2L6x6x1/2	4	39.2	11.33	1776.544	0.888272	$81.60	$3,698.11	*PER TRUSS*	$98,125.32
T-2	2L5x5x3/8	9	24.6	11.33	2508.462	1.254231	$68.00	$6,933.96	*QUANTITY*	1
T-2	2L8x6x1/2	14	46	16	10304	5.152	$74.82	$16,759.68	**TOTAL**	$98,125.32
T-3	W14x132	2	132	59	15576	7.788	$181.94	$21,468.92		
T-3	W14x132	2	132	37.5	9900	4.95	$181.94	$13,645.50		
T-3	W14x99	2	99	59	11682	5.841	$137.87	$16,268.66		
T-3	W14x99	1	99	76	7524	3.762	$137.87	$10,478.12	*PER TRUSS*	$99,653.79
T-3	W14x61	13	61	11	8723	4.3615	$88.53	$12,659.79	*QUANTITY*	1
T-3	2L8x8x1/2	14	52.8	16.5	12196.8	6.0984	$108.80	$25,132.80	**TOTAL**	$99,653.79
									GRAND TOTAL	**$1,035,220.98**
									$/SF	**$21.98**

Table 67: HPR's Proposed Design - Truss System Estimate



LONG SPAN TRUSS ECONOMICS COMPARISON & DESIGN

	Existing Long Span Trusses								TRUSSES	
	Structural Member	Quantity	Weight/ft. (PLF)	Length (ft)	Total Weight (lb)	Total Weight (tons)	Cost/ft.	Cost	Total Costs	
	W14x53	36	53	41	78228	39.114	$88.53	$130,670.28		
	W14x26	36	26	35	32760	16.38	$46.42	$58,489.20		
	W14x26	54	26	32	44928	22.464	$46.42	$80,213.76		
	W24x104	4	104	41	17056	8.528	$145.43	$23,850.52		
	W24x104	4	104	35	14560	7.28	$145.43	$20,360.20		
	W24x104	6	104	32	19968	9.984	$145.43	$27,922.56		
	2L5x3-1/2x3/8x3/8LLB	24		21.5	0	0	$71.04	$36,656.64	TOTAL	$378,163.16
Top	W14x43	2	43	12.4375	1069.625	0.5348125	$64.13	$1,595.23		
Top	W14x43	2	43	12.333	1060.638	0.530319	$64.13	$1,581.83		
Top	W14x43	2	43	12.229	1051.694	0.525847	$64.13	$1,568.49		
Top	W14x43	2	43	12.167	1046.362	0.523181	$64.13	$1,560.54		
Top	W14x43	2	43	12.094	1040.084	0.520042	$64.13	$1,551.18		
Top	W14x53	2	53	12.052	1277.512	0.638756	$88.53	$2,133.93		
Top	W14x53	2	53	12.021	1274.226	0.637113	$88.53	$2,128.44		
Top	W14x53	2	53	14	1484	0.742	$88.53	$2,478.84		
Bottom	W14x43	2	43	12.229	1051.694	0.525847	$64.13	$1,568.49		
Bottom	W14x43	2	43	12.167	1046.362	0.523181	$64.13	$1,560.54		
Bottom	W14x43	2	43	12.094	1040.084	0.520042	$64.13	$1,551.18		
Bottom	W14x43	2	43	12.052	1036.472	0.518236	$64.13	$1,545.79		
Bottom	W14x43	2	43	12.021	1033.806	0.516903	$64.13	$1,541.81		
Bottom	W14x43	2	43	14	1204	0.602	$64.13	$1,795.64		
Tie	W27x146	2	146	124.35	36310.2	18.1551	$200.78	$49,933.99		
Tie	W24x117	1	117	76	8892	4.446	$163.43	$12,420.68		
Verticals	W14x68	2	90	11.9375	2148.75	1.074375	$98.00	$2,339.75		
Verticals	W14x68	4	90	14	5040	2.52	$98.00	$5,488.00		
Verticals	W8x18	10	18	14	2520	1.26	$33.60	$4,704.00		
Diagonals	W8x18	14	18	18.439	4646.628	2.323314	$33.60	$8,673.71		
Verticals	W8x18	2	18	7.229	260.244	0.130122	$33.60	$485.79		
									PER TRUSS	$108,207.84
									QUANTITY	8
					TOTAL WEIGHT:	37.77	tons		TOTAL	$865,662.70
									GRAND TOTAL	$1,243,825.86
									$/SF	$26.41

Crane Analysis

Table 68: Overall Redesign Crane Analysis

Analysis is based on using the current project team's method versus HPR's method for the redesigned steel in the whole arena

Overhead & Profit Markup = 24.8%

	Design Difference (+/-)			
HPR Method	**Material**	**Labor/Equip**	**O&P**	**Total**
Trusses - 150 Ton, 40 Ton, with Shoring	-$271,989.69	-$36,652.64	-$76,543.30	-$385,185.63
Arena Steel - 150 Ton	-$50,262.03	$69,740.79	$4,830.73	$24,309.49
Catwalk - 150 Ton	$34,305.49	$9,360.67	$10,829.21	$54,495.37
Total	**-$287,946.23**	**$42,448.82**	**-$60,883.36**	**-$306,380.77**

Baseline Method				
Trusses - 200 Ton, 300 Ton, No Shoring	-$271,989.69	-$112,401.17	-$95,328.93	-$479,719.80
Arena Steel - 200 Ton	-$50,262.03	$8,822.34	-$10,277.04	-$51,716.73
Catwalk - 200 Ton	$34,305.49	$7,514.16	$10,371.27	$52,190.92
Total	**-$287,946.23**	**-$96,064.67**	**-$95,234.70**	**-$479,245.61**

Difference	**$0.00**	**$138,513.49**	**$34,351.35**	**$172,864.84**
				36.07%

Table 69: Redesign Roof System Baseline vs. HPR's Method - Crane Analysis

Analysis is based on using the current project team's method versus HPR's method for new roof system steel and truss erection

Overhead & Profit Markup = 24.8%

	Design Difference (+/-)				
HPR Method	**Material**	**Labor/Equip**	**O&P**	**Total (%)**	
Trusses	-$271,989.69	-$30,477.56	-$75,011.88	-$377,479.13	-25.01%
Shoring Towers	$0.00	-$6,175.08	-$1,531.42	-$7,706.50	
Catwalk	$34,305.49	$9,360.67	$10,829.21	$54,495.37	19.22%
Roofs	-$116,259.91	-$42,258.22	-$39,312.50	-$197,830.63	-13.74%
Total	**-$353,944.11**	**-$69,550.19**	**-$105,026.59**	**-$528,520.89**	**-16.35%**

Baseline Method					
Trusses	-$271,989.69	-$112,401.92	-$95,329.12	-$479,720.73	-31.78%
Catwalk	$34,305.49	$9,360.67	$10,829.21	$54,495.37	19.22%
Roofs	-$116,259.91	-$42,258.22	-$39,312.50	-$197,830.63	-13.74%
Total	**-$353,944.11**	**-$145,299.47**	**-$123,812.41**	**-$623,055.99**	**-19.28%**

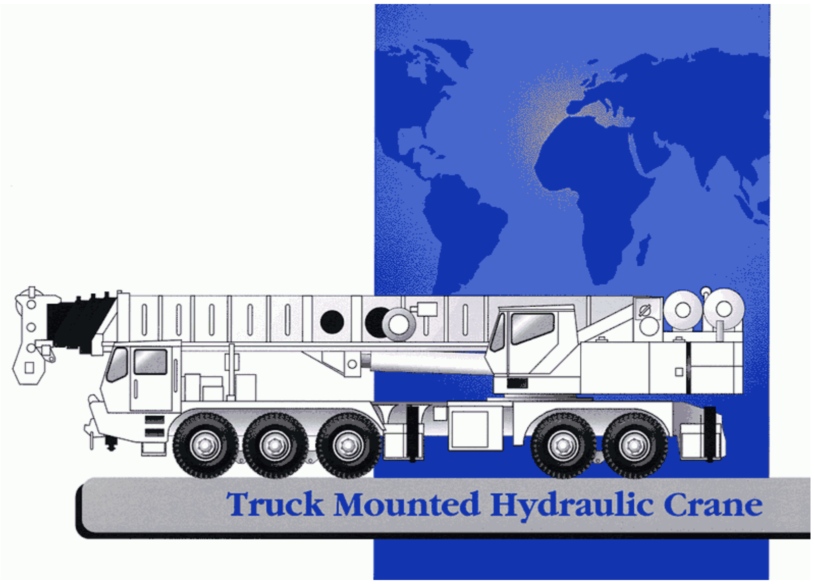
Difference	**$0.00**	**$75,749.28**	**$18,785.82**	**$94,535.10**	**15.17%**

Crane Cut Sheets

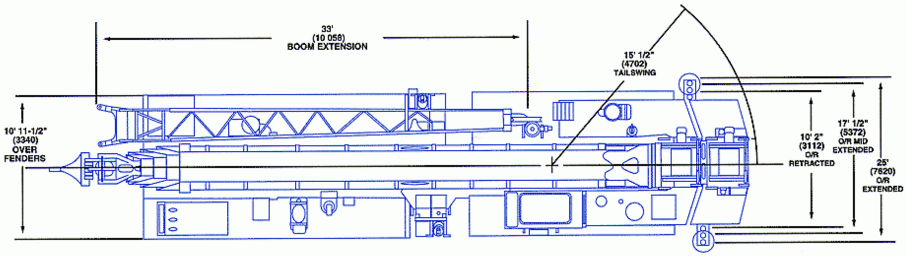
Figure 125: Grove TM9150 - 150-Ton Hydraulic Crane

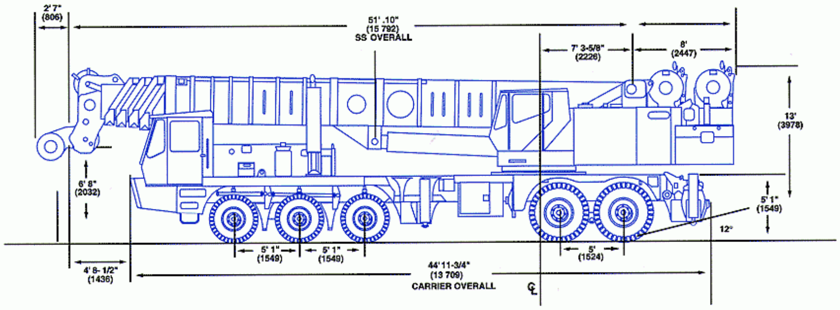
Figures are referenced from load charts found in document

http://www.bigge.com/crane-charts/truck-crane-charts/Grove-TM9150_NA_CS.pdf

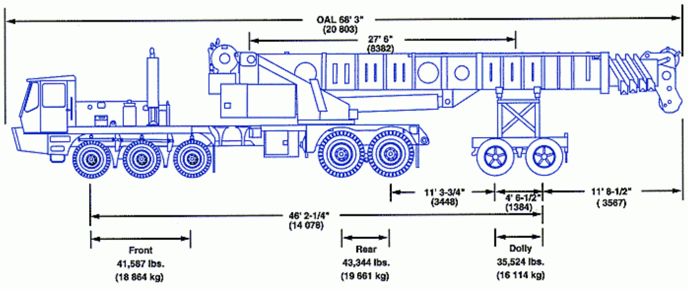


Dimensions





Axle Weight Distribution



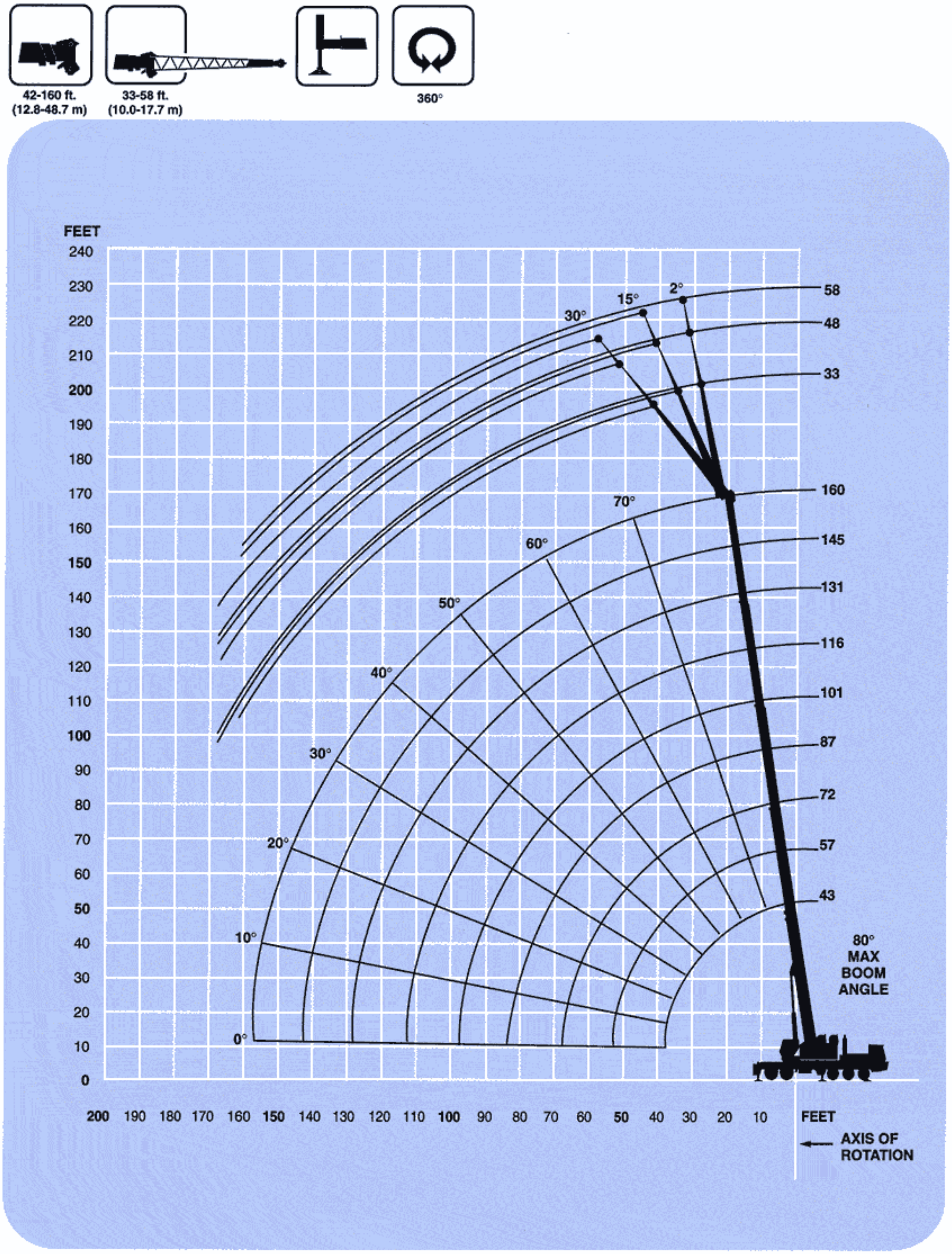
Machine equipped as follows:

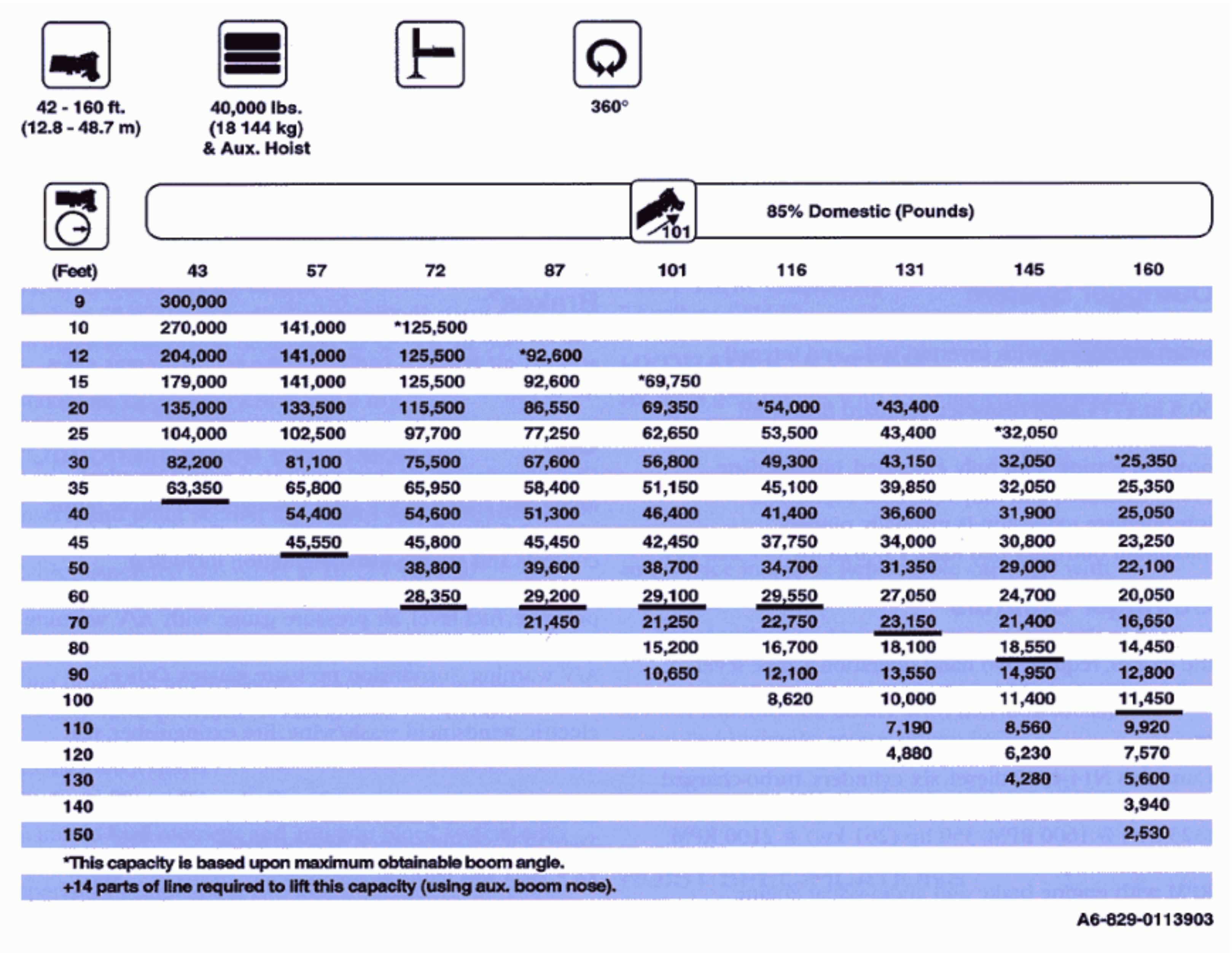
160 ft. (48.7 m) full power boom
Main hoist w/rope
Full fuel & hydraulics
Two axle dolly (5,730 lbs. [2599 kg])
(6) 445/65R22.5 front tires
(8) 14.00R25 rear tires

Components removed:

Counterweight
Front & rear O/R boxes
Aux hoist w/rope
Aux hoist structure
Aux boom nose
No block or ball
33 - 55 ft. (10.0 - 17.7 m)
Tele swingaway

Working range





42 - 160 ft.
(12.8 - 48.7 m)

40,000 lbs.
(18 144 kg)
& Aux. Hoist

360°

85% Domestic (Pounds)

(Feet)	43	57	72	87	101	116	131	145	160
9	300,000								
10	270,000	141,000	*125,500						
12	204,000	141,000	125,500	*92,600					
15	179,000	141,000	125,500	92,600	*69,750				
20	135,000	133,500	115,500	86,550	69,350	*54,000	*43,400		
25	104,000	102,500	97,700	77,250	62,650	53,500	43,400	*32,050	
30	82,200	81,100	75,500	67,600	56,800	49,300	43,150	32,050	*25,350
35	63,350	65,800	65,950	58,400	51,150	45,100	39,850	32,050	25,350
40		54,400	54,600	51,300	46,400	41,400	36,600	31,900	25,050
45		45,550	45,800	45,450	42,450	37,750	34,000	30,800	23,250
50			38,800	39,600	38,700	34,700	31,350	29,000	22,100
60			28,350	29,200	29,100	29,550	27,050	24,700	20,050
70				21,450	21,250	22,750	23,150	21,400	16,650
80					15,200	16,700	18,100	18,550	14,450
90					10,650	12,100	13,550	14,950	12,800
100						8,620	10,000	11,400	11,450
110							7,190	8,560	9,920
120							4,880	6,230	7,570
130								4,280	5,600
140									3,940
150									2,530

*This capacity is based upon maximum obtainable boom angle.

+14 parts of line required to lift this capacity (using aux. boom nose).

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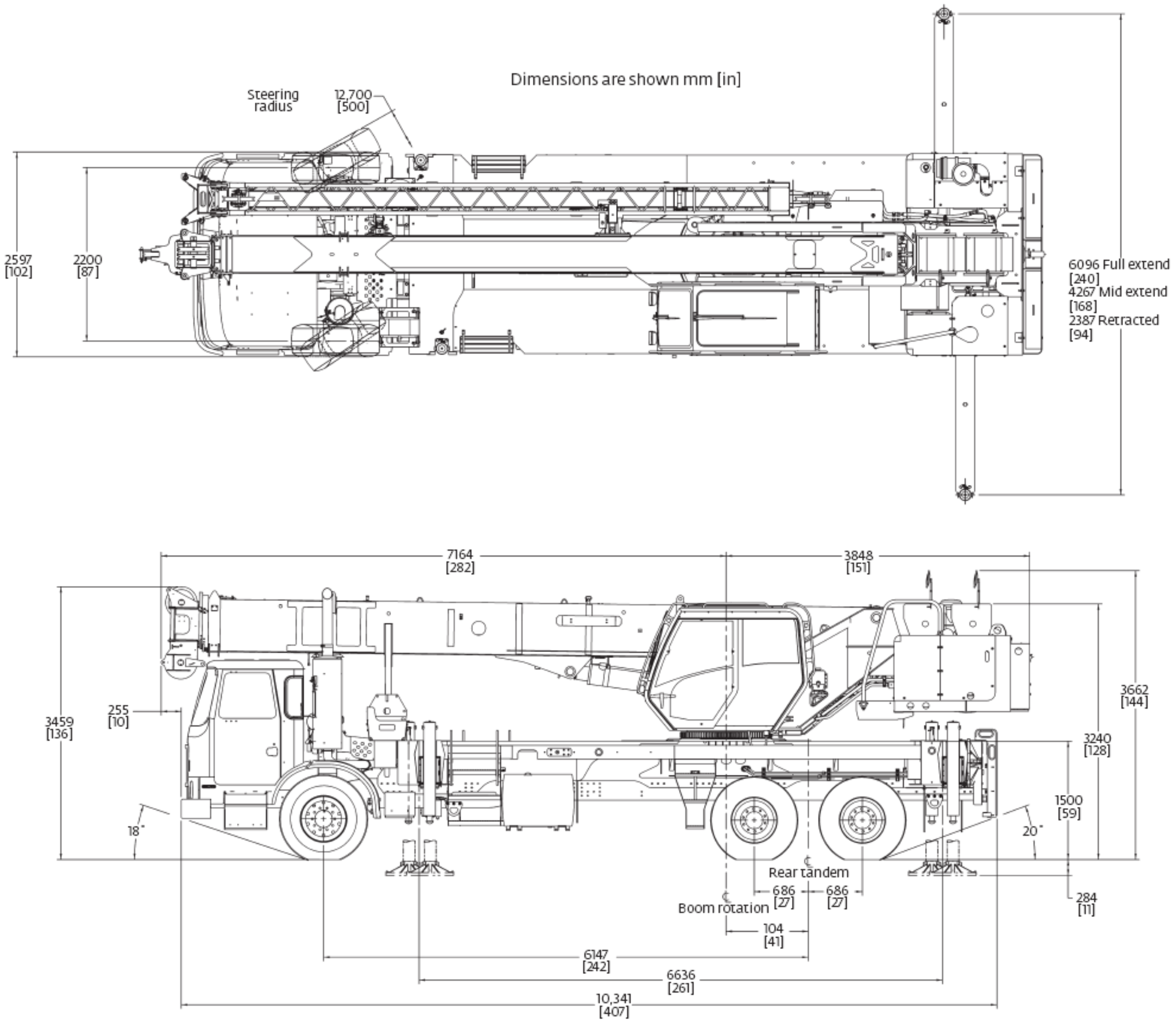
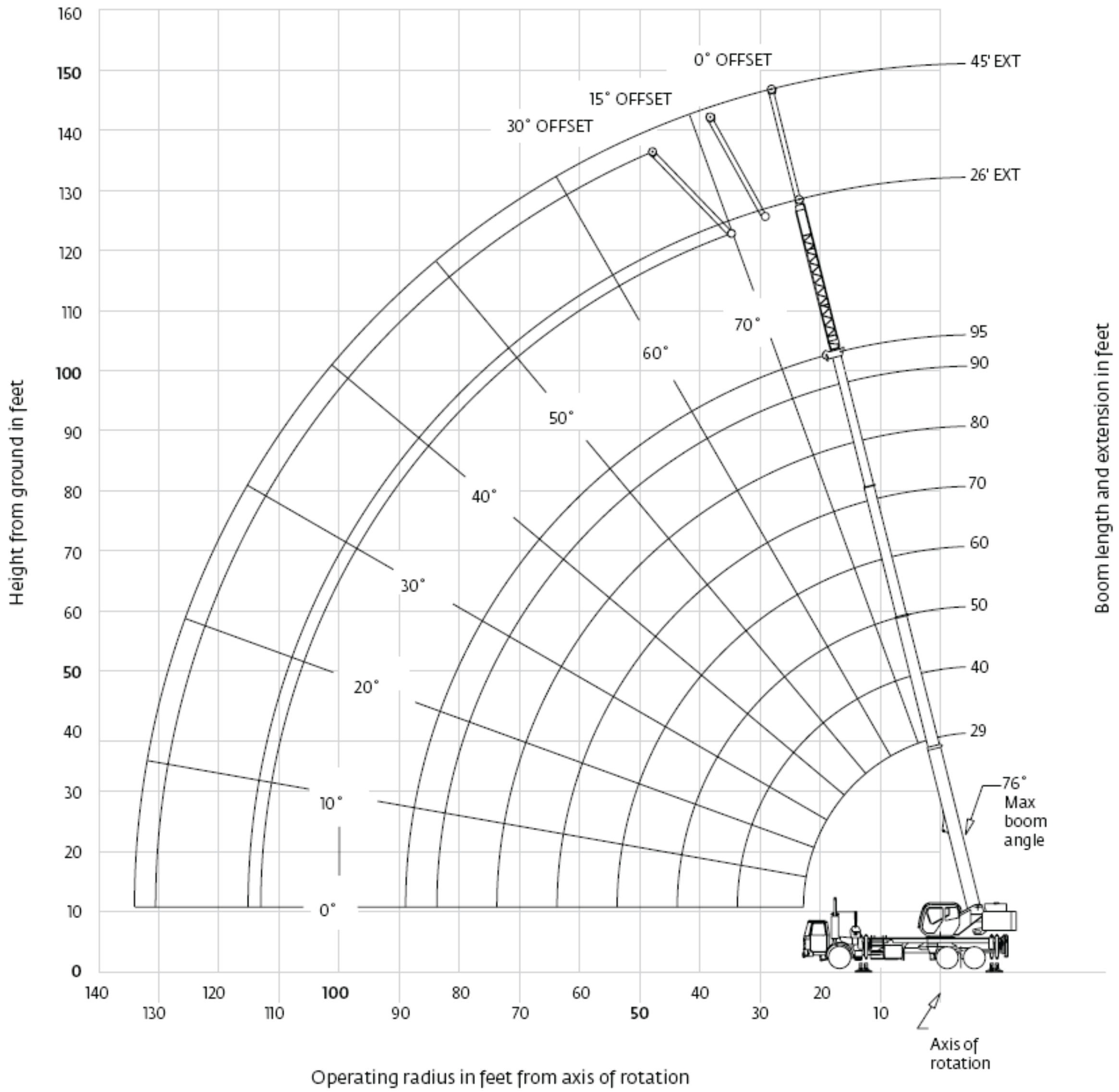
Figure 126: Grove TM500 - 40-Ton Hydraulic Crane

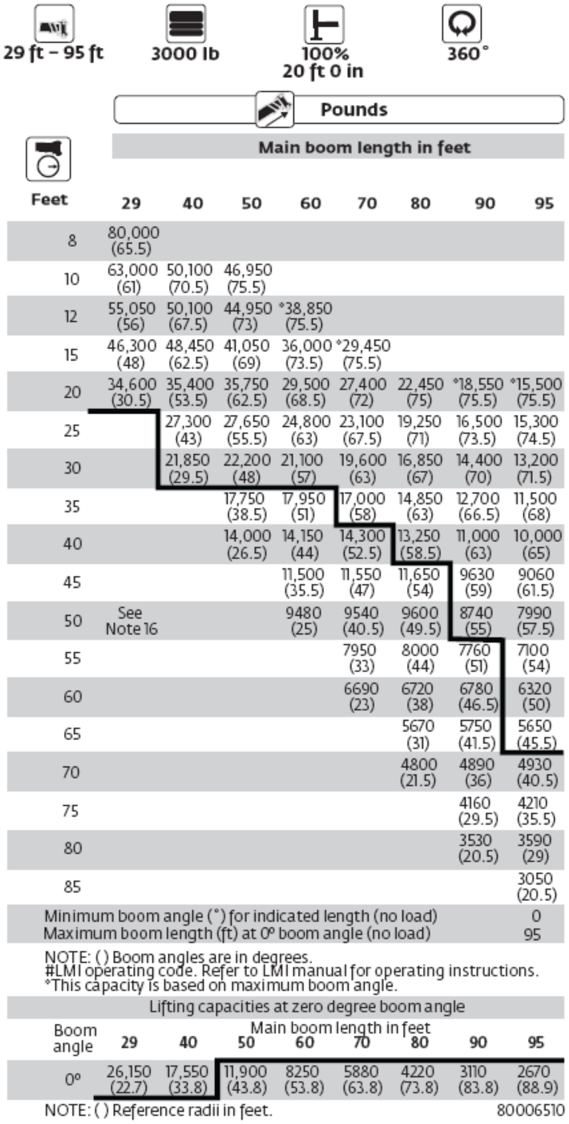
Figures are referenced from load charts found in document

http://www.bigge.com/crane-charts/truck-crane-charts/Grove-TM500E-2_Product_Guide.pdf



(Boom deflection not shown)





29 ft – 95 ft
3000 lb
100%
20 ft 0 in
360˚

Pounds

Feet	Main boom length in feet							
	29	40	50	60	70	80	90	95
8	80,000 (65.5)							
10	63,000 (61)	50,100 (70.5)	46,950 (75.5)					
12	55,050 (56)	50,100 (67.5)	44,950 (73)	*38,850 (75.5)				
15	46,300 (48)	48,450 (62.5)	41,050 (69)	36,000 (73.5)	*29,450 (75.5)			
20	34,600 (30.5)	35,400 (53.5)	35,750 (62.5)	29,500 (68.5)	27,400 (72)	22,450 (75)	*18,550 (75.5)	*15,500 (75.5)
25		27,300 (43)	27,650 (55.5)	24,800 (63)	23,100 (67.5)	19,250 (71)	16,500 (73.5)	15,300 (74.5)
30		21,850 (29.5)	22,200 (48)	21,100 (57)	19,600 (63)	16,850 (67)	14,400 (70)	13,200 (71.5)
35			17,750 (38.5)	17,950 (51)	17,000 (58)	14,850 (63)	12,700 (66.5)	11,500 (68)
40			14,000 (26.5)	14,150 (44)	14,300 (52.5)	13,250 (58.5)	11,000 (63)	10,000 (65)
45				11,500 (35.5)	11,550 (47)	11,650 (54)	9630 (59)	9060 (61.5)
50	See Note 16			9480 (25)	9540 (40.5)	9600 (49.5)	8740 (55)	7990 (57.5)
55					7950 (33)	8000 (44)	7760 (51)	7100 (54)
60					6690 (23)	6720 (38)	6780 (46.5)	6320 (50)
65						5670 (31)	5750 (41.5)	5650 (45.5)
70						4800 (21.5)	4890 (36)	4930 (40.5)
75							4160 (29.5)	4210 (35.5)
80							3530 (20.5)	3590 (29)
85								3050 (20.5)
Minimum boom angle (˚) for indicated length (no load)								0
Maximum boom length (ft) at 0º boom angle (no load)								95

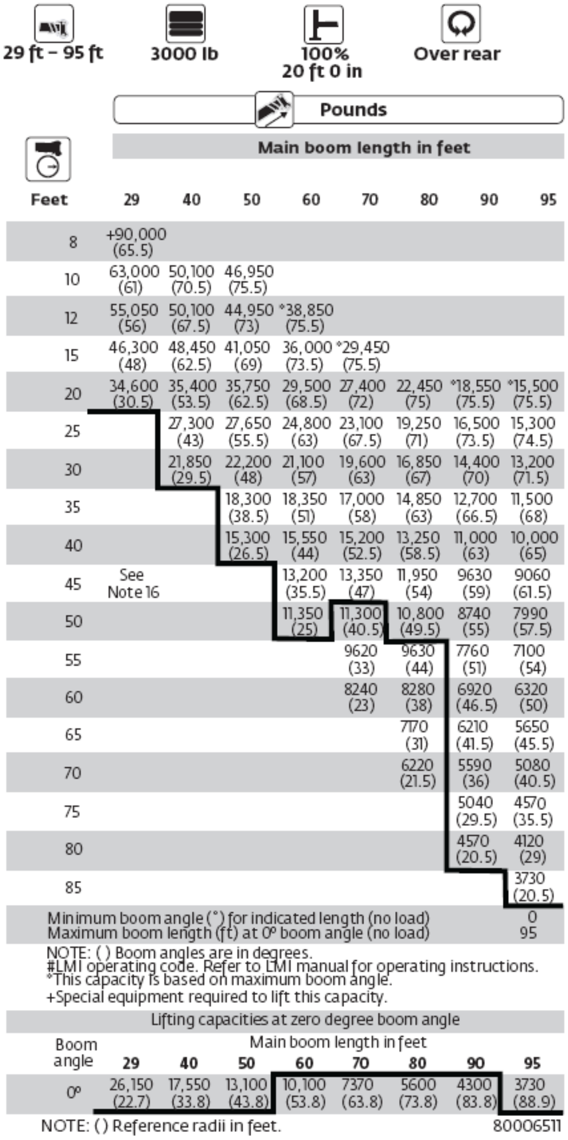
NOTE: ( ) Boom angles are in degrees.
#LMI operating code. Refer to LMI manual for operating instructions.
*This capacity is based on maximum boom angle.

Lifting capacities at zero degree boom angle

Boom angle	Main boom length in feet							
	29	40	50	60	70	80	90	95
0º	26,150 (22.7)	17,550 (33.8)	11,900 (43.8)	8250 (53.8)	5880 (63.8)	4220 (73.8)	3110 (83.8)	2670 (88.9)

NOTE: ( ) Reference radii in feet.

80006510



29 ft – 95 ft
3000 lb
100%
20 ft 0 in
Over rear

Pounds

Feet	Main boom length in feet							
	29	40	50	60	70	80	90	95
8	+90,000 (65.5)							
10	63,000 (61)	50,100 (70.5)	46,950 (75.5)					
12	55,050 (56)	50,100 (67.5)	44,950 (73)	*38,850 (75.5)				
15	46,300 (48)	48,450 (62.5)	41,050 (69)	36,000 (73.5)	*29,450 (75.5)			
20	34,600 (30.5)	35,400 (53.5)	35,750 (62.5)	29,500 (68.5)	27,400 (72)	22,450 (75)	*18,550 (75.5)	*15,500 (75.5)
25		27,300 (43)	27,650 (55.5)	24,800 (63)	23,100 (67.5)	19,250 (71)	16,500 (73.5)	15,300 (74.5)
30		21,850 (29.5)	22,200 (48)	21,100 (57)	19,600 (63)	16,850 (67)	14,400 (70)	13,200 (71.5)
35			18,300 (38.5)	18,350 (51)	17,000 (58)	14,850 (63)	12,700 (66.5)	11,500 (68)
40			15,300 (26.5)	15,550 (44)	15,200 (52.5)	13,250 (58.5)	11,000 (63)	10,000 (65)
45	See Note 16			13,200 (35.5)	13,350 (47)	11,950 (54)	9630 (59)	9060 (61.5)
50				11,350 (25)	11,300 (40.5)	10,800 (49.5)	8740 (55)	7990 (57.5)
55					9620 (33)	9630 (44)	7760 (51)	7100 (54)
60					8240 (23)	8280 (38)	6920 (46.5)	6320 (50)
65						7170 (31)	6210 (41.5)	5650 (45.5)
70						6220 (21.5)	5590 (36)	5080 (40.5)
75							5040 (29.5)	4570 (35.5)
80							4570 (20.5)	4120 (29)
85								3730 (20.5)
Minimum boom angle (˚) for indicated length (no load)								0
Maximum boom length (ft) at 0º boom angle (no load)								95

NOTE: ( ) Boom angles are in degrees.
#LMI operating code. Refer to LMI manual for operating instructions.
*This capacity is based on maximum boom angle.
+Special equipment required to lift this capacity.

Lifting capacities at zero degree boom angle

Boom angle	Main boom length in feet							
	29	40	50	60	70	80	90	95
0º	26,150 (22.7)	17,550 (33.8)	13,100 (43.8)	10,100 (53.8)	7370 (63.8)	5600 (73.8)	4300 (83.8)	3730 (88.9)

NOTE: ( ) Reference radii in feet.

80006511

Main Arena Roof System Cost Impact

Table 70: Main Arena Roof System Cost Breakdown

Overhead & Profit Markup = 24.8%

	Baseline				Redesign				Difference (+/-)				
Item	**Material Cost**	**Labor/Equip**	**O&P**	**Total Cost**	**Material Cost**	**Labor/Equip**	**O&P**	**Total Cost**	**Material**	**Labor/Equip**	**O&P**	**Total (%)**	
Trusses	$932,356.53	$277,032.71	$299,928.53	$1,509,317.77	$1,204,346.22	$307,510.27	$374,940.41	$1,886,796.90	-$271,989.69	-$30,477.56	-$75,011.88	-$377,479.13	-25.01%
Shoring Towers					$4,543.56	$1,631.52	$1,531.42	$7,706.50	-$4,543.56	-$1,631.52	-$1,531.42	-$7,706.50	
Catwalk	$169,866.84	$57,297.54	$56,336.77	$283,501.15	$135,561.35	$47,936.87	$45,507.56	$229,005.78	$34,305.49	$9,360.67	$10,829.21	$54,495.37	19.22%
Roofs	$781,075.14	$372,307.61	$286,038.92	$1,439,421.67	$897,335.05	$414,565.83	$325,351.42	$1,637,252.30	-$116,259.91	-$42,258.22	-$39,312.50	-$197,830.63	-13.74%
Total	**$1,883,298.51**	**$706,637.86**	**$642,304.22**	**$3,232,240.59**	**$2,241,786.18**	**$771,644.49**	**$747,330.81**	**$3,760,761.48**	**-$358,487.67**	**-$65,006.63**	**-$105,026.59**	**-$528,520.89**	**-16.35%**

Table 71: Roof System Current Design - End Truss Size

		Weight	Length	Total Wt
End Truss	W14 x 61	61	146.751	8951.811
	W14 x 99	99	196.002	19404.198
	W14 x 132	132	196.066	25880.712
	W24 x 146	146	41.604	6074.184
	2L8 x 8 x 1/2	53.4	250.928	13399.5552
			Total Weight (lbs)	**73711**
			Total Weight (Tons)	**37**
			Weight/LF	**377**
			Up to 100 ft Span	**126**

Table 72: Roof System Current Design - Inside Truss Size

		Weight	Length	Total Wt
Inside Truss	W14 x 61	61	35.182	2146.102
	W14 x 109	109	120.002	13080.218
	W14 x 145	145	76.025	11023.625
	W14 x 132	132	196.041	25877.412
	2L8x8x5/8	66	35.697	2356.002
	2L5x5x3/8	24.8	69.883	1733.0984
	2L6x4x3/8 LLBB	24.6	145.36	3575.856
	2L6x6x1/2	39.3	41.345	1624.8585
	2L8x6x1/2 LLBB	46.3	69.231	3205.3953
			Total Weight (lbs)	**64623**
			Total Weight (Tons)	**33**
			Weight/LF	**330**
			Up to 100 ft Span	**110**

Table 73: Roof System Current Design - Trusses & Purlins

Equipment costs based on same cranes used by Current Project Team

- 200 Ton & 300 Ton Hydraulic Cranes

Overhead & Profit Markup = 24.8%

Baseline Trusses	Quantity	Size	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
Built-Up End Truss (50-100' Span)	6	12 1/3	1 1/9	Ton	$2,278.50	$546.18	$168,609.00	$40,417.51	$51,838.57	$260,865.08
End Truss On-Site Butt-Weld 1/2" - Material	4				$45.57		$182.28	$0.00	$45.21	$227.49
End Truss On-Site Butt-Weld 1/2" - Labor	4	3	1 17/33	LF		$82.17	$0.00	$986.04	$244.54	$1,230.58
Built-Up Inside Truss (50-100' Span)	18	11	1 1/9	Ton	$2,278.50	$546.18	$451,143.00	$108,144.14	$138,703.21	$697,990.35
End Truss On-Site Butt-Weld 1/2" - Material	16				$45.57		$729.12	$0.00	$180.82	$909.94
End Truss On-Site Butt-Weld 1/2" - Labor	16	3	1 17/33	LF		$82.17	$0.00	$3,944.16	$978.15	$4,922.31
W14 x 74 - Brace		18	25/47	Ton	$1,884.96	$812.30	$33,929.28	$14,621.36	$12,040.56	$60,591.20
W14 x 61 - Brace		22	5/11	Ton	$2,045.61	$948.05	$45,003.42	$20,857.13	$16,333.42	$82,193.96
W14 x 30 - Brace		12	5/11	Ton	$2,045.61	$948.05	$24,547.32	$11,376.61	$8,909.14	$44,833.07
W14 x 38 - Brace		23	5/11	Ton	$2,045.61	$948.05	$47,049.03	$21,805.18	$17,075.84	$85,930.05
W14 x 43 - Brace		27	5/11	Ton	$2,045.61	$948.05	$55,231.47	$25,597.38	$20,045.56	$100,874.41
2L8 x 8 x 3/4 x 3/4 - Angle		21	1 1/4	Ton	$2,067.03	$345.25	$43,407.63	$7,250.18	$12,563.14	$63,220.94
W24 x 176 - Column		23	5/8	Ton	$1,724.31	$689.44	$39,659.13	$15,857.06	$13,768.01	$69,284.20
W24 x 146 - Column		5	5/8	Ton	$1,724.31	$689.44	$8,621.55	$3,447.19	$2,993.05	$15,061.78
2L6x6x1/2x3/4 - Angle		5	64/91	Ton	$2,848.86	$545.76	$14,244.30	$2,728.78	$4,209.32	$21,182.41
						Total	**$932,356.53**	**$277,032.71**	**$299,928.53**	**$1,509,317.77**

Table 74: Roof System Redesign Truss Size

Truss	Weight	Length	Total Wt
W14 x 68	68	79.875	5431.5
W14 x 43	43	271.647	11680.821
W14 x 53	53	76.146	4035.738
W27 x 146	146	248.7	36310.2
W24 x 117	117	76	8892
W8 x 18	18	412.604	7426.872
	Total Weight (lbs)		**73778**
	Total Weight (Tons)		**37**
	Weight/LF		**377**
	Up to 100 ft Span		**126**

Table 75: Roof System Redesign Trusses & Purlins

Equipment costs based on HPR's crane analysis (see Table 68 and 69 in Appendix G)

– 150 Ton & 40 Ton Hydraulic Crane

Overhead & Profit Markup = 24.8%

Trusses	Quantity	Size	Unit/Hr	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
Built Up End Truss (50-100' Span, 120 lb/ft)	24	12 1/3	1 1/4	Ton	$2,278.50	$403.25	$674,436.00	$119,361.58	$196,861.80	$990,659.38
End Truss On-Site Butt-Weld 1/2" - Material	16				$45.57		$729.12	$0.00	$180.82	$909.94
End Truss On-Site Butt-Weld 1/2" - Labor	16	4 1/3	1 17/33	LF		$82.17	$0.00	$5,697.12	$1,412.89	$7,110.01
W24 x 162		39	25/47	Ton	$1,724.31	$566.89	$67,248.09	$22,108.86	$22,160.52	$111,517.47
W14 x 82		118	5/11	Ton	$1,884.96	$666.37	$222,425.28	$78,631.27	$74,662.02	$375,718.57
2L6 x 6 x 1/2 x 3/4		6	64/91	Ton	$2,848.86	$504.28	$17,093.16	$3,025.65	$4,989.47	$25,108.28
2L5 x 3 1/2 x 3/8 x 3/8 LLBB		6	23/98	Ton	$3,502.17	$1,510.99	$21,013.02	$9,065.96	$7,459.59	$37,538.56
W14 x 99		73	5/11	Ton	$1,884.96	$666.37	$137,602.08	$48,644.77	$46,189.22	$232,436.07
W24 x 176 - Column		31	5/8	Ton	$1,724.31	$566.89	$53,453.61	$17,573.71	$17,614.77	$88,642.09
W24 x 146 - Column		6	5/8	Ton	$1,724.31	$566.89	$10,345.86	$3,401.36	$3,409.31	$17,156.53
						Total	**$1,204,346.22**	**$307,510.27**	**$374,940.41**	**$1,886,796.91**

Table 76: Roof System Redesign Shoring

Overhead & Profit Markup = 24.8%

Redesign - Shoring	Quantity	Duration	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
Truss 2'w x 5'h Shoring	88	3 1/2	Month	$12.81		$3,945.48		$978.48	$4,923.96
Erecting Each Frame	88				$10.28		$904.64	$224.35	$1,128.99
Dismantle Each Frame	88				$8.26		$726.88	$180.27	$907.15
Jacks	32	3 1/2	Month	$5.34		$598.08		$148.32	$746.40
					Total	**$4,543.56**	**$1,631.52**	**$1,531.42**	**$7,706.50**

Table 77: Roof System Current Design Catwalk

Equipment costs based on same cranes used by Current Project Team – 200 Ton Hydraulic Crane

Overhead & Profit Markup = 24.8%

Catwalk	Size	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
HSS 1.66 X .14	3	Ton	$2,859.57	$759.73	$8,578.71	$2,279.19	$2,692.76	$13,550.66
HSS 14X10X1/2	49	Ton	$2,559.69	$400.78	$125,424.81	$19,638.45	$35,975.69	$181,038.95
1/4" Checkered Plate	1506	SF	$8.41	$18.82	$12,665.46	$28,343.97	$10,170.34	$51,179.77
L4X4X3/8	6	Ton	$3,866.31	$1,172.65	$23,197.86	$7,035.92	$7,497.98	$37,731.75
				Total	**$169,866.84**	**$57,297.54**	**$56,336.77**	**$283,501.14**

Table 78: Roof System Redesign Catwalk

Equipment costs based on HPR's crane analysis (see Table 68 and 69 in Appendix G)

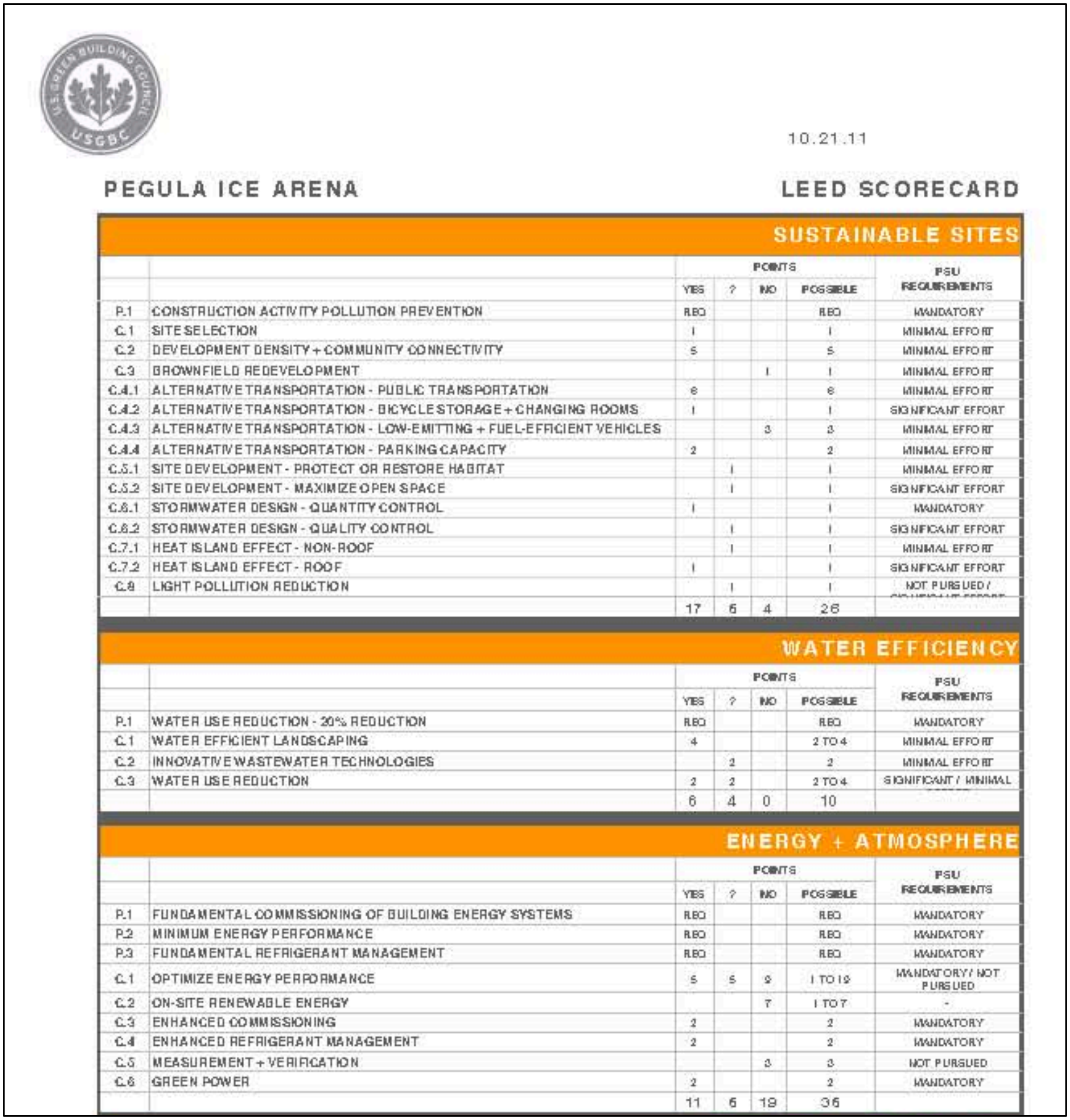
– 150 Ton Hydraulic Crane

Overhead & Profit Markup = 24.8%

Catwalk	Size	Unit	Material Cost per Unit	Equip/Labor per Unit	Total Material Cost	Total Equip/ Labor Cost	O&P	Total Cost
HSS 1.66 X .14	3	Ton	$2,859.57	$708.67	$8,578.71	$2,126.00	$2,654.77	$13,359.48
HSS 14X10X1/2	36	Ton	$2,559.69	$373.80	$92,148.84	$13,456.83	$26,190.21	$131,795.88
1/4" Checkered Plate	1383.584	SF	$8.41	$18.32	$11,635.94	$25,347.36	$9,171.86	$46,155.16
L4X4X3/8	6	Ton	$3,866.31	$1,167.78	$23,197.86	$7,006.69	$7,490.73	$37,695.27
				Total	**$135,561.35**	**$47,936.87**	**$45,507.56**	**$229,005.79**

APPENDIX H: Façade Redesign

Current Design's LEED Score Card



10.21.11

PEGULA ICE ARENA

LEED SCORECARD

SUSTAINABLE SITES

		POINTS				PSU REQUIREMENTS
		YES	?	NO	POSSIBLE	
P.1	CONSTRUCTION ACTIVITY POLLUTION PREVENTION	REQ			REQ	MANDATORY
C.1	SITE SELECTION	1			1	MINIMAL EFFORT
C.2	DEVELOPMENT DENSITY + COMMUNITY CONNECTIVITY	5			5	MINIMAL EFFORT
C.3	BROWNFIELD REDEVELOPMENT			1	1	MINIMAL EFFORT
C.4.1	ALTERNATIVE TRANSPORTATION - PUBLIC TRANSPORTATION	6			6	MINIMAL EFFORT
C.4.2	ALTERNATIVE TRANSPORTATION - BICYCLE STORAGE + CHANGING ROOMS	1			1	SIGNIFICANT EFFORT
C.4.3	ALTERNATIVE TRANSPORTATION - LOW-EMITTING + FUEL-EFFICIENT VEHICLES			3	3	MINIMAL EFFORT
C.4.4	ALTERNATIVE TRANSPORTATION - PARKING CAPACITY	2			2	MINIMAL EFFORT
C.5.1	SITE DEVELOPMENT - PROTECT OR RESTORE HABITAT		1		1	MINIMAL EFFORT
C.5.2	SITE DEVELOPMENT - MAXIMIZE OPEN SPACE		1		1	SIGNIFICANT EFFORT
C.6.1	STORMWATER DESIGN - QUANTITY CONTROL	1			1	MANDATORY
C.6.2	STORMWATER DESIGN - QUALITY CONTROL		1		1	SIGNIFICANT EFFORT
C.7.1	HEAT ISLAND EFFECT - NON-ROOF		1		1	MINIMAL EFFORT
C.7.2	HEAT ISLAND EFFECT - ROOF	1			1	SIGNIFICANT EFFORT
C.8	LIGHT POLLUTION REDUCTION		1		1	NOT PURSUED /
		17	6	4	26	

WATER EFFICIENCY

		POINTS				PSU REQUIREMENTS
		YES	?	NO	POSSIBLE	
P.1	WATER USE REDUCTION - 20% REDUCTION	REQ			REQ	MANDATORY
C.1	WATER EFFICIENT LANDSCAPING	4			2 TO 4	MINIMAL EFFORT
C.2	INNOVATIVE WASTEWATER TECHNOLOGIES		2		2	MINIMAL EFFORT
C.3	WATER USE REDUCTION	2	2		2 TO 4	SIGNIFICANT / MINIMAL
		6	4	0	10	

ENERGY + ATMOSPHERE

		POINTS				PSU REQUIREMENTS
		YES	?	NO	POSSIBLE	
P.1	FUNDAMENTAL COMMISSIONING OF BUILDING ENERGY SYSTEMS	REQ			REQ	MANDATORY
P.2	MINIMUM ENERGY PERFORMANCE	REQ			REQ	MANDATORY
P.3	FUNDAMENTAL REFRIGERANT MANAGEMENT	REQ			REQ	MANDATORY
C.1	OPTIMIZE ENERGY PERFORMANCE	5	5	9	1 TO 19	MANDATORY/ NOT PURSUED
C.2	ON-SITE RENEWABLE ENERGY			7	1 TO 7	-
C.3	ENHANCED COMMISSIONING	2			2	MANDATORY
C.4	ENHANCED REFRIGERANT MANAGEMENT	2			2	MANDATORY
C.5	MEASUREMENT + VERIFICATION			3	3	NOT PURSUED
C.6	GREEN POWER	2			2	MANDATORY
		11	6	19	36	

MATERIALS + RESOURCES

		POINTS				PSU REQUIREMENTS
		YES	?	NO	POSSIBLE	
P.1	STORAGE + COLLECTION OF RECYCLABLES	REQ			REQ	MANDATORY
C.1.1	BUILDING REUSE - MAINTAIN EXISTING WALLS, FLOORS, AND ROOF			3	1 TO 3	MINIMAL EFFORT
C.1.2	BUILDING REUSE - MAINTAIN 50% OF INTERIOR NON-STRUCTURAL ELEMENTS			1	1	MINIMAL EFFORT
C.2	CONSTRUCTION WASTE MANAGEMENT	2			1 TO 2	MANDATORY
C.3	MATERIALS REUSE			2	1 TO 2	MINIMAL EFFORT
C.4	RECYCLED CONTENT	2			1 TO 2	MANDATORY/ SIGNIFICANT EFFORT
C.5	REGIONAL MATERIALS	2			1 TO 2	MANDATORY
C.6	RAPIDLY RENEWABLE MATERIALS		1		1	MINIMAL EFFORT
C.7	CERTIFIED WOOD	1			1	MANDATORY
		7	1	6	14	

INDOOR ENVIRONMENTAL QUALITY

		POINTS				PSU REQUIREMENTS
		YES	?	NO	POSSIBLE	
P.1	MINIMUM INDOOR AIR QUALITY PERFORMANCE	REQ			REQ	MANDATORY
P.2	ENVIRONMENTAL TOBACCO SMOKE (ETS) CONTROL	REQ			REQ	MANDATORY
C.1	OUTDOOR AIR DELIVERY MONITORING	1			1	MANDATORY
C.2	INCREASED VENTILATION			1	1	NOT PURSUED
C.3.1	CONSTRUCTION IAQ MANAGEMENT PLAN	1			1	MANDATORY
C.3.2	CONSTRUCTION IAQ MANAGEMENT PLAN	1		-	1	MANDATORY
C.4.1	LOW-EMITTING MATERIALS	1		-	1	MANDATORY
C.4.2	LOW-EMITTING MATERIALS	1		-	1	MANDATORY
C.4.3	LOW-EMITTING MATERIALS	1		-	1	MANDATORY
C.4.4	LOW-EMITTING MATERIALS	1		-	1	MANDATORY
C.5	INDOOR CHEMICAL + POLLUTION SOURCE CONTROL	1		-	1	MANDATORY
C.6.1	CONTROLLABILITY OF SYSTEMS	1		-	1	MANDATORY
C.6.2	CONTROLLABILITY OF SYSTEMS	1		-	1	SIGNIFICANT EFFORT
C.7.1	THERMAL COMFORT	1		-	1	SIGNIFICANT EFFORT
C.7.2	THERMAL COMFORT	1		-	1	MANDATORY
C.8.1	DAYLIGHT AND VIEWS	1		-	1	SIGNIFICANT EFFORT
C.8.2	DAYLIGHT AND VIEWS	-		1	1	MINIMAL EFFORT
		13	0	2	15	

INNOVATION + DESIGN PROCESS

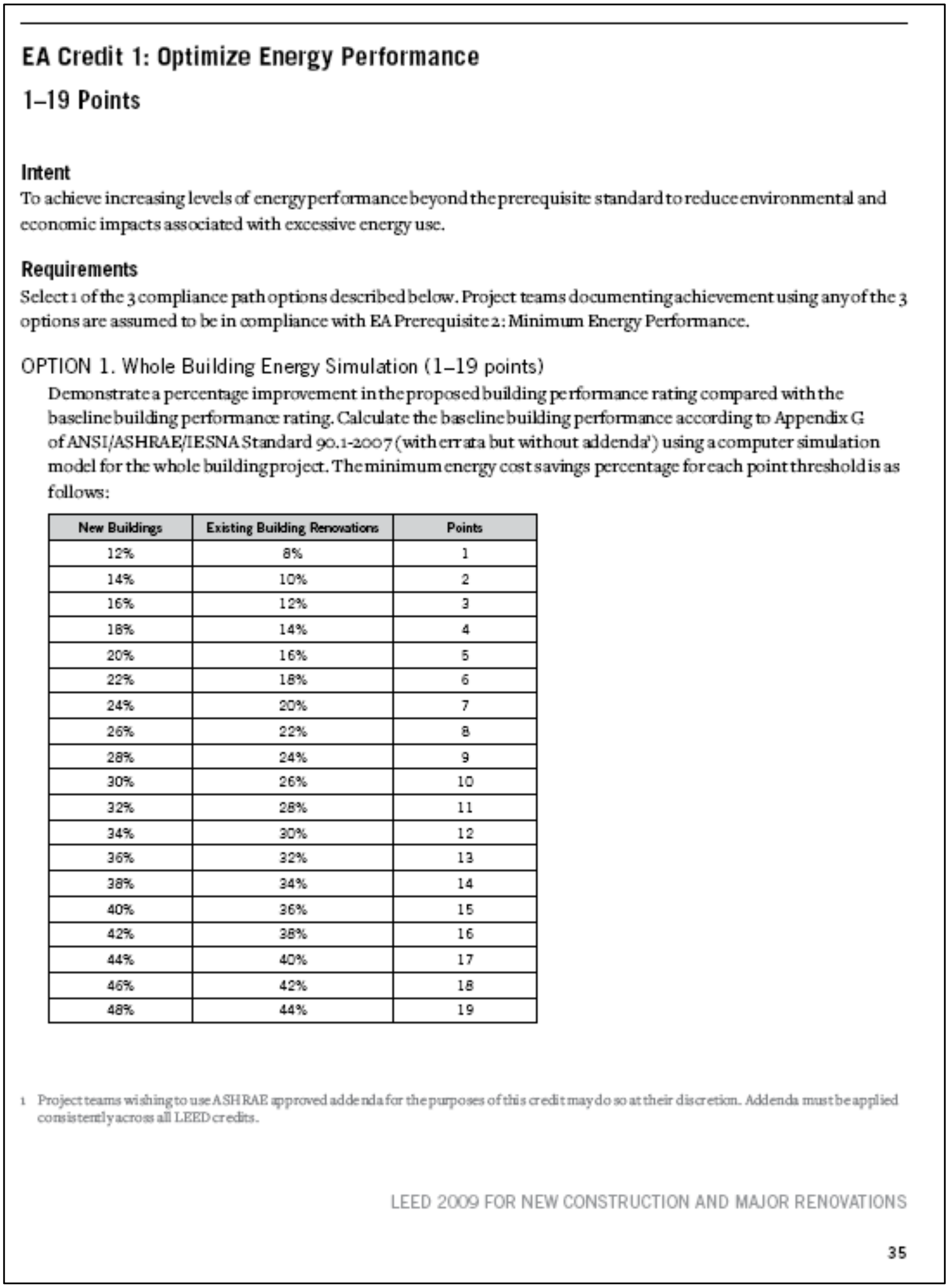
		POINTS				PSU REQUIREMENTS
		YES	?	NO	POSSIBLE	
C.1.1	INNOVATION IN DESIGN - GREEN CLEANING	1		-	1	MINIMAL EFFORT
C.1.2	INNOVATION IN DESIGN - EDUCATION	1		-	1	MINIMAL EFFORT
C.1.3	INNOVATION IN DESIGN - WASTE STREAM	-	1	-	1	MINIMAL EFFORT
C.1.4	INNOVATION IN DESIGN - ICE GENERATION	1	1	-	1	MINIMAL EFFORT
C.1.5	INNOVATION IN DESIGN	-	1	-	1	SIGNIFICANT EFFORT
C.2	LEED ACCREDITED PROFESSIONAL	1		-	1	MINIMAL EFFORT
		4	3	0	6	

REGIONAL PRIORITY CREDITS

		POINTS				PSU REQUIREMENTS
		YES	?	NO	POSSIBLE	
C.1.1	REGIONAL PRIORITY - SS C.4.4 - ALTERNATIVE TRANSPORTATION	1		-	1	MINIMAL EFFORT
C.1.2	REGIONAL PRIORITY - WE C.1 WATER EFFICIENT LANDSCAPING	1		-	1	MINIMAL EFFORT
C.1.3	REGIONAL PRIORITY - WE C.2 INNOVATIVE WASTEWATER TREATMENT	-		-	1	MINIMAL EFFORT
C.1.4	REGIONAL PRIORITY -	-	1	-	1	MINIMAL EFFORT
		2	1	0	4	

PLATINUM = 80 TO 110	GOLD = 60 TO 79	YES	?	NO
SILVER = 50 TO 59	CERTIFIED = 40 TO 49	60	19	31

LEED Energy and Atmosphere Credit 1



EA Credit 1: Optimize Energy Performance

1–19 Points

Intent

To achieve increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use.

Requirements

Select 1 of the 3 compliance path options described below. Project teams documenting achievement using any of the 3 options are assumed to be in compliance with EA Prerequisite 2: Minimum Energy Performance.

OPTION 1. Whole Building Energy Simulation (1–19 points)

Demonstrate a percentage improvement in the proposed building performance rating compared with the baseline building performance rating. Calculate the baseline building performance according to Appendix G of ANSI/ASHRAE/IESNA Standard 90.1-2007 (with errata but without addenda[1]) using a computer simulation model for the whole building project. The minimum energy cost savings percentage for each point threshold is as follows:

New Buildings	Existing Building Renovations	Points
12%	8%	1
14%	10%	2
16%	12%	3
18%	14%	4
20%	16%	5
22%	18%	6
24%	20%	7
26%	22%	8
28%	24%	9
30%	26%	10
32%	28%	11
34%	30%	12
36%	32%	13
38%	34%	14
40%	36%	15
42%	38%	16
44%	40%	17
46%	42%	18
48%	44%	19

---

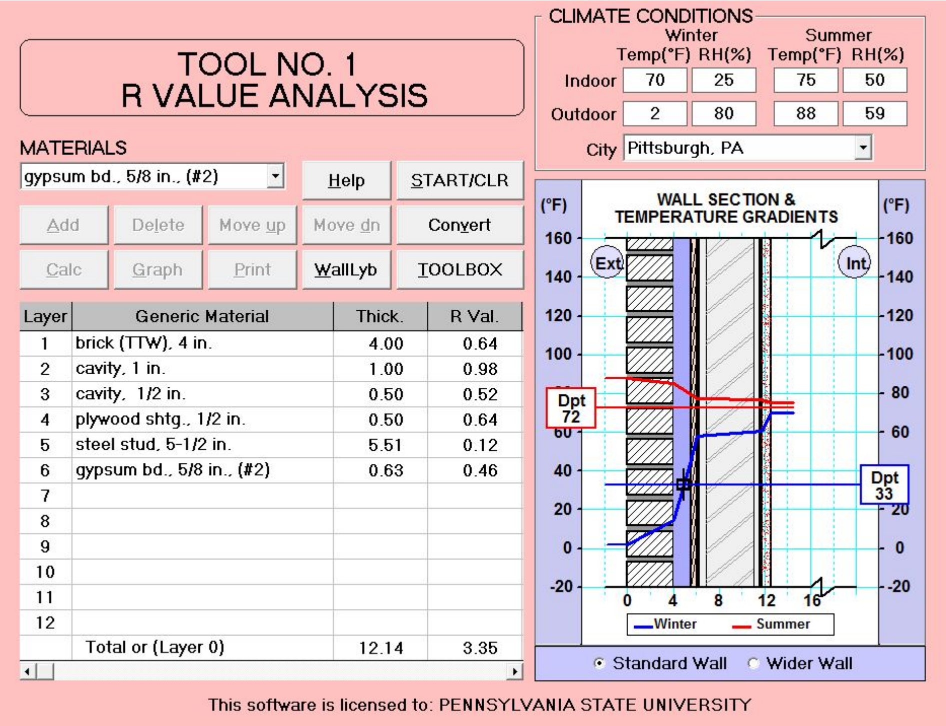
[1] Project teams wishing to use ASHRAE approved addenda for the purposes of this credit may do so at their discretion. Addenda must be applied consistently across all LEED credits.

LEED 2009 FOR NEW CONSTRUCTION AND MAJOR RENOVATIONS

35

H.A.M. Toolbox Analyses

Figure 127: Poor Exterior Cavity Wall Assembly - No Insulation



CLIMATE CONDITIONS

	Winter Temp(°F)	Winter RH(%)	Summer Temp(°F)	Summer RH(%)
Indoor	70	25	75	50
Outdoor	2	80	88	59

City: Pittsburgh, PA

MATERIALS: gypsum bd., 5/8 in., (#2)

Layer	Generic Material	Thick.	R Val.
1	brick (TTW), 4 in.	4.00	0.64
2	cavity, 1 in.	1.00	0.98
3	cavity, 1/2 in.	0.50	0.52
4	plywood shtg., 1/2 in.	0.50	0.64
5	steel stud, 5-1/2 in.	5.51	0.12
6	gypsum bd., 5/8 in., (#2)	0.63	0.46
7			
8			
9			
10			
11			
12			
	Total or (Layer 0)	12.14	3.35

● Standard Wall ○ Wider Wall

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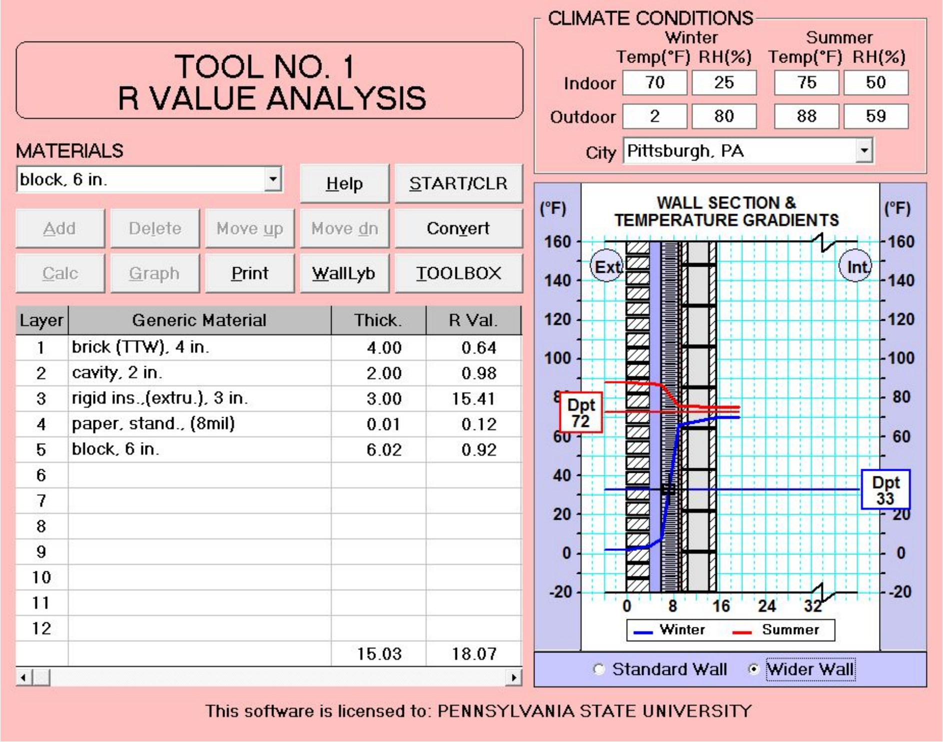
Figure 128: CMU Block Backup Exterior Cavity Wall - R-Value Analysis



CLIMATE CONDITIONS

	Winter Temp(°F)	Winter RH(%)	Summer Temp(°F)	Summer RH(%)
Indoor	70	25	75	50
Outdoor	2	80	88	59

City: Pittsburgh, PA

MATERIALS: block, 6 in.

Layer	Generic Material	Thick.	R Val.
1	brick (TTW), 4 in.	4.00	0.64
2	cavity, 2 in.	2.00	0.98
3	rigid ins.,(extru.), 3 in.	3.00	15.41
4	paper, stand., (8mil)	0.01	0.12
5	block, 6 in.	6.02	0.92
6			
7			
8			
9			
10			
11			
12			
		15.03	18.07

○ Standard Wall ● Wider Wall

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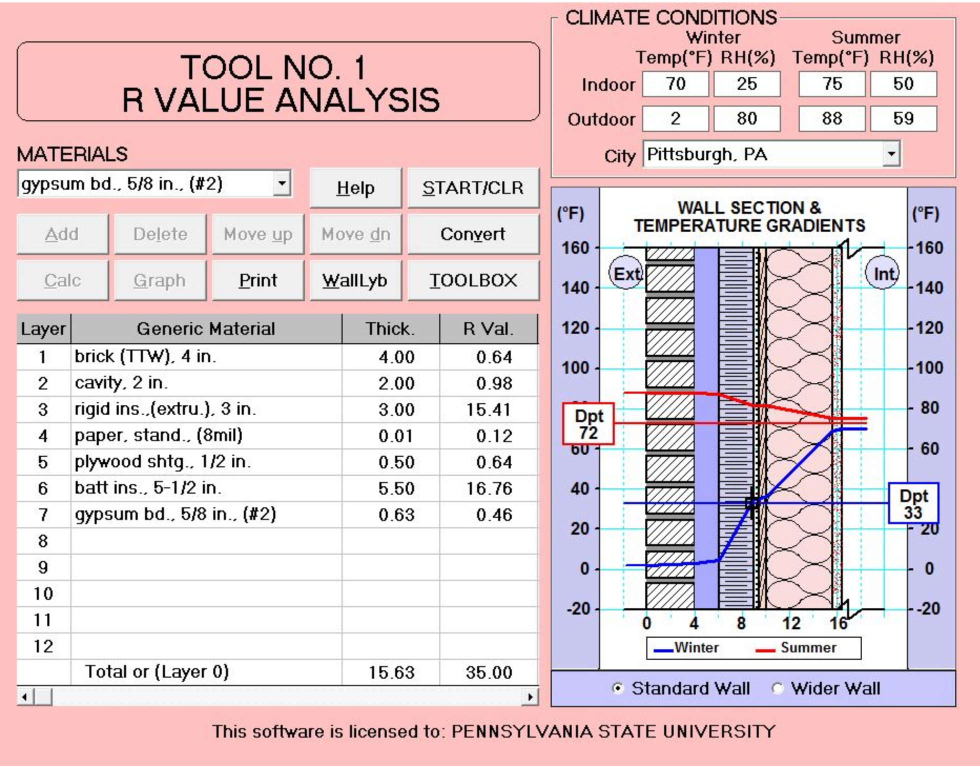
Figure 129: Structural Stud Backup - Exterior Cavity Wall - R-Value Analysis



CLIMATE CONDITIONS

	Winter Temp(°F)	Winter RH(%)	Summer Temp(°F)	Summer RH(%)
Indoor	70	25	75	50
Outdoor	2	80	88	59

City: Pittsburgh, PA

MATERIALS: gypsum bd., 5/8 in., (#2)

Layer	Generic Material	Thick.	R Val.
1	brick (TTW), 4 in.	4.00	0.64
2	cavity, 2 in.	2.00	0.98
3	rigid ins.,(extru.), 3 in.	3.00	15.41
4	paper, stand., (8mil)	0.01	0.12
5	plywood shtg., 1/2 in.	0.50	0.64
6	batt ins., 5-1/2 in.	5.50	16.76
7	gypsum bd., 5/8 in., (#2)	0.63	0.46
8			
9			
10			
11			
12			
	Total or (Layer 0)	15.63	35.00

● Standard Wall ○ Wider Wall

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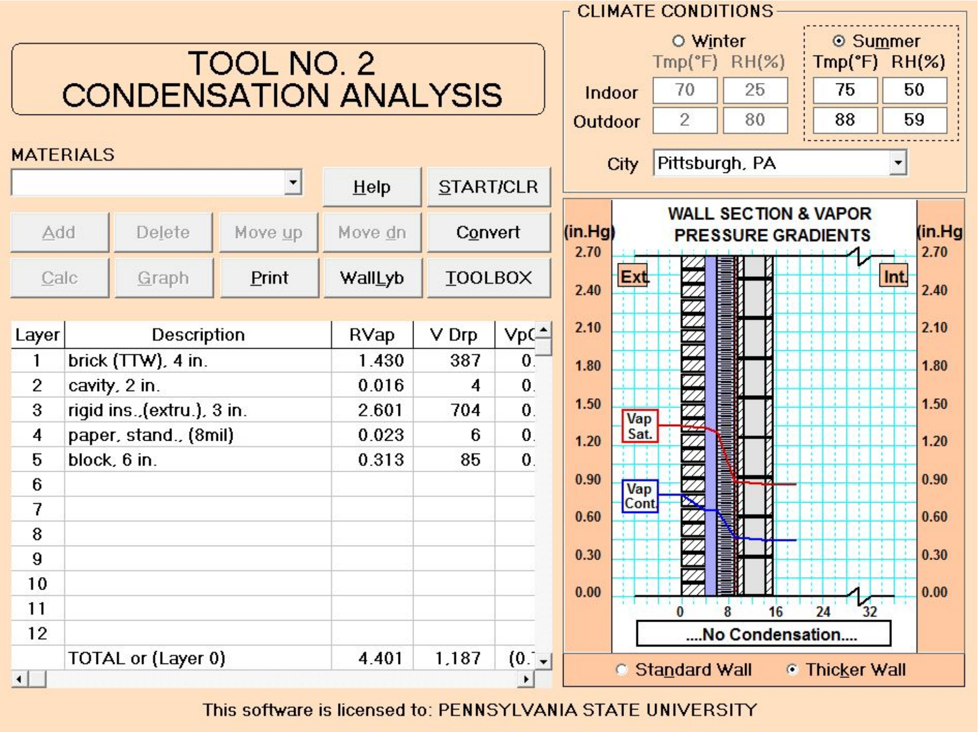
Figure 130: CMU Block Backup - Summer - Condensation Analysis



CLIMATE CONDITIONS

	○ Winter Tmp(°F)	○ Winter RH(%)	● Summer Tmp(°F)	● Summer RH(%)
Indoor	70	25	75	50
Outdoor	2	80	88	59

City: Pittsburgh, PA

MATERIALS

Layer	Description	RVap	V Drp	VpC
1	brick (TTW), 4 in.	1.430	387	0.
2	cavity, 2 in.	0.016	4	0.
3	rigid ins.,(extru.), 3 in.	2.601	704	0.
4	paper, stand., (8mil)	0.023	6	0.
5	block, 6 in.	0.313	85	0.
6				
7				
8				
9				
10				
11				
12				
	TOTAL or (Layer 0)	4.401	1,187	(0.

....No Condensation....

○ Standard Wall ● Thicker Wall

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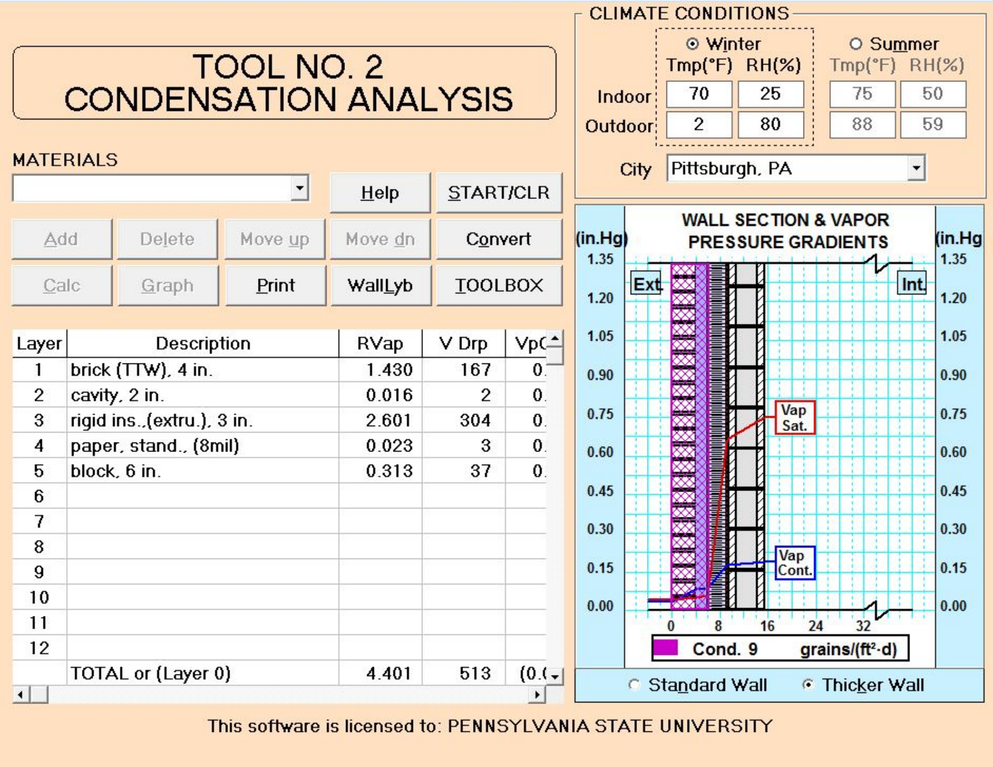
Figure 131: CMU Block Backup - Winter - Condensation Analysis



CLIMATE CONDITIONS

	● Winter Tmp(°F)	● Winter RH(%)	○ Summer Tmp(°F)	○ Summer RH(%)
Indoor	70	25	75	50
Outdoor	2	80	88	59

City: Pittsburgh, PA

Layer	Description	RVap	V Drp	VpC
1	brick (TTW), 4 in.	1.430	167	0.
2	cavity, 2 in.	0.016	2	0.
3	rigid ins.,(extru.), 3 in.	2.601	304	0.
4	paper, stand., (8mil)	0.023	3	0.
5	block, 6 in.	0.313	37	0.
6				
7				
8				
9				
10				
11				
12				
	TOTAL or (Layer 0)	4.401	513	(0.(

🟪 Cond. 9 grains/(ft²·d)

○ Standard Wall ● Thicker Wall

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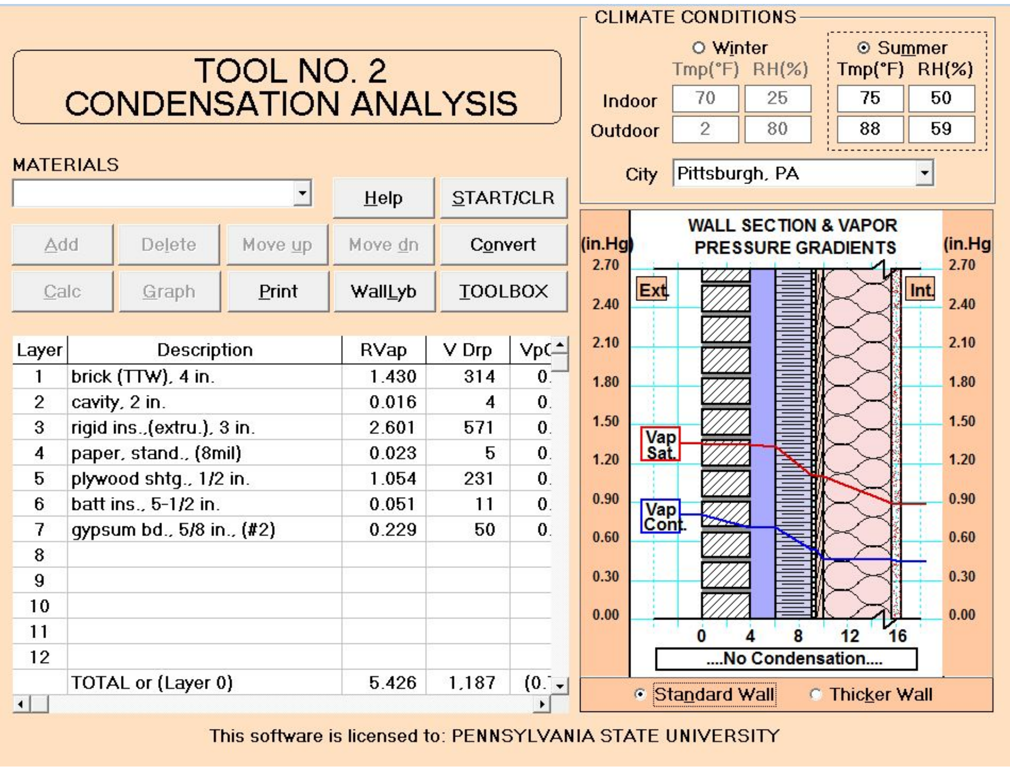
Figure 132: Structural Stud Backup - Summer - Condensation Analysis



CLIMATE CONDITIONS

	○ Winter Tmp(°F)	○ Winter RH(%)	● Summer Tmp(°F)	● Summer RH(%)
Indoor	70	25	75	50
Outdoor	2	80	88	59

City: Pittsburgh, PA

Layer	Description	RVap	V Drp	VpC
1	brick (TTW), 4 in.	1.430	314	0.
2	cavity, 2 in.	0.016	4	0.
3	rigid ins.,(extru.), 3 in.	2.601	571	0.
4	paper, stand., (8mil)	0.023	5	0.
5	plywood shtg., 1/2 in.	1.054	231	0.
6	batt ins., 5-1/2 in.	0.051	11	0.
7	gypsum bd., 5/8 in., (#2)	0.229	50	0.
8				
9				
10				
11				
12				
	TOTAL or (Layer 0)	5.426	1,187	(0.'

....No Condensation....

● Standard Wall ○ Thicker Wall

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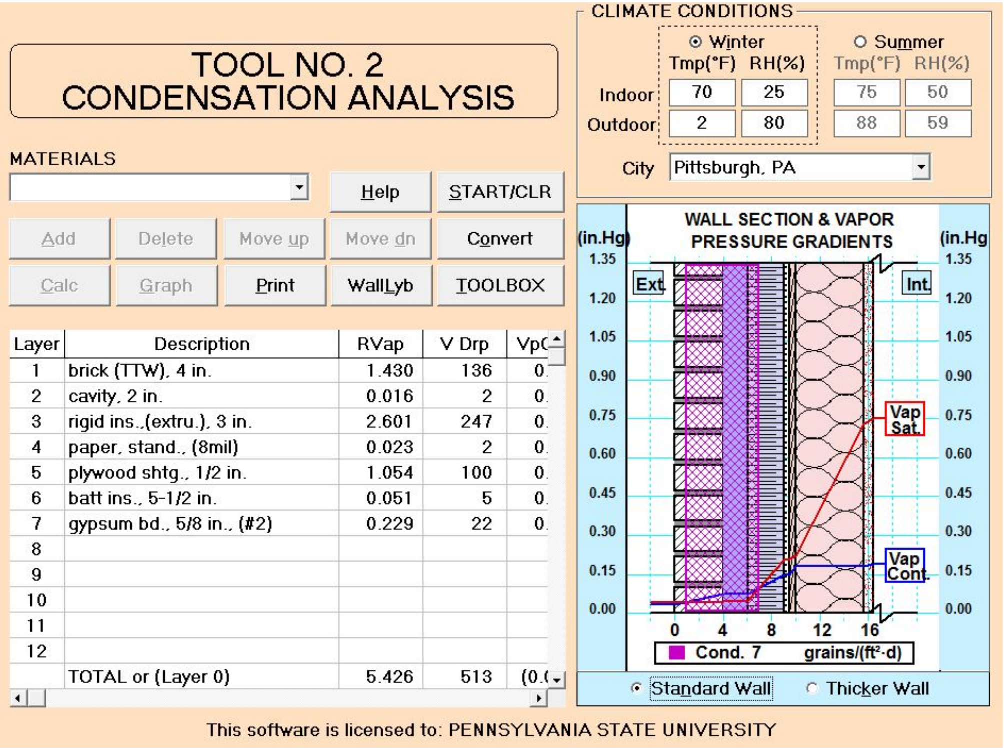
Figure 133: Structural Stud Backup - Winter - Condensation Analysis



TOOL NO. 2
CONDENSATION ANALYSIS

CLIMATE CONDITIONS

	● Winter Tmp(°F)	● Winter RH(%)	○ Summer Tmp(°F)	○ Summer RH(%)
Indoor	70	25	75	50
Outdoor	2	80	88	59

City: Pittsburgh, PA

Layer	Description	RVap	V Drp	VpC
1	brick (TTW), 4 in.	1.430	136	0.
2	cavity, 2 in.	0.016	2	0.
3	rigid ins.,(extru.), 3 in.	2.601	247	0.
4	paper, stand., (8mil)	0.023	2	0.
5	plywood shtg., 1/2 in.	1.054	100	0.
6	batt ins., 5-1/2 in.	0.051	5	0.
7	gypsum bd., 5/8 in., (#2)	0.229	22	0.
8				
9				
10				
11				
12				
	TOTAL or (Layer 0)	5.426	513	(0.(

Cond. 7 grains/(ft²-d)

● Standard Wall ○ Thicker Wall

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Façade Redesign Cost Impact

Table 79: Façade & Entrances Cost Breakdown

Overhead & Profit Markup = 24.8%

	Baseline				Redesign				Difference (+/-)				
Item	**Material Cost**	**Labor/Equip**	**O&P**	**Total Cost**	**Material Cost**	**Labor/Equip**	**O&P**	**Total Cost**	**Material**	**Labor/Equip**	**O&P**	**Total (%)**	
Exterior Glazing w/ Mullions (East Façade Only)	$490,688.23	$78,840.92	$141,243.23	$710,772.38	$397,294.83	$63,835.01	$114,360.20	$575,490.04	$93,393.40	$15,005.91	$26,883.03	$135,282.34	23.51%
Exterior Walls (East Faç & Entrances)	$0.00	$0.00	$0.00	$0.00	$84,019.18	$101,256.60	$45,948.39	$231,224.17	-$84,019.18	-$101,256.60	-$45,948.39	-$231,224.17	---
Total	**$490,688.23**	**$78,840.92**	**$141,243.23**	**$710,772.38**	**$481,314.01**	**$165,091.61**	**$160,308.59**	**$806,714.21**	**$9,374.22**	**-$86,250.69**	**-$19,065.36**	**-$95,941.83**	**-13.50%**

Table 80: East Façade Material Cost Breakdown

Overhead & Profit Markup = 24.8%

	Baseline				Redesign				Difference (+/-)				
East Façade	**Material Cost**	**Labor/Equip**	**O&P**	**Total Cost**	**Material Cost**	**Labor/Equip**	**O&P**	**Total Cost**	**Material**	**Labor/Equip**	**O&P**	**Total (%)**	
Glazing	$422,137.77	$67,826.63	$121,511.17	$611,475.57	$396,124.73	$63,647.01	$114,023.39	$573,795.13	$26,013.04	$4,179.62	$7,487.78	$37,680.44	6.57%
Exterior Walls	$0.00	$0.00	$0.00	$0.00	$40,240.18	$52,111.98	$22,903.34	$115,255.50	-$40,240.18	-$52,111.98	-$22,903.34	-$115,255.50	---
Total	**$422,137.77**	**$67,826.63**	**$121,511.17**	**$611,475.57**	**$436,364.91**	**$115,758.99**	**$136,926.73**	**$689,050.63**	**-$14,227.14**	**-$47,932.36**	**-$15,415.56**	**-$77,575.06**	**-12.69%**

Table 81: Main & Student Entrances Cost Breakdown

Overhead & Profit Markup = 24.8%

	Baseline				Redesign				Difference (+/-)				
Entrances	**Material Cost**	**Labor/Equip**	**O&P**	**Total Cost**	**Material Cost**	**Labor/Equip**	**O&P**	**Total Cost**	**Material**	**Labor/Equip**	**O&P**	**Total (%)**	
Glazing	$68,550.46	$11,014.29	$19,732.06	$99,296.81	$1,170.10	$188.00	$336.81	$1,694.91	$67,380.36	$10,826.29	$19,395.25	$97,601.90	5758.53%
Exterior Walls (East Faç & Entrances)	$0.00	$0.00	$0.00	$0.00	$43,779.00	$49,144.62	$23,045.06	$115,968.68	-$43,779.00	-$49,144.62	-$23,045.06	-$115,968.68	---
Total	**$68,550.46**	**$11,014.29**	**$19,732.06**	**$99,296.81**	**$44,949.10**	**$49,332.62**	**$23,381.87**	**$117,663.59**	**$23,601.36**	**-$38,318.33**	**-$3,649.81**	**-$18,366.78**	**-18.50%**

Façade Redesign Schedule Impact

Table 82: Façade & Entrance Schedule Impact

	Baseline Manhours	**Redesign Manhours**	**Difference (%)**	
Glazing	1984.81	1607.03	377.78	19.03%
Exterior Walls	0	2982.73	-2982.73	
Total	**1984.81**	**4589.76**	**-2604.95**	**-131.24%**

Table 83: East Façade Schedule Impact

East Façade	**Baseline Manhours**	**Redesign Manhours**	**Difference (%)**	
Glazing for East Façade	1707.86	1602.3	105.56	6.18%
Brick & Other Materials for East Façade		1333.29	-1333.29	
Total	**1707.86**	**2935.59**	**-1227.73**	**-71.89%**

Table 84: Entrances Schedule Impact

Entrances	Baseline Manhours	Redesign Manhours	Difference (%)	
Glazing for Entrances	276.95	4.73	272.22	98.29%
Brick & Other Materials for Entrances		1649.44	-1649.44	
Total	**276.95**	**1654.17**	**-1377.22**	**-497.28%**

APPENDIX I: Redesign Schedule

Table 85: HPR's Project Redesign Schedule

Activity ID	Activity Name	Remaining Duration	Start	Finish
PSU HOCKEY	Penn State Ice Arena Redesign	469	12-Dec-11	11-Oct-13
A1000	MOBILIZE TRAILERS TO SITE	10	12-Dec-11	23-Dec-11
A1010	MOBILIZE MGMT TEAM TO SITE	10	27-Jan-12	09-Feb-12
A1020	SITE PREP	20	10-Feb-12	08-Mar-12
A1030	SITE UTILITIES	96	10-Feb-12	25-Jun-12
A1040	EXCAVATION	28	24-Feb-12	03-Apr-12
A1050	FOUNDATIONS - PILES, FOOTERS, & WALLS	188	28-Mar-12	20-Dec-12
A1060	SLAB ON GRADE	143	24-Apr-12*	13-Nov-12
A1070	STEEL ERECTION	152	21-May-12*	24-Dec-12
A1080	METAL DECKING	132	31-May-12*	05-Dec-12
A1090	SLAB ON METAL DECK	130	08-Jun-12*	11-Dec-12
A1100	ERECT STEEL STAIRS	128	11-Jun-12*	10-Dec-12
A1110	EXTERIOR WALLS	153	28-Jun-12*	04-Feb-13
A1120	ROOF ENCLOSURES	123	10-Jul-12*	02-Jan-13
A1130	SHORING TOWERS	74	12-Jul-12*	24-Oct-12
A1140	BUILD-UP & ERECT TRUSSES	74	12-Jul-12*	24-Oct-12
A1150	EQUIPMENT INSTALLATION	187	12-Jul-12*	04-Apr-13
A1160	ELEVATORS INSTALLATION	184	16-Jul-12*	03-Apr-13
A1170	INTERIOR STUD FRAMING	123	18-Jul-12*	10-Jan-13
A1180	CURTAIN WALLS	124	23-Jul-12*	16-Jan-13
A1190	INTERIOR FINISHES	198	25-Jul-12*	02-May-13
A1200	ROUGH-IN	129	26-Jul-12*	28-Jan-13
A1210	FIRE SPRINKLERS	138	06-Aug-12*	19-Feb-13
A1220	DRYWALL	158	21-Aug-12*	03-Apr-13
A1230	TRUSS DECKING	68	29-Aug-12*	04-Dec-12
A1240	PRECAST STADIA - MAIN ARENA	61	17-Sep-12*	11-Dec-12
A1250	ELECTRICAL	108	26-Oct-12*	29-Mar-13
A1260	LIGHTING	107	01-Nov-12*	03-Apr-13
A1270	HVAC	104	05-Nov-12*	02-Apr-13
A1280	PLUMBING	106	15-Nov-12*	16-Apr-13
A1290	SCREEN WALL	6	26-Nov-12*	03-Dec-12
A1300	PRECAST STADIA - AUXILIARY RINK	4	04-Dec-12*	07-Dec-12
A1310	STADIA STEPS	40	12-Dec-12*	07-Feb-13
A1320	ICE FLOOR 4" UNDERDRAIN	15	12-Dec-12*	03-Jan-13
A1330	SITEWORK & LANDSCAPE	170	13-Dec-12*	13-Aug-13
A1340	ICE SLABS	80	07-Jan-13*	26-Apr-13
A1350	MAIN ARENA SEATS & RAILINGS	57	18-Feb-13*	07-May-13
A1360	SYSTEMS TESTING & START-UP	120	25-Feb-13*	13-Aug-13
A1370	AUXILIARY RINK SEATS & RAILINGS	10	18-Apr-13*	01-May-13
A1380	PSU FURNITURE, FIXTURES, & EQUIPMENT	50	04-Jun-13*	13-Aug-13
A1390	COMMISSIONING	50	18-Jun-13*	27-Aug-13
A1400	PENN STATE MOVE-IN	15	14-Aug-13*	04-Sep-13
A1410	1ST PUCK DROP	1	11-Oct-13*	11-Oct-13

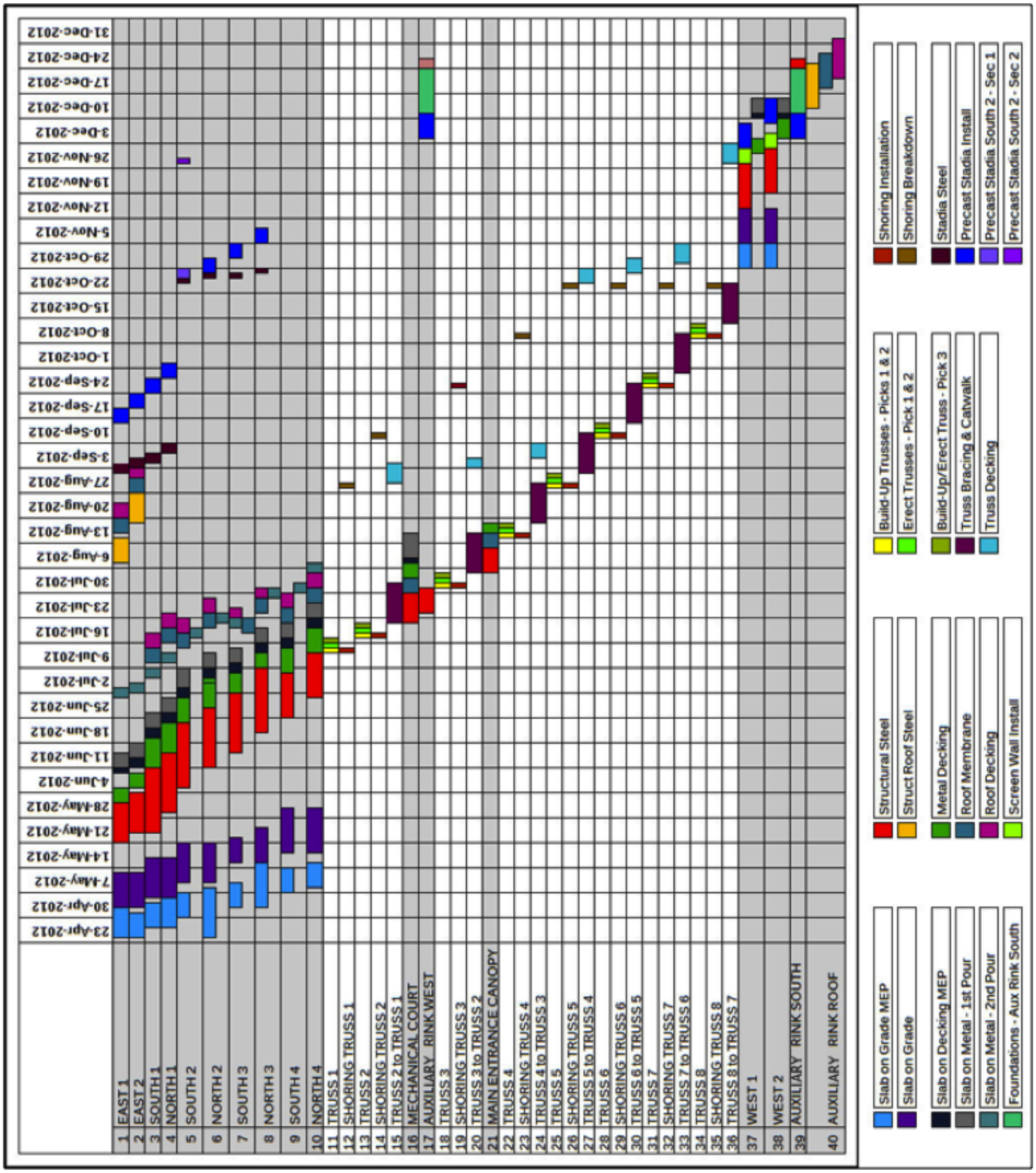
Table 86: HPR's Project Overall Redesign Schedule Impact

	Baseline				Redesign				Difference (+/-)			
Item - Schedule Days	**Item Time**	**Item Units**	**Project Days**	**Sched Days**	**Item Time**	**Item Units**	**Project Days**	**Sched Days**	**Item Time**	**Item Units**	**Project Days**	**Sched Days**
Excavation (Days)	251		35	35	183		28	28	68		7	7
Foundation Walls (sf)/Columns(ft)		25231.884	59	59		21506.739	51	51		3725.145	8	8
Int Wall Framing (sf)		225077.115	89	122		215502.236	86	118		9574.879	3	4
Int Wall Drywall (sf)		478486.734	85	141		428826.946	77	128		49659.788	8	13
Arena Bowl Stadia/Walls (tons)		162	34	84		210.625	45	110		-48.625	-11	-26
Arena Bowl Seating (each)		5947	53	53		6118	55	55		-171	-2	-2
Arena Bowl Steps (cf)		3434.954	41	41		2785.315	34	34		649.639	7	7
Exterior Wall Framing (sf)/Sheathing		65162.774	75	109		121887.955	141	205		-56725.181	-66	-96
Exterior Wall Insulation (sf)		40309.989	21	64		51017.272	27	83		-10707.283	-6	-19
Exterior Wall Vapor Barrier (sf)		50748.327	21	64		75794.894	32	98		-25046.567	-11	-34
Exterior Brick (sf)		40292.063	61	78		49717.223	76	98		-9425.16	-15	-20
Exterior Brick Ties to Framing (sf)		20410.958	24	64		28860.084	34	91		-8449.126	-10	-27
Exterior/Interior CMU (sf)		35330.784	31	31		35489.519	32	32		-158.735	-1	-1
Exterior Brick Ties to CMU (sf)		19881.105	12	29		20857.139	13	32		-976.034	-1	-3
Steel Structure Members (tons)		537	91	91		566	96	96		-29	-5	-5
Build-Up Trusses (welded ft)		60	16	16		69.333	19	19		-9.333	-3	-3
Errect Trusses (tons)		272	8	8		352	11	11		-80	-3	-3
Shoring Towers											-19	
Truss Braces (tons)		128	36	36		242	69	69		-114	-33	-33
Install Roof (sf)		129840.736	55	105		139398.348	60	115		-9557.612	-5	-10
Curtain Wall/Spandrel (sf)		13102.478	46	65		11879.334	42	59		1223.144	4	6

Table 87: 4D Steel & Truss Erection Schedule

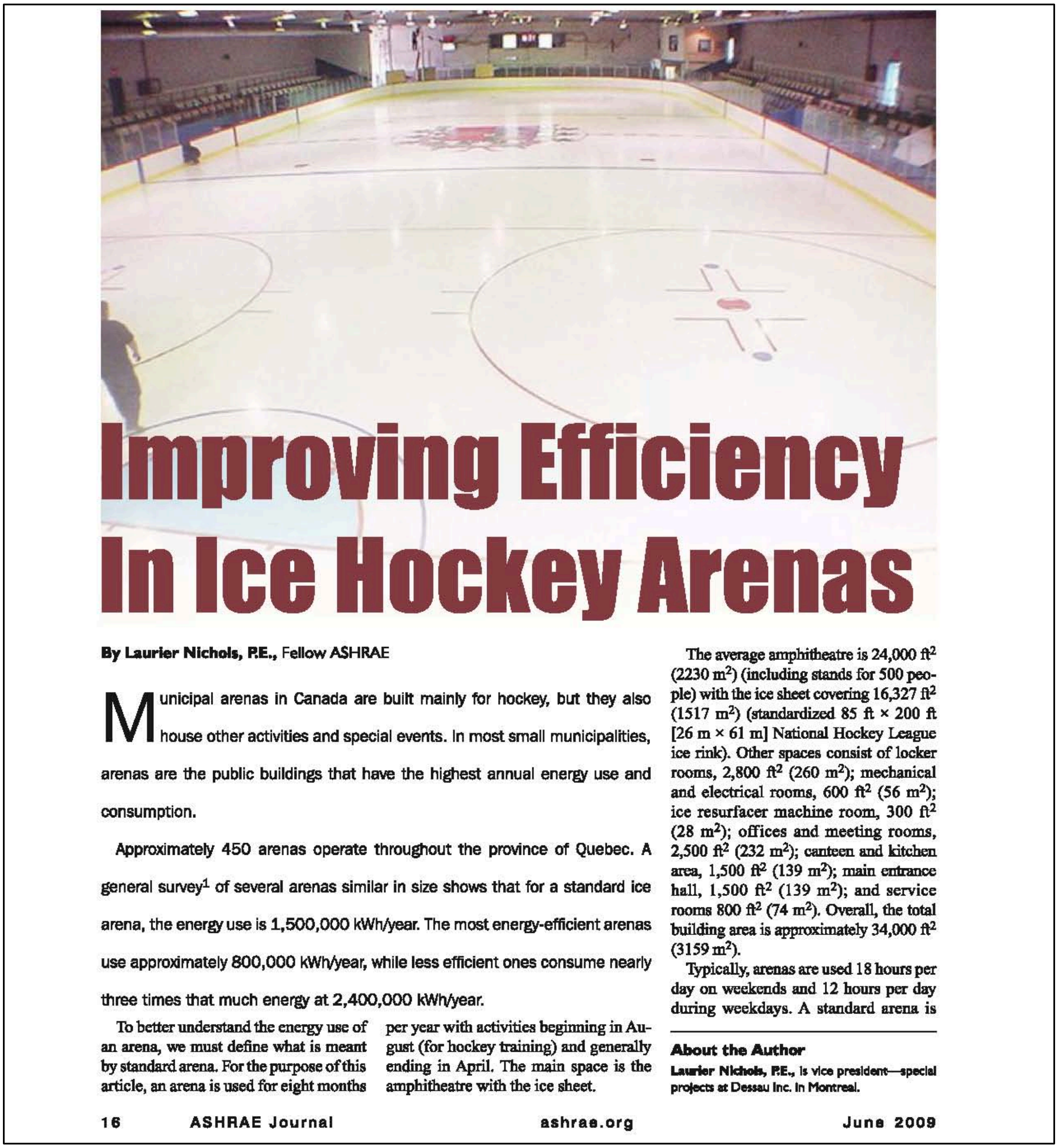
	Task Name	Duration	Start	Finish
1	STRUCTURAL STEEL EAST 1	7 days	Mon 5/21/12	Wed 5/30/12
2	STRUCTURAL STEEL EAST 2	7 days	Wed 5/23/12	Fri 6/1/12
3	STRUCTURAL STEEL SOUTH 1	12 days	Wed 5/23/12	Fri 6/8/12
4	STRUCTURAL STEEL NORTH 1	12 days	Tue 5/29/12	Wed 6/13/12
5	STRUCTURAL STEEL SOUTH 2	13 days	Tue 6/5/12	Thu 6/21/12
6	STRUCTURAL STEEL NORTH 2	12 days	Mon 6/11/12	Tue 6/26/12
7	STRUCTURAL STEEL SOUTH 3	12 days	Thu 6/14/12	Fri 6/29/12
8	STRUCTURAL STEEL NORTH 3	12 days	Wed 6/20/12	Fri 7/6/12
9	STRUCTURAL STEEL SOUTH 4	8 days	Mon 6/25/12	Thu 7/5/12
10	STRUCTURAL STEEL NORTH 4	8 days	Fri 6/29/12	Wed 7/11/12
11	BUILD-UP TRUSS 1 - PICK 1	1 day	Thu 7/12/12	Thu 7/12/12
12	BUILD-UP TRUSS 1 - PICK 2	1 day	Thu 7/12/12	Thu 7/12/12
13	SHORING TOWER TRUSS 1	35 days	Thu 7/12/12	Wed 8/29/12
14	ERECT TRUSS 1 - PICK 1	1 day	Fri 7/13/12	Fri 7/13/12
15	ERECT TRUSS 1 - PICK 2	1 day	Fri 7/13/12	Fri 7/13/12
16	BUILD-UP TRUSS 1 - PICK 3	1 day	Mon 7/16/12	Mon 7/16/12
17	ERECT TRUSS 1 - PICK 3	1 day	Mon 7/16/12	Mon 7/16/12
18	BUILD-UP TRUSS 2 - PICK 1	1 day	Tue 7/17/12	Tue 7/17/12
19	BUILD-UP TRUSS 2 - PICK 2	1 day	Tue 7/17/12	Tue 7/17/12
20	SHORING TOWER TRUSS 2	41 days	Tue 7/17/12	Wed 9/12/12
21	ERECT TRUSS 2 - PICK 1	1 day	Wed 7/18/12	Wed 7/18/12
22	ERECT TRUSS 2 - PICK 2	1 day	Wed 7/18/12	Wed 7/18/12
23	BUILD-UP TRUSS 2 - PICK 3	1 day	Thu 7/19/12	Thu 7/19/12
24	ERECT TRUSS 2 - PICK 3	1 day	Thu 7/19/12	Thu 7/19/12
25	ERECT BRACING T2-T1	8 days	Fri 7/20/12	Tue 7/31/12
26	STRUCTURAL STEEL NORTH MECH COURT	6 days	Fri 7/20/12	Fri 7/27/12
27	STRUCTURAL STEEL AUXILLIARY RINK WEST	5 days	Tue 7/24/12	Mon 7/30/12
28	BUILD-UP TRUSS 3 - PICK 1	1 day	Tue 7/31/12	Tue 7/31/12
29	BUILD-UP TRUSS 3 - PICK 2	1 day	Tue 7/31/12	Tue 7/31/12
30	SHORING TOWER TRUSS 3	41 days	Tue 7/31/12	Wed 9/26/12
31	ERECT TRUSS 3 - PICK 1	1 day	Wed 8/1/12	Wed 8/1/12
32	ERECT TRUSS 3 - PICK 2	1 day	Wed 8/1/12	Wed 8/1/12
33	BUILD-UP TRUSS 3 - PICK 3	1 day	Thu 8/2/12	Thu 8/2/12
34	ERECT TRUSS 3 - PICK 3	1 day	Thu 8/2/12	Thu 8/2/12
35	ERECT BRACING T3-T2	8 days	Fri 8/3/12	Tue 8/14/12
36	STRUCTURAL STEEL NORTHEAST ENTER CANOPY	5 days	Fri 8/3/12	Thu 8/9/12
37	STRUCTURAL STEEL EAST 1 ROOF	5 days	Tue 8/7/12	Mon 8/13/12
38	BUILD-UP TRUSS 4 - PICK 1	1 day	Tue 8/14/12	Tue 8/14/12
39	BUILD-UP TRUSS 4 - PICK 2	1 day	Tue 8/14/12	Tue 8/14/12
40	SHORING TOWER TRUSS 4	41 days	Tue 8/14/12	Wed 10/10/12
41	ERECT TRUSS 4 - PICK 1	1 day	Wed 8/15/12	Wed 8/15/12
42	ERECT TRUSS 4 - PICK 2	1 day	Wed 8/15/12	Wed 8/15/12
43	BUILD-UP TRUSS 4 - PICK 3	1 day	Thu 8/16/12	Thu 8/16/12
44	ERECT TRUSS 4 - PICK 3	1 day	Thu 8/16/12	Thu 8/16/12
45	ERECT BRACING T4-T3	8 days	Fri 8/17/12	Tue 8/28/12
46	STRUCTURAL STEEL EAST 2 ROOF	6 days	Fri 8/17/12	Fri 8/24/12
47	BUILD-UP TRUSS 5 - PICK 1	1 day	Tue 8/28/12	Tue 8/28/12
48	BUILD-UP TRUSS 5 - PICK 2	1 day	Tue 8/28/12	Tue 8/28/12
49	SHORING TOWER TRUSS 5	41 days	Tue 8/28/12	Wed 10/24/12
50	ERECT TRUSS 5 - PICK 1	1 day	Wed 8/29/12	Wed 8/29/12
51	ERECT TRUSS 5 - PICK 2	1 day	Wed 8/29/12	Wed 8/29/12
52	BUILD-UP TRUSS 5 - PICK 3	1 day	Thu 8/30/12	Thu 8/30/12
53	ERECT TRUSS 5 - PICK 3	1 day	Thu 8/30/12	Thu 8/30/12
54	ERECT BRACING T5-T4	8 days	Fri 8/31/12	Wed 9/12/12
55	STADIA STEEL EAST 1-2	3 days	Fri 8/31/12	Wed 9/5/12
56	STADIA STEEL SOUTH 1 & NORTH 1	3 days	Thu 9/6/12	Mon 9/10/12
57	BUILD-UP TRUSS 6 - PICK 1	1 day	Wed 9/12/12	Wed 9/12/12
58	BUILD-UP TRUSS 6 - PICK 2	1 day	Wed 9/12/12	Wed 9/12/12
59	SHORING TOWER TRUSS 6	31 days	Wed 9/12/12	Wed 10/24/12
60	ERECT TRUSS 6 - PICK 1	1 day	Thu 9/13/12	Thu 9/13/12
61	ERECT TRUSS 6 - PICK 2	1 day	Thu 9/13/12	Thu 9/13/12
62	BUILD-UP TRUSS 6 - PICK 3	1 day	Fri 9/14/12	Fri 9/14/12
63	ERECT TRUSS 6 - PICK 3	1 day	Fri 9/14/12	Fri 9/14/12
64	ERECT BRACING T6-T5	8 days	Mon 9/17/12	Wed 9/26/12
65	PRECAST STADIA MAIN ARENA - GEN PUBLIC/CLUB	53 days	Mon 9/17/12	Thu 11/29/12
66	BUILD-UP TRUSS 7 - PICK 1	1 day	Wed 9/26/12	Wed 9/26/12
67	BUILD-UP TRUSS 7 - PICK 2	1 day	Wed 9/26/12	Wed 9/26/12
68	SHORING TOWER TRUSS 7	21 days	Wed 9/26/12	Wed 10/24/12
69	ERECT TRUSS 7 - PICK 1	1 day	Thu 9/27/12	Thu 9/27/12
70	ERECT TRUSS 7 - PICK 2	1 day	Thu 9/27/12	Thu 9/27/12
71	BUILD-UP TRUSS 7 - PICK 3	1 day	Fri 9/28/12	Fri 9/28/12
72	ERECT TRUSS 7 - PICK 3	1 day	Fri 9/28/12	Fri 9/28/12
73	ERECT BRACING T7-T6	8 days	Mon 10/1/12	Wed 10/10/12
74	BUILD-UP TRUSS 8 - PICK 1	1 day	Wed 10/10/12	Wed 10/10/12
75	BUILD-UP TRUSS 8 - PICK 2	1 day	Wed 10/10/12	Wed 10/10/12
76	SHORING TOWER TRUSS 8	11 days	Wed 10/10/12	Wed 10/24/12
77	ERECT TRUSS 8 - PICK 1	1 day	Thu 10/11/12	Thu 10/11/12
78	ERECT TRUSS 8 - PICK 2	1 day	Thu 10/11/12	Thu 10/11/12
79	BUILD-UP TRUSS 8 - PICK 3	1 day	Fri 10/12/12	Fri 10/12/12
80	ERECT TRUSS 8 - PICK 3	1 day	Fri 10/12/12	Fri 10/12/12
81	ERECT BRACING T8-T7	8 days	Mon 10/15/12	Wed 10/24/12
82	STADIA STEEL SOUTH 2-3	2 days	Thu 10/25/12	Fri 10/26/12
83	STADIA STEEL NORTH 2-3	2 days	Fri 10/26/12	Mon 10/29/12
84	STRUCTURAL STEEL WEST 1	10 days	Wed 11/14/12	Wed 11/28/12
85	STRUCTURAL STEEL WEST 2	10 days	Mon 11/19/12	Mon 12/3/12
86	PRECAST STADIA MAIN ARENA - STUDENT/LOGE	9 days	Thu 11/29/12	Tue 12/11/12
87	PRECAST STADIA AUXILIARY RINK	4 days	Tue 12/4/12	Fri 12/7/12
88	FOUNDATIONS SOUTH AUX RINK	9 days	Mon 12/10/12	Thu 12/20/12
89	STRUCTURAL AUXILIARY RINK ROOF	9 days	Wed 12/12/12	Mon 12/24/12
90	STRUCTURAL AUXILIARY RINK SOUTH	2 days	Fri 12/21/12	Mon 12/24/12

Table 88: Steel & Truss Erection Short Interval Project Schedule (SIPS)



APPENDIX J: Ice Generation System Research

Improving Efficiency in Ice Hockey Arenas



Improving Efficiency In Ice Hockey Arenas

By Laurier Nichols, P.E., Fellow ASHRAE

Municipal arenas in Canada are built mainly for hockey, but they also house other activities and special events. In most small municipalities, arenas are the public buildings that have the highest annual energy use and consumption.

Approximately 450 arenas operate throughout the province of Quebec. A general survey[1] of several arenas similar in size shows that for a standard ice arena, the energy use is 1,500,000 kWh/year. The most energy-efficient arenas use approximately 800,000 kWh/year, while less efficient ones consume nearly three times that much energy at 2,400,000 kWh/year.

To better understand the energy use of an arena, we must define what is meant by standard arena. For the purpose of this article, an arena is used for eight months per year with activities beginning in August (for hockey training) and generally ending in April. The main space is the amphitheatre with the ice sheet.

The average amphitheatre is 24,000 ft^2 (2230 m^2) (including stands for 500 people) with the ice sheet covering 16,327 ft^2 (1517 m^2) (standardized 85 ft × 200 ft [26 m × 61 m] National Hockey League ice rink). Other spaces consist of locker rooms, 2,800 ft^2 (260 m^2); mechanical and electrical rooms, 600 ft^2 (56 m^2); ice resurfacer machine room, 300 ft^2 (28 m^2); offices and meeting rooms, 2,500 ft^2 (232 m^2); canteen and kitchen area, 1,500 ft^2 (139 m^2); main entrance hall, 1,500 ft^2 (139 m^2); and service rooms 800 ft^2 (74 m^2). Overall, the total building area is approximately 34,000 ft^2 (3159 m^2).

Typically, arenas are used 18 hours per day on weekends and 12 hours per day during weekdays. A standard arena is

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used approximately 100 hours per week. The ice is resurfaced approximately 65 times per week.

The lighting of a nonefficient amphitheatre uses approximately 32 kW for most ice activities. Most of the lighting fixtures are installed above the ice rink (1.9 W/ft^2 [20.5 W/m^2]) and lower density lighting fixtures are installed above the stands (0.7 W/ft^2 [7.5 W/m^2]). Elsewhere in the building, the average lighting power is approximately (2 W/ft^2 [21.5 W/m^2]) for a total of 15 kW. Exterior lighting could amount to 2 kW.

The ventilation requirements of the amphitheater are approximately 10,000 cfm (4719 L/s), but the author's observations show that ventilation is not continuously used. Ventilation of an amphitheater is used for 15 minutes after each ice resurfacing to evacuate the pollution created by the propane gas combustion of the ice resurfacing machine. Several arenas use pollution detectors to monitor the ventilation use, which explains why the ventilation is not in continuous operation. Other ventilation systems with a total of fresh air of 7,000 cfm (3304 L/s) are used for the other spaces.

The refrigeration load of a standard arena, operating for eight months, is 70 tons (246 kW) of cooling using an average 110 hp (82 kW) for the refrigeration compressors. The brine pump (850 gpm [54 L/s]) generally uses a 25 hp (19 kW) motor. The refrigeration equipment is in use throughout the eight months of operation.

Typical municipal ice arenas consume 1500 MWh/year.

Heating is provided either by natural gas, propane gas, oil or electricity. In the province of Quebec, several arenas are heated with electricity, but most arenas use a dual source of energy (either gas and electricity or oil and electricity). Stands are heated in most municipal arenas. When heated, the stands are frequently kept to a comfort level with radiant gas units.

As an exercise for evaluating the energy savings measures, let's assume that we have a nonefficient arena with an annual energy use of 1,950,000 kWh. The total energy consumption could be divided into the following uses as shown in *Figure 1*.

Several energy-saving measures could be implemented in an existing building such as this one or when planning a new building.

Heat Recovery on Exhaust

In northern regions, the first energy saving measure to implement is usually the heat recovery of energy leaving the building in the exhausted air. This can be used for preheating the outside air being introduced for ventilation. This measure has a significant impact on the whole energy balance of the building. For instance, in this typical building, the energy savings with the use of a thermal wheel at 75% efficiency could reach 250,000 kWh. This savings will appear on the heating usage.

Subfloor Heating Using Heat Recovery

When an arena is used for more than seven months, it is important to eliminate the possibility of freezing the subsoil. In fact, the concrete slab under ice rinks had to be replaced in several arenas because of damages created by the formation of frost in the soil under the floor. To eliminate this problem, 4 in. (102 mm) of polystyrene insulation is installed under the concrete slab of the ice rink. Heating must be provided in the soil under the insulation to prevent freezing. The average heating requirement amounts to 20,500 Btu/h to 27,300 Btu/h (6 kW to 8 kW). It is used for the full eight months of operation. The heating of the subfloor could be provided by the heat rejection of the condenser of the refrigeration equipment.

As this is a low-temperature requirement, it could be provided at a condensing temperature that could be limited at 70°F (21°C) during winter months. The potential savings is equal to the total heat requirement of 35,000 kWh.

DHW and Surfacing Water Requirement

Domestic hot water and water used by the ice resurfacer require a higher temperature. The refrigeration gas superheat available at the outlet of the compressor offers an excellent opportunity for the heating of DHW. The problem with DHW and ice surfacing water is the wide variation of daily demand. Therefore, water storage is required. Successful preheating of domestic water is achieved with a 2,000 gallon (7571 L) water storage tank (often two tanks of 1,000 gallons (3785 L) each). With this amount of storage, it often happens that in the morning after heat recovery of the gas superheat, the 2,000 gallons (7571 L) may be at 170°F (77°C), ready for the daily operation. Monitoring of energy savings in some arenas show that the full DHW and surfacing water requirement could be provided with heat recovery on the gas superheat. The annual savings could amount to 130,000 kWh.

Brine Pump

Several tests were conducted in the Montreal area by modifying the distribution of the brine in the floor slab under the ice. The modified distribution used a four-pass arrangement instead of the conventional two-pass arrangement. This modification had a major impact on the energy use of the brine pump. It cut the energy requirement by 50%. Tests conducted showed the ice quality was the same and that no noticeable change in the activities carried out on the ice was reported during the test period. It was once reported that the four-pass distribution was better than the two-pass distribution. This specific comment was for a central refrigeration plant for two ice sheets,

one being with the four-pass distribution and the other with the two-pass distribution. Because of a faulty installation (too much concrete over the plastic pipes), the operator had to lower the brine temperature when starting the two-pass ice sheet. The ice quality was good for the four-pass ice sheet with a higher temperature at 4°F (–16°C).

The thickness of concrete over the plastic pipes and the thickness of the ice over the slab have a major impact on the performance of heat exchanges. It is important that the concrete slab be leveled from within so that the ice thickness is limited to 1 in. (25 mm). The thickness of concrete over the plastic pipes should also be limited to 1 in. (25 mm). A 4 in. (102 mm) thickness of concrete means that the brine temperature must be lowered by 10°F (5.5°C).

Some questions remain on the brine velocity in the pipes. Should the brine flow be in the turbulent mode? Often, the heat transferred from the brine to the ice is low. A standard arena uses 53,000 ft (16 154 m) of plastic polyethylene pipes for the heat transfer with the ice. If we assume 70 tons (246 kW) for the refrigeration, it means that the heat transfer amounts to 16 Btu/ft (15 W/m) of pipe. This means that a brine flow in the laminar mode would have less impact on the heat transfer. The resistive film created by a laminar flow has more impact in a heat exchanger where the heat transfer is 1,000 Btu/ft (961 W/m) of pipe.

The four-pass arrangement generates an energy savings of 70,000 kWh on the pump's energy requirements and 20,000 kWh on the refrigeration equipment (lower heat generated by the brine pump). This represents annual savings of $6,000 for an arena in the Montreal area.

Heat Recovery for Heating

The refrigeration equipment of an arena could also act as a heat pump. All heat removed from the ice could be used for heating spaces and the outside air for ventilation purposes. Although heat is recovered from the exhaust, residual heating is still required for ventilation. It is easy to use rejected heat from the refrigeration equipment as it does not require high condensation temperature. Moreover, the heat recovery does not negatively impact on the performance of the refrigeration compressors.

Heat recovery condensers could be used for heating of space. Heating equipment would have to be selected for operation at low temperatures, so it does not require high condensation temperature (more than 100°F [38°C]).

When full heat recovery is achieved on the refrigeration equipment, almost all space heating, as well as ventilation heating, could be provided. This would represent annual savings of 475,000 kWh.

Low-e Ceiling

The refrigeration load of an ice arena is a complex mix of radiation and convection. Studies show that the radiation has a major impact on the refrigeration load. It is possible to lower the radiation exchange between the ice sheet and the ceiling with the use of a low-e ceiling by installing a high reflection (low-e) aluminized plastic sheet under the structural trusses of the ceiling. This addition will lower the radiation exchange with the ceiling, but it will increase the radiation exchange from the perimeter stands because of the higher reflection. An ASHRAE research project is currently under way to help understand the radiation exchange process that occurs in an arena. Monitoring of the addition of a low-e ceiling shows a 15% savings on the refrigeration equipment, which translates into annual savings of 67,500 kWh.

Figure 1: Inefficient arena (1,950,000 kWh).

Efficient Lighting System

Improvement in the lighting efficiency could be used to lower the energy use of an arena. Lighting fixtures have a large proportion of radiation components and, when installed over the ice sheet they generate a refrigeration load. Creative lighting systems could be used for arenas. Some experiences with T-5 or T-8 fluorescent lighting systems were successful as they create the possibility to modulate the lighting level according to the activities taking place on the ice. Lighting level can be adapted to the type of activity. It is easy to understand that a child below 10 years old won't shoot the puck at 100 mph (45 m/s) as a professional hockey player would. A high lighting level is not always needed. Efficient lighting level could generate annual savings of more than 50,000 kWh per year.

Efficient Refrigeration Equipment

Several energy-efficiency measures could be implemented on the refrigeration equipment such as: modulation of the condensing pressure, liquid subcooling, electronic expansion valves, flooded-type evaporator, variable frequency drive on compressor, thermal storage, etc. Simulation of the operation of the refrigeration equipment is the best tool to evaluate the advantages of its improvement. Lowering the energy requirement of the refrigeration equipment is often not possible when heat recovery is required for heating at a higher condensing pressure. Liquid subcooling is required with an alternative refrigerant such as R-410 or R-507. Lowering the condensing pressure will improve the refrigeration cycle, but a higher condensing pressure should be used if heat recovery is required.

It is always better to extract heat from the refrigeration equipment when heat is required than trying to improve the refrigeration cycle itself. Improving energy efficiency of an existing arena was achieved without lowering the condensing pressure.

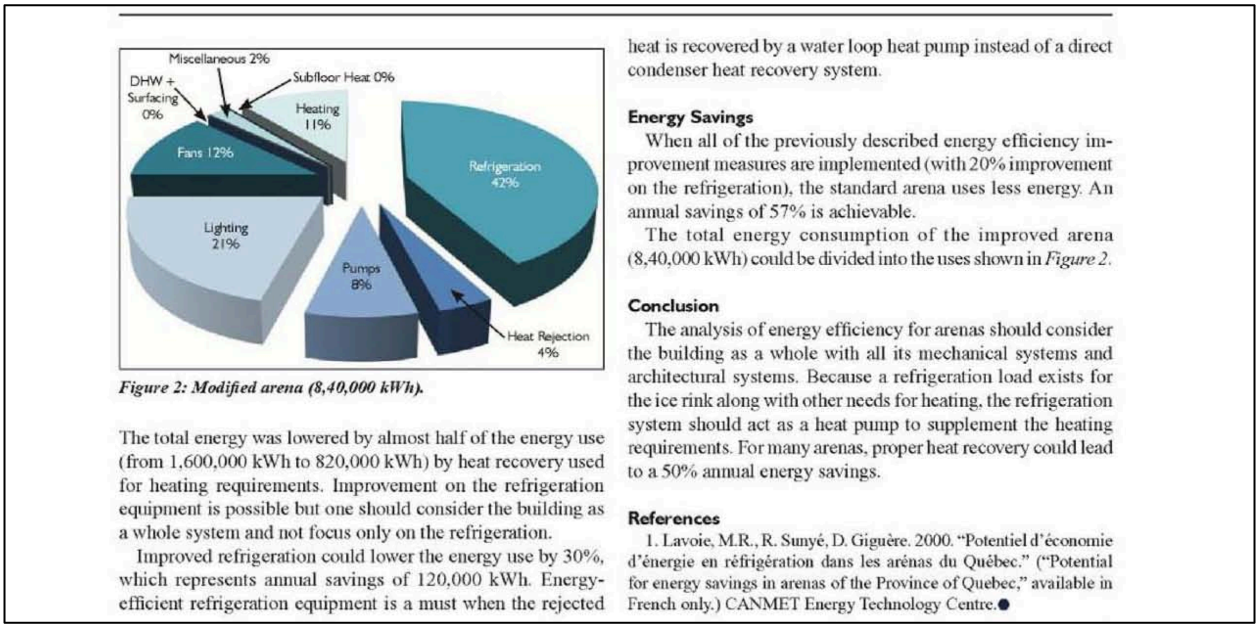

Figure 2: Modified arena (8,40,000 kWh).

The total energy was lowered by almost half of the energy use (from 1,600,000 kWh to 820,000 kWh) by heat recovery used for heating requirements. Improvement on the refrigeration equipment is possible but one should consider the building as a whole system and not focus only on the refrigeration.

Improved refrigeration could lower the energy use by 30%, which represents annual savings of 120,000 kWh. Energy-efficient refrigeration equipment is a must when the rejected heat is recovered by a water loop heat pump instead of a direct condenser heat recovery system.

Energy Savings

When all of the previously described energy efficiency improvement measures are implemented (with 20% improvement on the refrigeration), the standard arena uses less energy. An annual savings of 57% is achievable.

The total energy consumption of the improved arena (8,40,000 kWh) could be divided into the uses shown in *Figure 2*.

Conclusion

The analysis of energy efficiency for arenas should consider the building as a whole with all its mechanical systems and architectural systems. Because a refrigeration load exists for the ice rink along with other needs for heating, the refrigeration system should act as a heat pump to supplement the heating requirements. For many arenas, proper heat recovery could lead to a 50% annual energy savings.

References

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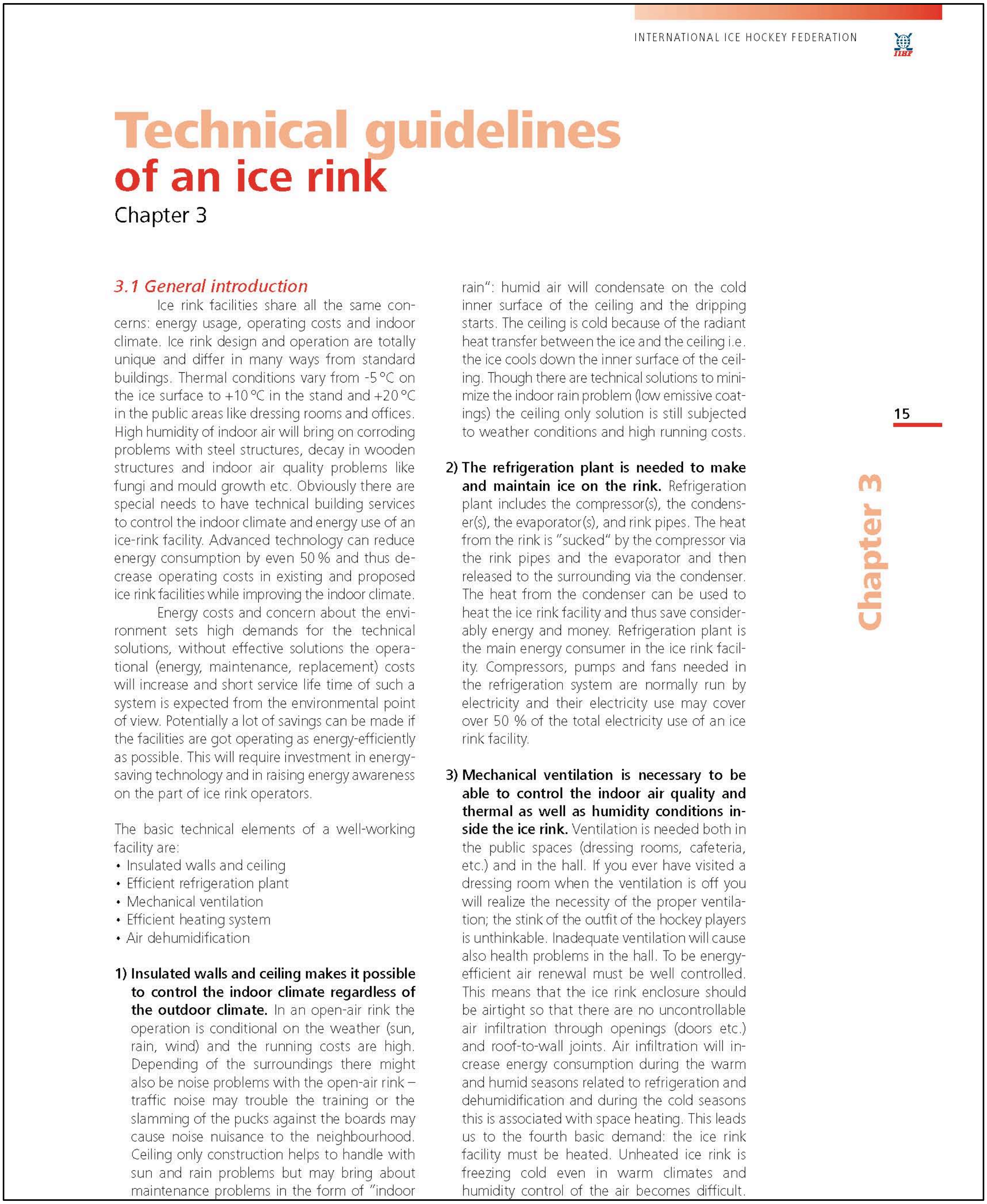
Technical Guidelines of an Ice Rink



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Technical guidelines of an ice rink

Chapter 3

3.1 General introduction

Ice rink facilities share all the same concerns: energy usage, operating costs and indoor climate. Ice rink design and operation are totally unique and differ in many ways from standard buildings. Thermal conditions vary from -5 °C on the ice surface to +10 °C in the stand and +20 °C in the public areas like dressing rooms and offices. High humidity of indoor air will bring on corroding problems with steel structures, decay in wooden structures and indoor air quality problems like fungi and mould growth etc. Obviously there are special needs to have technical building services to control the indoor climate and energy use of an ice-rink facility. Advanced technology can reduce energy consumption by even 50 % and thus decrease operating costs in existing and proposed ice rink facilities while improving the indoor climate.

Energy costs and concern about the environment sets high demands for the technical solutions, without effective solutions the operational (energy, maintenance, replacement) costs will increase and short service life time of such a system is expected from the environmental point of view. Potentially a lot of savings can be made if the facilities are got operating as energy-efficiently as possible. This will require investment in energy-saving technology and in raising energy awareness on the part of ice rink operators.

The basic technical elements of a well-working facility are:

- Insulated walls and ceiling
- Efficient refrigeration plant
- Mechanical ventilation
- Efficient heating system
- Air dehumidification

1) **Insulated walls and ceiling makes it possible to control the indoor climate regardless of the outdoor climate.** In an open-air rink the operation is conditional on the weather (sun, rain, wind) and the running costs are high. Depending of the surroundings there might also be noise problems with the open-air rink – traffic noise may trouble the training or the slamming of the pucks against the boards may cause noise nuisance to the neighbourhood. Ceiling only construction helps to handle with sun and rain problems but may bring about maintenance problems in the form of ”indoor rain”: humid air will condensate on the cold inner surface of the ceiling and the dripping starts. The ceiling is cold because of the radiant heat transfer between the ice and the ceiling i.e. the ice cools down the inner surface of the ceiling. Though there are technical solutions to minimize the indoor rain problem (low emissive coatings) the ceiling only solution is still subjected to weather conditions and high running costs.

2) **The refrigeration plant is needed to make and maintain ice on the rink.** Refrigeration plant includes the compressor(s), the condenser(s), the evaporator(s), and rink pipes. The heat from the rink is ”sucked” by the compressor via the rink pipes and the evaporator and then released to the surrounding via the condenser. The heat from the condenser can be used to heat the ice rink facility and thus save considerably energy and money. Refrigeration plant is the main energy consumer in the ice rink facility. Compressors, pumps and fans needed in the refrigeration system are normally run by electricity and their electricity use may cover over 50 % of the total electricity use of an ice rink facility.

3) **Mechanical ventilation is necessary to be able to control the indoor air quality and thermal as well as humidity conditions inside the ice rink.** Ventilation is needed both in the public spaces (dressing rooms, cafeteria, etc.) and in the hall. If you ever have visited a dressing room when the ventilation is off you will realize the necessity of the proper ventilation; the stink of the outfit of the hockey players is unthinkable. Inadequate ventilation will cause also health problems in the hall. To be energy-efficient air renewal must be well controlled. This means that the ice rink enclosure should be airtight so that there are no uncontrollable air infiltration through openings (doors etc.) and roof-to-wall joints. Air infiltration will increase energy consumption during the warm and humid seasons related to refrigeration and dehumidification and during the cold seasons this is associated with space heating. This leads us to the fourth basic demand: the ice rink facility must be heated. Unheated ice rink is freezing cold even in warm climates and humidity control of the air becomes difficult.

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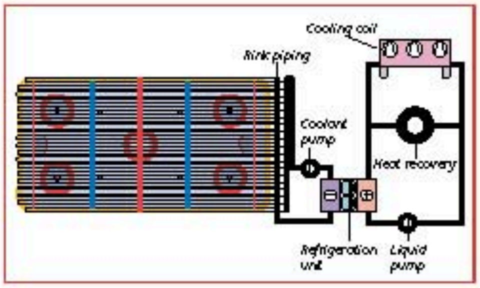


Figure 1. Refrigeration plant, indirect cooling system.

4) Ventilation offers also a means to heat the ice rink. Heating the ice rink with air necessitates the use of re-circulated air and that the ventilation unit is equipped with heating coil(s). Remarkable energy-savings can be achieved when using waste heat of the refrigeration process to warm up the air.

5) The dehumidification plant is needed in well-working facility to dry the rink air. Excess moisture in indoor air will cause corrosion of metal structures, rotting of wooden structures, fungi and mould growth, increased energy consumption and ice quality problems.

Energy consumption is in the key role when speaking of the life cycle costs and above all the environmental load of the facility during its life cycle. The key to the effective utilization of the energy resources in new as well as in retrofit and refurbishment projects is in the consciousness of the energy-sinks and the various parameters affecting the energy consumption.

The construction, plant system and operation define the energy consumption of an ice rink. The construction characteristics are the heat and moisture transfer properties of the roof and walls, as well as air infiltration through cracks and openings in the building envelope. The structure of the floor is also important from the energy point of view. Plant characteristics include the refrigeration, ventilation, dehumidification, heating, lighting and ice maintenance systems. The operational characteristics are the length of the skating season, air temperature and humidity, ice temperature, supply air temperature and fresh air intake of the air-handling unit as well as the control- and adjustment parameters of the appliances. Figure 3 shows the energy spectrums of typical training rinks and figure 4 illustrates the energy flows of a typical small ice rink.

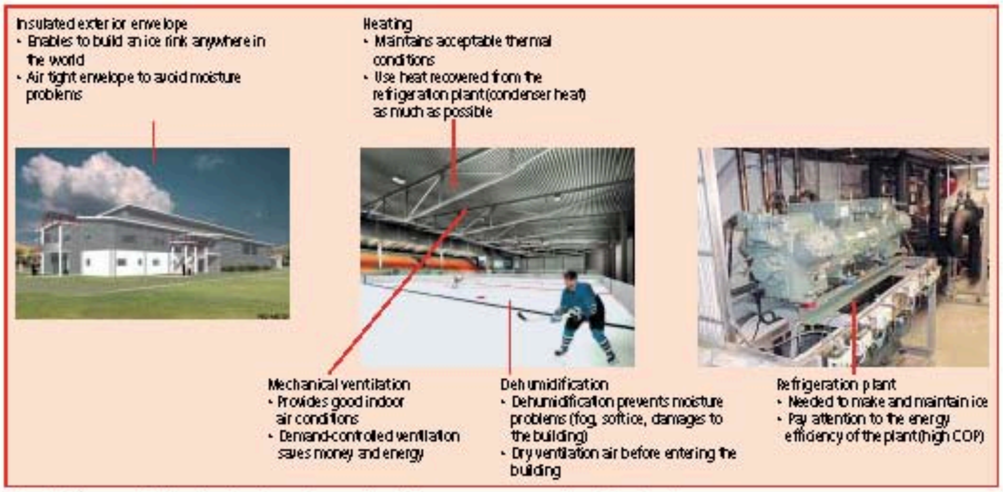
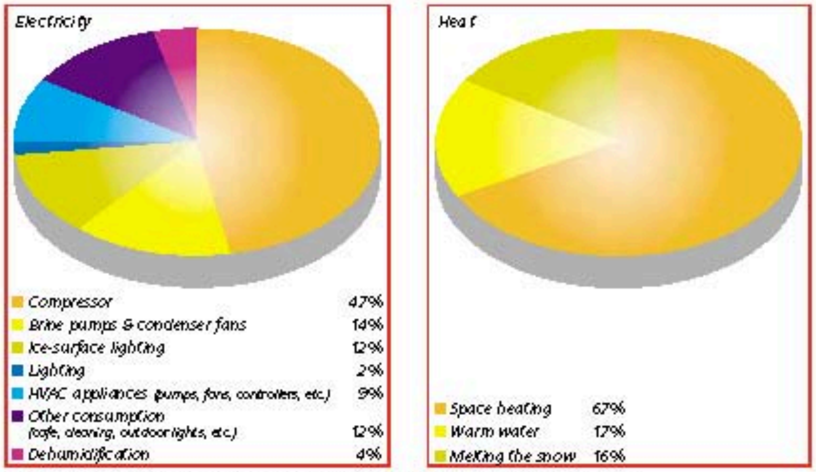


Figure 2. The construction, plant system and operation define energy consumption of an ice rink.



Compressor	47%
Brine pumps & condenser fans	14%
Ice-surface lighting	12%
Lighting	2%
HVAC appliances (pumps, fans, controllers, etc.)	9%
Other consumption (cafe, cleaning, outdoor lights, etc.)	12%
Dehumidification	4%

Space heating	67%
Warm water	17%
Making the snow	16%

Figure 3. Main electricity and heat consumption components of a typical training facility.

In an ideal situation the heating demand of the ice rink is totally covered with recovered heat from the refrigeration process. In practice extra heat is still needed to cover the needs of hot tap water and heating peaks. Moreover a backup heating system is needed to meet the heating demands when the compressors are not running for example during dry floor events (concerts, shows, meetings, etc.).

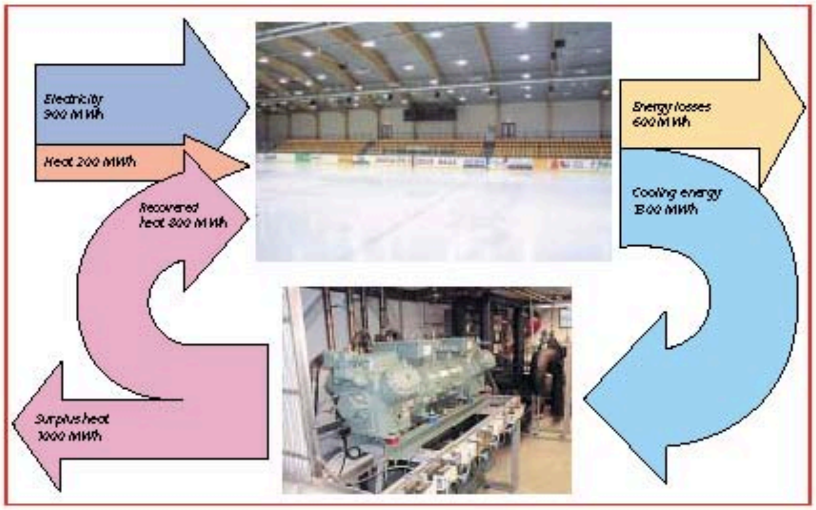


Figure 4. While producing cold, the "ice plant" provides heat that can be utilized in space heating and hot water production. Still there is a great deal of extra heat that could be made good use of for example in a nearby indoor swimming pool.

Layout

Four of the six dressing rooms with showers are under the seat along the long side of the hall and the other two dressing rooms at the end of the hall. On top of these two dressing rooms there are office rooms, lecture room, cafeteria, TV stand and air conditioner. Technical room (refrigeration unit) is placed in a separate container outside of the rink.

Structures

The mast-supported grid constructure of the rink is made of glue laminated timber. The roofing and the walls are made of polyurethane elements. To improve the energy efficiency of the rink the air tight polyurethane elements are equipped with low emissivity coating laminated on the indoor surface of the elements. The elements have also acoustic dressing which improves the acoustic atmosphere of the rink. The facades are made of profiled metal sheets.

In this manual we will concentrate on a structural system of a grid supported by columns and the materials for this structural system can be divided into four main categories:

- Steel structures
- Wood structures
- Reinforced concrete structures
- Mix material structures of steel, wood and/or concrete

3.4.1 Structural system as used in the IIHF prototype

The roof structure consists of steel trusses supported each by two concrete columns. At support points the bottom boom of the truss bears on an elastomeric bearing pad bolted to the supporting concrete column. The whole roof structure of steel (see roofing 3.3.2) is floating on top of the concrete framework. The concrete columns are mounted ridged to the concrete foundations.

Regarding to the region of the planned new ice rink, the horizontal loads of the roof structure, like snow are highly affecting when choosing the most economical structural system. If the snow loads are not remarkable, the steel trusses could easily cost efficiently be spanned over the spectator stand and the dashed board, using the span length like 40 to 45 meters and concrete column raster of 6 to 8 meters. A minimum free space between the ice surface and the bottom of steel trusses should be at least 6 meters.

In order to avoid serious problems with humidity, like corrosion etc. the mechanical and electrical plant must be equipped with a dehumidification system.

3.4.2 Envelope, roofing

The main function of an ice rink envelope is air tightness and not particularly thermal insulation. The envelope structure can be done most efficiently to fulfil only that one main characteristic.

Materials and structural system

Steel support	Wood support	Reinforced concrete	Mix material combinations
+ long span length + global availability + pre-fab system + cost	+ long span length + non corroding + pre-fab system + fire protection	+ global availability + non corroding + pre-fab system + fire protection	+ long span length + fire protection + pre-fab system + cost
- corroding - fire protection - maintenance	- global availability - cost - maintenance - decaying	- cost - beam span length - acoustic feature - flexibility in use	- corroding - decaying - cost - maintenance

Figure 5. Material features of main supporters.

If the idea of a modular system is found possible and reasonable, the best flexibility in use with either steel or wood frame structures. However through careful and skilled engineering the later changes of the supporting structure are also possible with all other materials and systems.

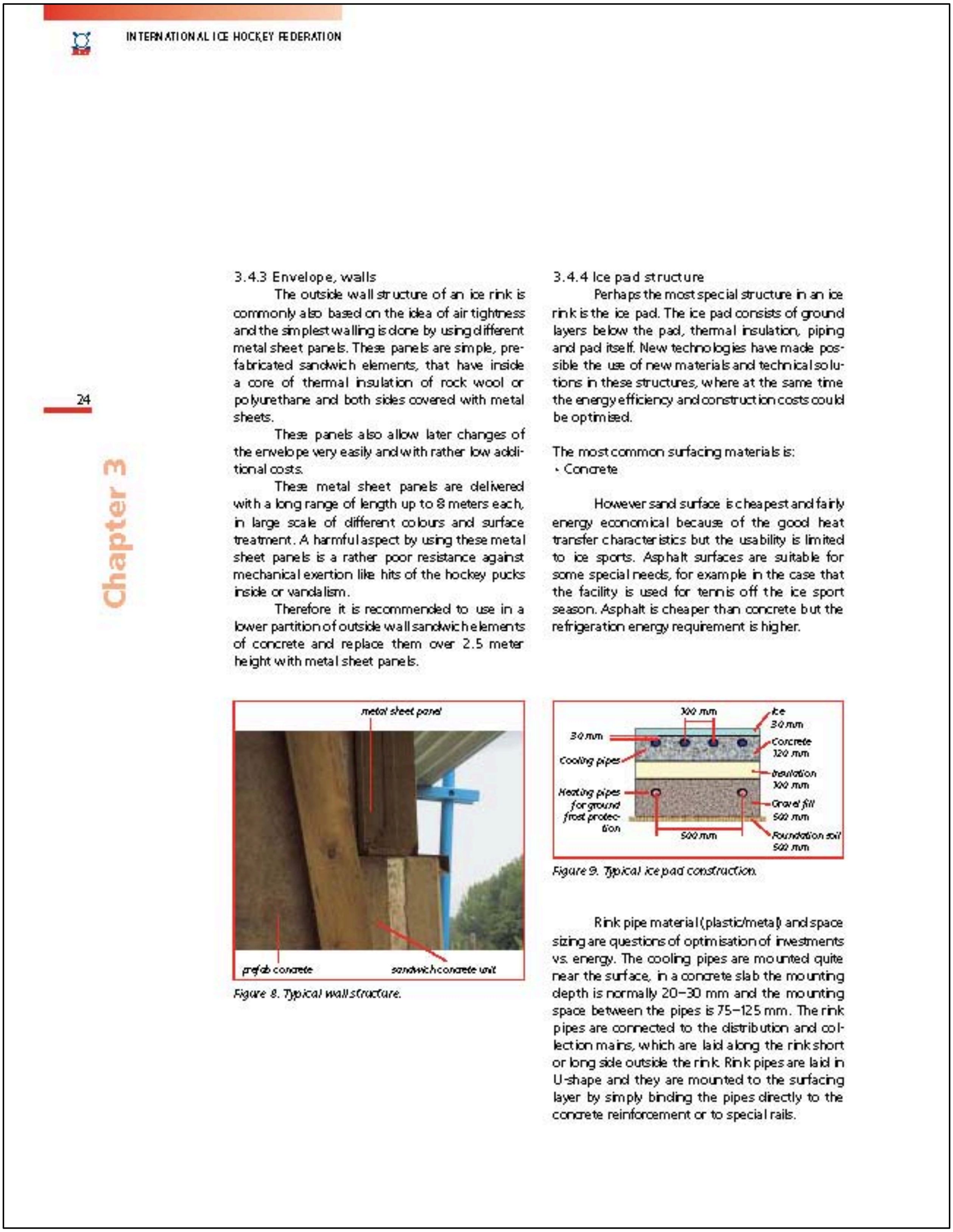
In the design phase all structural capabilities of the building for later enlargement should be defined in combination with the size of the plot, traffic situation and possible changes in the surrounding.

By becoming aware of the special features of an ice rink, there are several possibilities to optimise the ice rink construction costs that will also lower the later operational costs.

Most used roofing structures consist of following layers:

- Profiled, load bearing steels sheets
- Vapour barrier
- Thermal insulation (10 cm to 15 cm rock wool)
- Water insulation

Figure 6. Typical roof structure.



3.4.3 Envelope, walls

The outside wall structure of an ice rink is commonly also based on the idea of air tightness and the simplest walling is done by using different metal sheet panels. These panels are simple, prefabricated sandwich elements, that have inside a core of thermal insulation of rock wool or polyurethane and both sides covered with metal sheets.

These panels also allow later changes of the envelope very easily and with rather low additional costs.

These metal sheet panels are delivered with a long range of length up to 8 meters each, in large scale of different colours and surface treatment. A harmful aspect by using these metal sheet panels is a rather poor resistance against mechanical exertion like hits of the hockey pucks inside or vandalism.

Therefore it is recommended to use in a lower partition of outside wall sandwich elements of concrete and replace them over 2.5 meter height with metal sheet panels.

Figure 8. Typical wall structure.

3.4.4 Ice pad structure

Perhaps the most special structure in an ice rink is the ice pad. The ice pad consists of ground layers below the pad, thermal insulation, piping and pad itself. New technologies have made possible the use of new materials and technical solutions in these structures, where at the same time the energy efficiency and construction costs could be optimised.

The most common surfacing materials is:
- Concrete

However sand surface is cheapest and fairly energy economical because of the good heat transfer characteristics but the usability is limited to ice sports. Asphalt surfaces are suitable for some special needs, for example in the case that the facility is used for tennis off the ice sport season. Asphalt is cheaper than concrete but the refrigeration energy requirement is higher.

Figure 9. Typical ice pad construction.

Rink pipe material (plastic/metal) and space sizing are questions of optimisation of investments vs. energy. The cooling pipes are mounted quite near the surface, in a concrete slab the mounting depth is normally 20–30 mm and the mounting space between the pipes is 75–125 mm. The rink pipes are connected to the distribution and collection mains, which are laid along the rink short or long side outside the rink. Rink pipes are laid in U-shape and they are mounted to the surfacing layer by simply binding the pipes directly to the concrete reinforcement or to special rails.

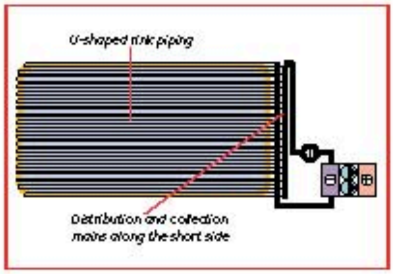


Figure 10. Collectors along the short side of the ice rink.

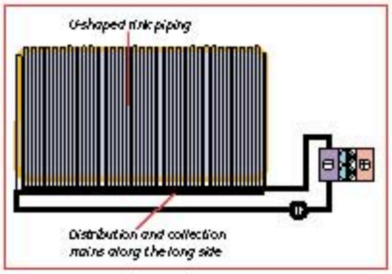


Figure 11. Collectors along the long side of the ice rink.

Figure 12. Plastic rink piping connections to the distribution and the collection mains (thermally insulated).

3.5 Mechanical and electrical plant

The effective utilization of the energy resources has become an important aspect in the design of new facilities. There are many different energy conservation measures that can be incorporated in the planning stage. In planning the hardware configuration and construction of an ice rink, it is important to consider the types of activities, special requirements and interest of the various user groups in question. Table 1 summarise the main indoor air design values, which can be used in designing technical building services. It is important to set these values already in the pre-design stage in order to control the demands.

3.5.1 Refrigeration plant

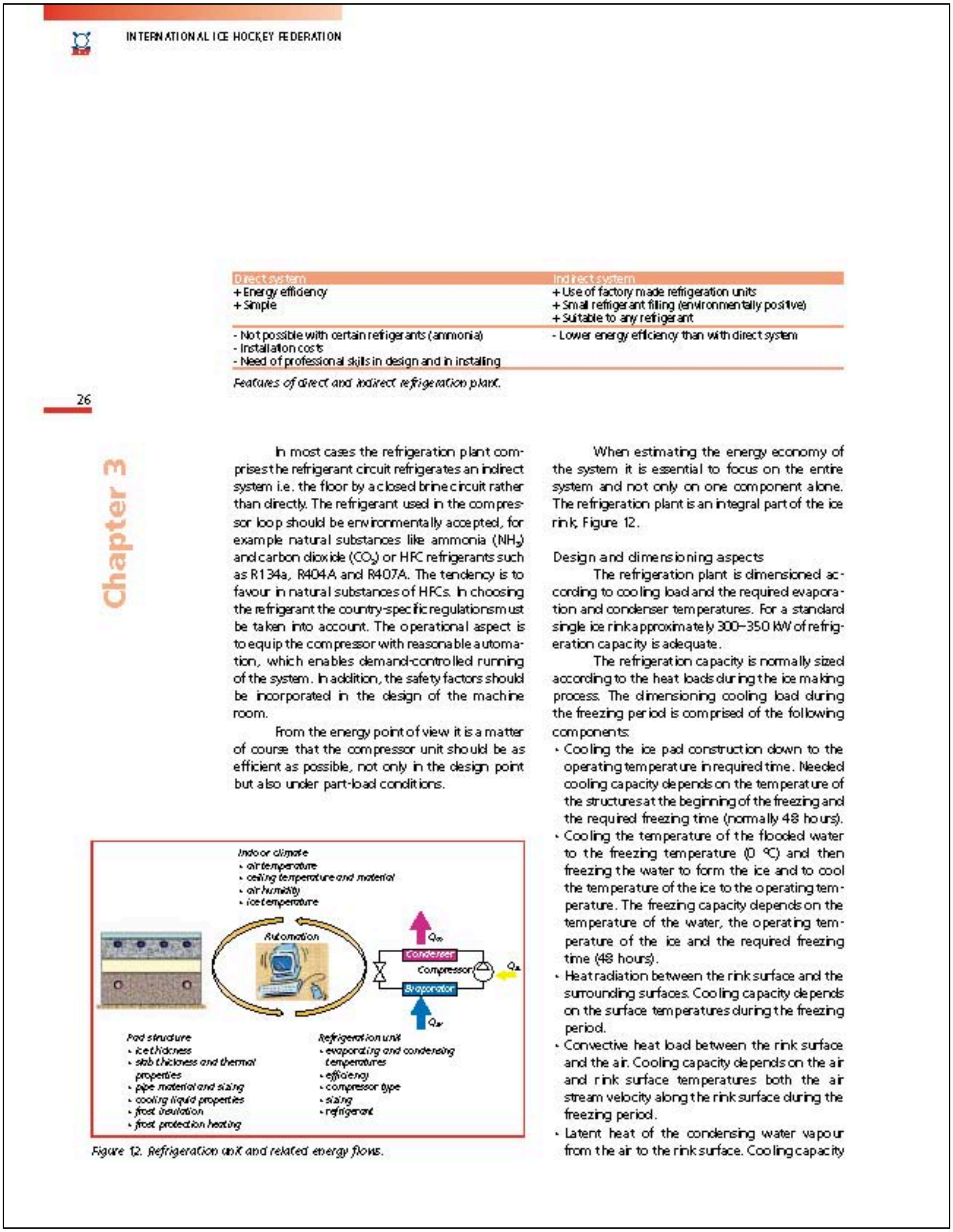
Refrigeration plant is fundamental to the ice-rink facility. Much used, but true, phrase is that the refrigeration unit is the heart of the ice rink. Almost all of the energy-flows are connected to the refrigeration process in one way or another. It is quite normal that the electricity consumption of the refrigeration system accounts for over 50 % of the total electricity consumption and the heat loss of the ice can be over 60 % of the total heating demand of an ice rink.

In the design stage, when choosing the refrigeration unit one has to consider the economics, energy usage, environment, operation, maintenance and safety.

The design of the refrigeration plant can be either so-called direct or indirect system. In a direct system the rink piping works as the evaporator, whereas an indirect system is comprised of separate evaporator (heat exchanger) and the ice pad is indirectly cooled by special coolant in closed circulation loop. The energy efficiency of the direct system is in general better than the efficiency of the indirect system. On the other hand the first cost of the direct system is higher than that of the indirect system. Moreover indirect systems can't be used with for example ammonia in several countries because of health risks in the case of refrigerant leaks. Table 2 summarises the advantages and disadvantages of the different systems.

Action	Air temperature of the rink space °C		Ice temperature, °C	Max. relative humidity of the rink space (%)	Min. fresh air intake l/s/occupant
	Rink (at 1.5 m height)	Tribune (operative)			
Hockey					
- game	+6	+10.+15	-5	70	4...8 / spectator
- training	+6	+6. +15	-3	70	12 / player
Figure					
- competition	+12	+10.+15	-4	70	4...8 / spectator
- training	+6	+6. +15	-3	70	12 / skater
Other	+18	+18	-	-	8 / person

Indoor air design values for small ice rink (rink space).



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Direct system	Indirect system
+ Energy efficiency + Simple	+ Use of factory made refrigeration units + Small refrigerant filling (environmentally positive) + Suitable to any refrigerant
- Not possible with certain refrigerants (ammonia) - Installation costs - Need of professional skills in design and in installing	- Lower energy efficiency than with direct system

Features of direct and indirect refrigeration plant.

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Chapter 3

In most cases the refrigeration plant comprises the refrigerant circuit refrigerates an indirect system i.e. the floor by a closed brine circuit rather than directly. The refrigerant used in the compressor loop should be environmentally accepted, for example natural substances like ammonia (NH_3) and carbon dioxide (CO_2) or HFC refrigerants such as R134a, R404A and R407A. The tendency is to favour in natural substances of HFCs. In choosing the refrigerant the country-specific regulations must be taken into account. The operational aspect is to equip the compressor with reasonable automation, which enables demand-controlled running of the system. In addition, the safety factors should be incorporated in the design of the machine room.

From the energy point of view it is a matter of course that the compressor unit should be as efficient as possible, not only in the design point but also under part-load conditions.

Figure 12. Refrigeration unit and related energy flows.

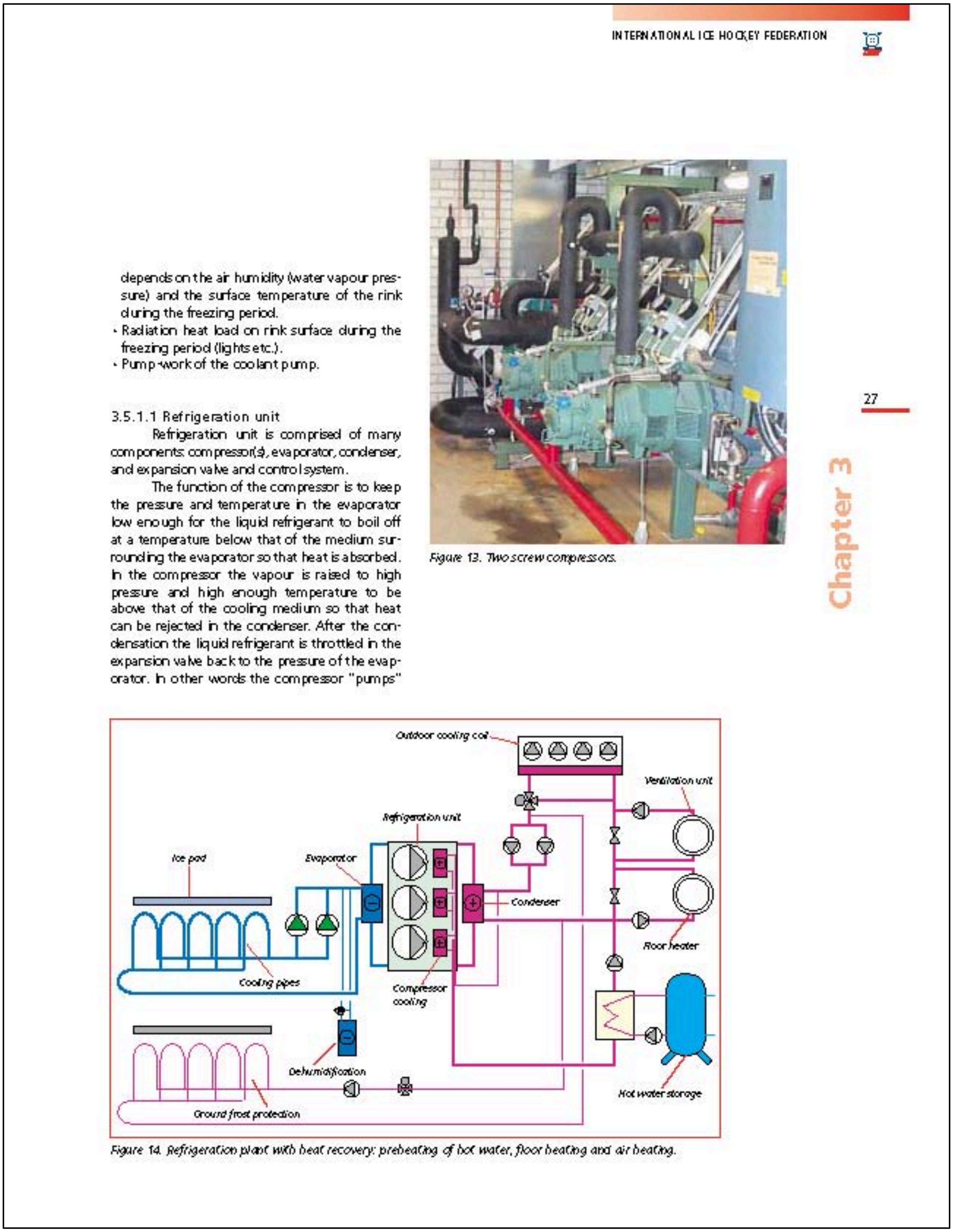
When estimating the energy economy of the system it is essential to focus on the entire system and not only on one component alone. The refrigeration plant is an integral part of the ice rink, Figure 12.

Design and dimensioning aspects

The refrigeration plant is dimensioned according to cooling load and the required evaporation and condenser temperatures. For a standard single ice rink approximately 300–350 kW of refrigeration capacity is adequate.

The refrigeration capacity is normally sized according to the heat loads during the ice making process. The dimensioning cooling load during the freezing period is comprised of the following components:

- Cooling the ice pad construction down to the operating temperature in required time. Needed cooling capacity depends on the temperature of the structures at the beginning of the freezing and the required freezing time (normally 48 hours).
- Cooling the temperature of the flooded water to the freezing temperature (0 °C) and then freezing the water to form the ice and to cool the temperature of the ice to the operating temperature. The freezing capacity depends on the temperature of the water, the operating temperature of the ice and the required freezing time (48 hours).
- Heat radiation between the rink surface and the surrounding surfaces. Cooling capacity depends on the surface temperatures during the freezing period.
- Convective heat load between the rink surface and the air. Cooling capacity depends on the air and rink surface temperatures both the air stream velocity along the rink surface during the freezing period.
- Latent heat of the condensing water vapour from the air to the rink surface. Cooling capacity



depends on the air humidity (water vapour pressure) and the surface temperature of the rink during the freezing period.

- Radiation heat load on rink surface during the freezing period (lights etc.).
- Pump-work of the coolant pump.

3.5.1.1 Refrigeration unit

Refrigeration unit is comprised of many components: compressor(s), evaporator, condenser, and expansion valve and control system.

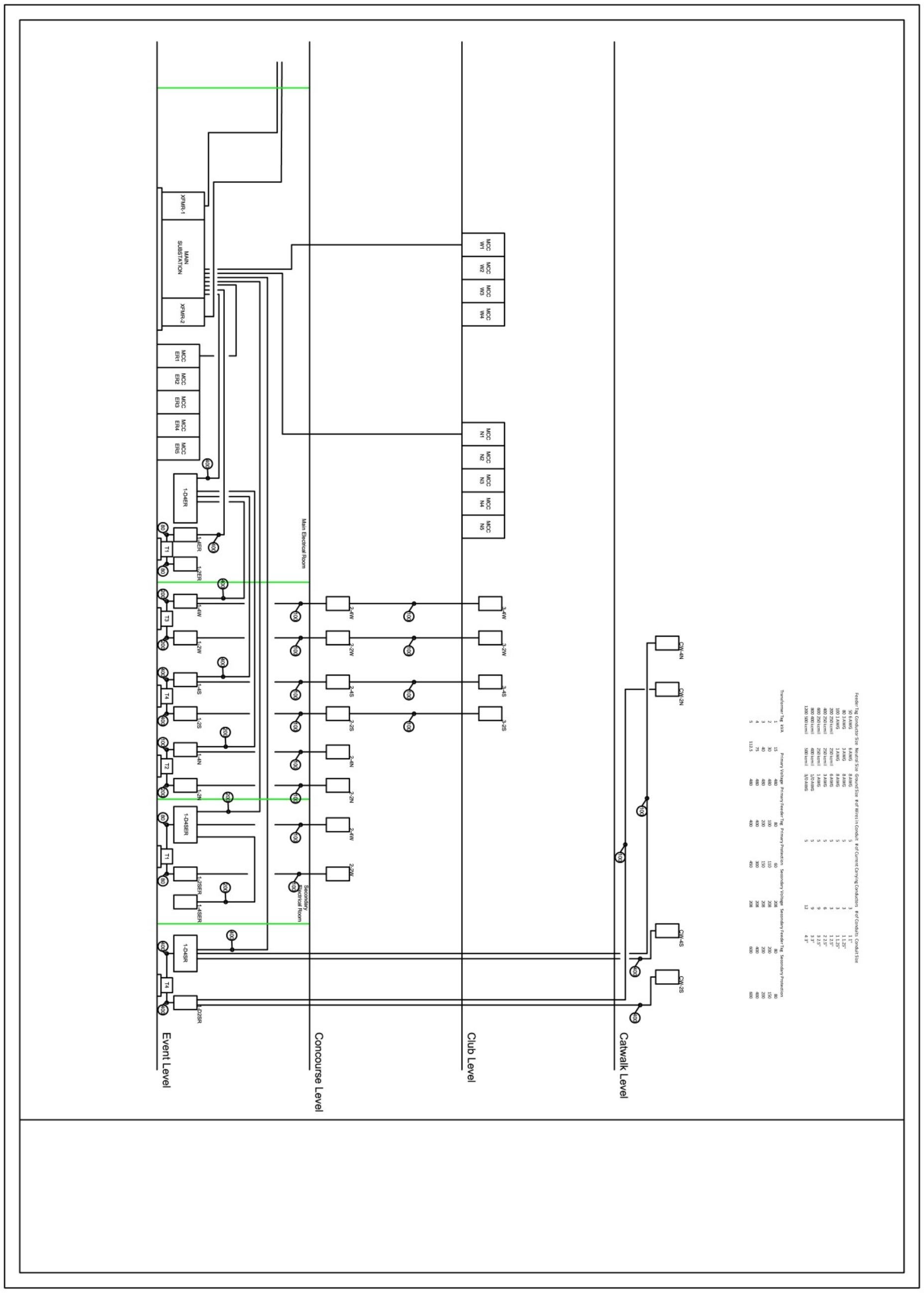
The function of the compressor is to keep the pressure and temperature in the evaporator low enough for the liquid refrigerant to boil off at a temperature below that of the medium surrounding the evaporator so that heat is absorbed. In the compressor the vapour is raised to high pressure and high enough temperature to be above that of the cooling medium so that heat can be rejected in the condenser. After the condensation the liquid refrigerant is throttled in the expansion valve back to the pressure of the evaporator. In other words the compressor "pumps"

Figure 13. Two screw compressors.

Figure 14. Refrigeration plant with heat recovery: preheating of hot water, floor heating and air heating.

APPENDIX K: Normal Building Electrical System

For the purpose of this BIM thesis, only the main normal distribution power was investigated. To this affect the entire building's normal power distribution was modeled in the BIM model and coordinated with the other disciplines. From the coordinated model a riser diagram was produced to visualize the electrical system in a simpler manner. This riser was then tag with the appropriate feeder tags after a voltage drop calculation was done. The electrical system was designed to meet all relevant codes stated in the NEC 2011 edition.



Feeder Tag	Conductor Size	Neutral Size	Ground Size	# of Wires in Conduit	# of Current Carrying Conductors	# of Conduits	Conduit Size
50	6 AWG	6 AWG	8 AWG	5	3	1	1"
80	3 AWG	3 AWG	8 AWG	5	3	1	1.25"
100	1 AWG	1 AWG	8 AWG	5	3	1	1.25"
200	250 kcmil	250 kcmil	6 AWG	5	3	1	2.5"
400	250 kcmil	250 kcmil	3 AWG	5	6	2	2.5"
600	250 kcmil	250 kcmil	1 AWG	5	9	3	2.5"
800	400 kcmil	400 kcmil	1/0 AWG	5	9	3	3"
1200	500 kcmil	500 kcmil	3/0 AWG	5	12	4	3"

Transformer Tag	kVA	Primary Voltage	Primary Feeder Tag	Primary Protection	Secondary Voltage	Secondary Feeder Tag	Secondary Protection
1	15	480	80	60	208	80	80
2	30	480	100	110	208	200	150
3	40	480	200	150	208	200	200
4	75	480	400	300	208	400	400
5	112.5	480	400	450	208	600	600

Voltage Drop

Feeder Tag	Conductor	3 phase Voltage	Conductor Resistance (ohms/1000ft)	Current in Conductors (amps)	Voltage Drop @ 1000 feet	Voltage Drop @ 500 feet	Voltage Drop @ 250 feet	Maximum Feeder Length (5% VD) (ft)
50	6 AWG	480	0.490	50	42.4	21.2	10.6	565.6
80	3 AWG	480	0.250	80	34.6	17.3	8.7	692.8
100	1 AWG	480	0.160	100	27.7	13.9	6.9	866.1
200	250 kcmil	480	0.057	200	19.7	9.9	4.9	1215.5
400	250 kcmil	480	0.057	200	19.7	9.9	4.9	1215.5
600	250 kcmil	480	0.057	200	19.7	9.9	4.9	200.0
800	400 kcmil	480	0.038	267	17.6	8.8	4.4	1367.4
1200	500 kcmil	480	0.032	300	16.6	8.3	4.2	1443.4
2000	900 kcmil	480	0.019	400	13.2	6.6	3.3	1823.3
4000	900 kcmil	480	0.019	444	14.6	7.3	3.7	1640.9
5000	900 kcmil	480	0.019	385	12.7	6.3	3.2	1896.2

Feeder Tag	Conductor	3 phase Voltage	Conductor Resistance (ohms/1000ft)	Current in Conductors (amps)	Voltage Drop @ 1000 feet	Voltage Drop @ 500 feet	Voltage Drop @ 250 feet	Maximum Feeder Length (5% VD) (ft)
50	6 AWG	208	0.49	50	42.434	21.217	10.6085	245.0864873
80	3 AWG	208	0.25	80	34.64	17.32	8.66	300.2309469
100	1 AWG	208	0.16	100	27.712	13.856	6.928	375.2886836
200	250 kcmil	208	0.057	200	19.7448	9.8724	4.9362	526.7209594
400	250 kcmil	208	0.057	200	19.7448	9.8724	4.9362	526.7209594
600	250 kcmil	208	0.057	200	19.7448	9.8724	4.9362	526.7209594
800	400 kcmil	208	0.038	266.6666667	17.55093333	8.775466667	4.387733333	592.5610794
1200	500 kcmil	208	0.032	300	16.6272	8.3136	4.1568	625.4811393
2000	900 kcmil	208	0.019	400	13.1632	6.5816	3.2908	790.0814392
4000	900 kcmil	208	0.019	444.4444444	14.62577778	7.312888889	3.656444444	711.0732952
5000	900 kcmil	208	0.019	384.6153846	12.65692308	6.328461538	3.164230769	821.6846967

Transformers

Transformer Tag	kVA	Primary Voltage	Primary Feeder Tag	Primary Protection	Secondary Voltage	Secondary Feeder Tag	Secondary Protection
1	15	480	80	60	208	80	80
2	30	480	100	110	208	200	150
3	40	480	200	150	208	200	200
4	75	480	400	300	208	400	400
5	112.5	480	400	450	208	600	600

480/277V Feeders

Feeder Tag	Conductor Size	Neutral Size	Ground Size	# of Wires in Conduit	# of Current Carrying Conductors	# of Conduits	Conduit Size
50	6 AWG	6 AWG	8 AWG	5	3	1	1"
80	3 AWG	3 AWG	8 AWG	5	3	1	1.25"
100	1 AWG	1 AWG	8 AWG	5	3	1	1.25"
200	250 kcmil	250 kcmil	6 AWG	5	3	1	2.5"
400	250 kcmil	250 kcmil	3 AWG	5	6	2	2.5"
600	250 kcmil	250 kcmil	1 AWG	5	9	3	2.5"
800	400 kcmil	400 kcmil	1/0 AWG	5	9	3	3"
1200	500 kcmil	500 kcmil	3/0 AWG	5	12	4	3"
2000	900 kcmil	900 kcmil	250 kcmil	5	15	5	4"
4000	900 kcmil	900 kcmil	250 kcmil	5	27	9	4"
5000	900 kcmil	900 kcmil	250 kcmil	5	39	13	4"

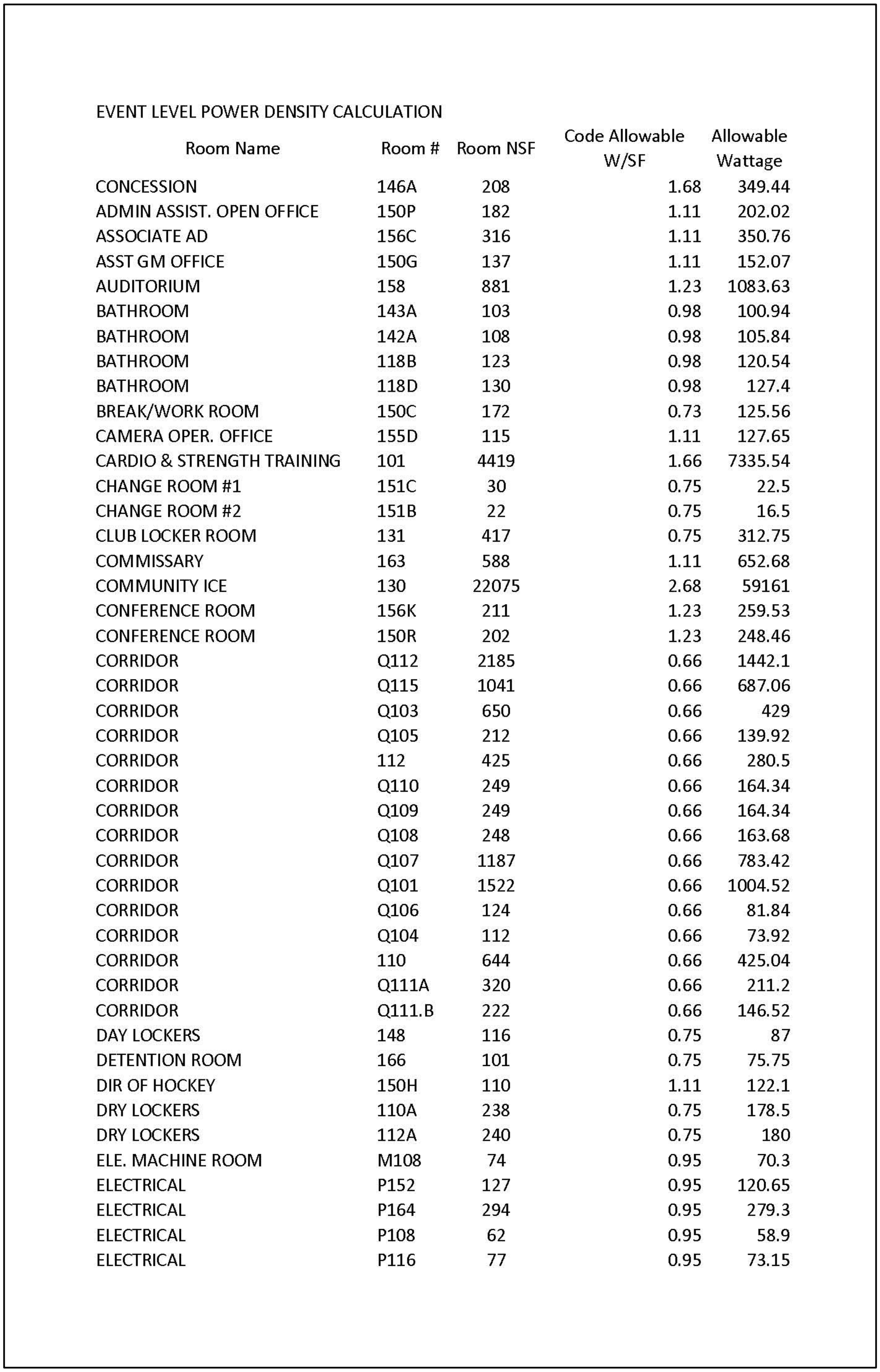
Note: Insulated wire rated to 75 degrees (THHN, THWN)
Feeder Tags 2000 and above are not feasible to use in construction, switch to busway

Panelboards

Floor	Voltage	Bldg Quad	System	Panel Name	VA	Watts	Demand Load	Demand Amps	Panelboard Size	MCB	Feed From...	Notes
Event Level	208/120V	West	Normal	**1-2W**	38700	38700	19355	161	200	200	1-4W via T3	
Event Level	208/120V	North	Normal	**1-2N**	24500	24500	12255	102	200	200	1-4N via T2	
Event Level	208/120V	East	Normal	**1-2SER**	23000	23000	11505	200	200	200	1-D4SER via T1	
Event Level	208/120V	South	Normal	**1-2S**	41000	41000	20505	171	200	200	1-4S via T4	
Event Level	480/277	West	Normal	**1-4W**	58000	58000	72500	262	400	400	1-D4ER	
Event Level	480/277	North	Normal	**1-4N**	36300	36300	45375	164	200	200	1-D4ER	
Event Level	480/277	East	Normal	**1-4SER**	8100	8100	10125	37	200	200	1-D4SER	
Event Level	480/277	South	Normal	**1-4S**	59000	59000	73750	266	400	400	1-D4ER	
Concourse Level	208/120V	West	Normal	**2-2W**	23400	23400	11705	98	100	100	1-2W	
Concourse Level	208/120V	North	Normal	**2-2N**	4300	4300	2155	18	100	100	1-2N	
Concourse Level	208/120V	East	Normal	**2-2E**	3600	3600	1805	15	100	100	1-2SER	
Concourse Level	208/120V	South	Normal	**2-2S**	20000	20000	10005	83	100	100	1-2S	
Concourse Level	480/277	West	Normal	**2-4W**	9900	9900	12375	45	100	100	1-4W	
Concourse Level	480/277	North	Normal	**2-4N**	2600	2600	3250	12	100	100	1-4N	
Concourse Level	480/277	East	Normal	**2-4E**	3000	3000	3750	14	100	100	1-4SER	
Concourse Level	480/277	South	Normal	**2-4S**	7900	7900	9875	36	100	100	1-4S	
Club Level	208/120V	West	Normal	**3-2W**	17400	17400	8705	73	100	100	2-2W	
Club Level	208/120V	South	Normal	**3-2S**	12420	12420	6215	52	100	100	2-2S	
Club Level	480/277	West	Normal	**3-4W**	5000	5000	6250	23	100	100	2-4W	
Club Level	480/277	South	Normal	**3-4S**	3100	3100	3875	14	100	100	2-4S	
Catwalk	480/277	-	Normal	**CW-4S**	27000	27000	33750	122	100	100	1-D4SR	
Catwalk	480/277	-	Normal	**CW-4N**	27000	27000	33750	122	100	100	1-D4SR	
Catwalk	208/120	-	Normal	**CW-2S**	20000	20000	25000	208	225	225	1-D2SR	
Catwalk	208/120	-	Normal	**CW-2N**	20000	20000	25000	208	225	225	1-D2SR	
Event Level	208/120V	West	Normal	**1-4ER**	77100	77100	96375	348	400	400	MSB	
Event Level	480/277	West	Normal	**1-2ER**	3400	3400	3400	28	100	100	1-4ER via T1	

Distribution Board

Floor	Voltage	Bldg Quad	System	Panel Name	VA	Watts	Demand Load	Demand Amps	Panelboard Size	MCB	Feed From..	Notes
Event Level	480/277	Electrical Room	Normal	1-D4ER	153422	153422	76280	275	400	400	MSB	
Event Level	480/277	Secondary Electrical Room	Normal	1-D4SER	39525	39525	27788	101	200	200	MSB	
Event Level	480/277	Show Power Room	Normal	1-D4SR	67500	67500	67500	244	400	400	MSB	
Event Level	208/120	Show Power Room	Normal	1-D2SR	40000	40000	40000	333	400	400	1-D4SR via T4	



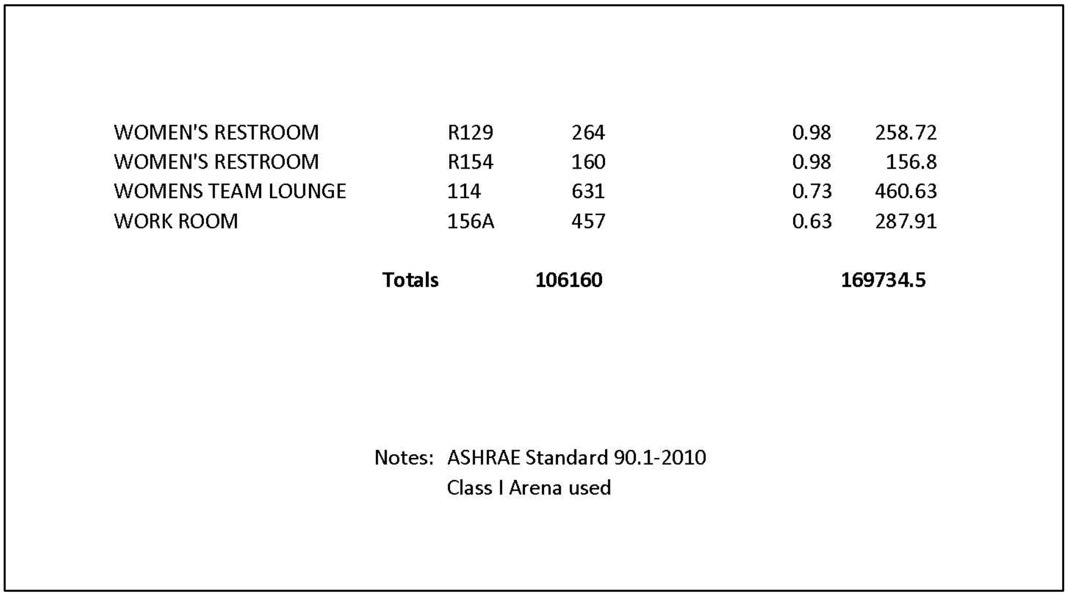
EVENT LEVEL POWER DENSITY CALCULATION

Room Name	Room #	Room NSF	Code Allowable W/SF	Allowable Wattage
CONCESSION	146A	208	1.68	349.44
ADMIN ASSIST. OPEN OFFICE	150P	182	1.11	202.02
ASSOCIATE AD	156C	316	1.11	350.76
ASST GM OFFICE	150G	137	1.11	152.07
AUDITORIUM	158	881	1.23	1083.63
BATHROOM	143A	103	0.98	100.94
BATHROOM	142A	108	0.98	105.84
BATHROOM	118B	123	0.98	120.54
BATHROOM	118D	130	0.98	127.4
BREAK/WORK ROOM	150C	172	0.73	125.56
CAMERA OPER. OFFICE	155D	115	1.11	127.65
CARDIO & STRENGTH TRAINING	101	4419	1.66	7335.54
CHANGE ROOM #1	151C	30	0.75	22.5
CHANGE ROOM #2	151B	22	0.75	16.5
CLUB LOCKER ROOM	131	417	0.75	312.75
COMMISSARY	163	588	1.11	652.68
COMMUNITY ICE	130	22075	2.68	59161
CONFERENCE ROOM	156K	211	1.23	259.53
CONFERENCE ROOM	150R	202	1.23	248.46
CORRIDOR	Q112	2185	0.66	1442.1
CORRIDOR	Q115	1041	0.66	687.06
CORRIDOR	Q103	650	0.66	429
CORRIDOR	Q105	212	0.66	139.92
CORRIDOR	112	425	0.66	280.5
CORRIDOR	Q110	249	0.66	164.34
CORRIDOR	Q109	249	0.66	164.34
CORRIDOR	Q108	248	0.66	163.68
CORRIDOR	Q107	1187	0.66	783.42
CORRIDOR	Q101	1522	0.66	1004.52
CORRIDOR	Q106	124	0.66	81.84
CORRIDOR	Q104	112	0.66	73.92
CORRIDOR	110	644	0.66	425.04
CORRIDOR	Q111A	320	0.66	211.2
CORRIDOR	Q111.B	222	0.66	146.52
DAY LOCKERS	148	116	0.75	87
DETENTION ROOM	166	101	0.75	75.75
DIR OF HOCKEY	150H	110	1.11	122.1
DRY LOCKERS	110A	238	0.75	178.5
DRY LOCKERS	112A	240	0.75	180
ELE. MACHINE ROOM	M108	74	0.95	70.3
ELECTRICAL	P152	127	0.95	120.65
ELECTRICAL	P164	294	0.95	279.3
ELECTRICAL	P108	62	0.95	58.9
ELECTRICAL	P116	77	0.95	73.15

ELECTRICAL ROOM	P125	765	0.95	726.75
ELEV #1	V101	1952		0
ELEV #2	V103	103		0
ELEV MACHINE ROOM	M150	81	0.95	76.95
ELEV. MACHINE ROOM	M160	76	0.95	72.2
EMERGENCY POWER	P124	321	0.95	304.95
EQUIPMENT	108	691	0.95	656.45
EVENT ICE	120	16542	3.01	49791.42
EVENT STAFF LOCKER RM.	157	427	0.75	320.25
EXAM ROOM	111A	161	1.66	267.26
FEMALE COACH LOCKER RM.	118A	89	0.75	66.75
FIGURE SKATING PROS	151	243	1.11	269.73
FIRE COMMAND CENTER	160	40	1.11	44.4
GM OFFICE	150F	186	1.11	206.46
HEAD-IN ROOM	159	82	0.66	54.12
HYDROTHERAPY ROOM	111D	719	1.66	1193.54
ICE PLANT	123	1923	0.95	1826.85
ICE SUPPORT	117	2690	0.95	2555.5
JAN.	J142	117	0.63	73.71
JAN.	J153	39	0.63	24.57
LAUNDRY	108A	379	0.63	238.77
LOADING DOCK	162	658	0.63	414.54
LOBBY	149	2166	0.9	1949.4
LOCKER ROOM	141	371	0.75	278.25
LOCKER ROOM	139	375	0.75	281.25
LOCKER ROOM	140	350	0.75	262.5
LOCKER ROOM	138	366	0.75	274.5
LOCKER ROOM	135	425	0.75	318.75
LOCKER ROOM	137	401	0.75	300.75
LOCKER ROOM	136	378	0.75	283.5
LOCKER ROOM	134	378	0.75	283.5
MAIN COMMUNICATION RM.	109	140	1.11	155.4
MALE COACH LOCKER RM.	118C	119	0.75	89.25
MECHANICAL ROOM	M122	1328	0.95	1261.6
MEDIA SUITE	155	319	1.11	354.09
MEN ASST COACH	156F	106	1.11	117.66
MEN ASST COACH	156E	158	1.11	175.38
MEN ASST COACH	156H	142	1.11	157.62
MEN DIR HOCKEY OPS	156B	109	1.11	120.99
MEN ICE HOCKEY LOCKER RM.	110D	1332	0.75	999
MEN RECRUIT LOUNGE	156G	153	0.73	111.69
MEN'S COACH LOCKER RM.	102A	188	0.75	141
MEN'S COACH LOUNGE	102	186	0.73	135.78
MEN'S EQUIPMENT	107	360	0.63	226.8
MEN'S RESTROOM	R128	264	0.98	258.72
MEN'S RESTROOM	R153	159	0.98	155.82
MEN'S TEAM LOUNGE	105	598	0.73	436.54

OFFICE	156J	318	1.11	352.98
OFFICE	150E	115	1.11	127.65
OFFICE	151A	149	1.11	165.39
OFFICE	155A	115	1.11	127.65
OFFICE	101B	131	1.11	145.41
OFFICE	106	114	1.11	126.54
OFFICE	111C	125	1.11	138.75
OFFICE	123A	103	1.11	114.33
OFFICE	111G	126	1.11	139.86
OFFICIAL LOCKER	145	84	0.75	63
OFFICIAL LOCKER	143	91	0.75	68.25
OFFICIAL LOCKER	142	87	0.75	65.25
OFFICIAL LOCKER	144	86	0.75	64.5
OPEN OFFICE	156D	161	0.98	157.78
PARTY ROOM	127	607	1.23	746.61
PARTY ROOM STORAGE	T126	112	0.63	70.56
PENALTY	120E	47	3.01	141.47
PENALTY	120D	53	2.68	142.04
PENALTY	120C	50	2.68	134
RAPID HANDS TRAINING	103	168	1.66	278.88
RAPID SHOT TRAINING	104	537	1.66	891.42
RECEPTION	156	564	0.66	372.24
RESTROOM	138A	180	0.98	176.4
RESTROOM	135A	211	0.98	206.78
RESTROOM	134A	206	0.98	201.88
RESTROOM	131A	109	0.98	106.82
RESTROOM	157A	204	0.98	199.92
RESTROOM	110B	205	0.98	200.9
RESTROOM	111B	61	0.98	59.78
RESTROOM	112B	199	0.98	195.02
SEATING	126	1350	0.43	580.5
SECURITY OFFICE	161	123	1.11	136.53
SERVER	150D	75	1.11	83.25
SHOW POWER	167	333	0.95	316.35
SHOWER	139B	305	0.75	228.75
SHOWER	134B	102	0.75	76.5
SHOWER	131B	54	0.75	40.5
SHOWER	157B	81	0.75	60.75
SHOWER	138B	121	0.75	90.75
SHOWER	135B	139	0.75	104.25
SHOWER ROOM	110C	305	0.75	228.75
SHOWER ROOM	112C	423	0.75	317.25
SKATE RENTAL	147	517	1.68	868.56
STAIR	Z105	166	0.69	114.54
STAIR	Z103	268	0.69	184.92
STAIR	Z101	231	0.69	159.39
STAIR	Z102	233	0.69	160.77

STEAM ROOM	111E	147	0.75	110.25
STEAM ROOM	111F	147	0.75	110.25
STORAGE	147A	110	0.63	69.3
STORAGE	128	183	0.63	115.29
STORAGE	121	720	0.63	453.6
STORAGE	154	348	0.63	219.24
STORAGE	164	261	0.63	164.43
STORAGE	101A	167	0.63	105.21
STORAGE	105B	76	0.63	47.88
STORAGE	115A	81	0.63	51.03
STORAGE	133	1425	0.63	897.75
STORAGE	168	1177	0.63	741.51
TEAM BENCH	120B	197	2.68	527.96
TEAM BENCH	120A	197	2.68	527.96
TELE/DATA	T152	93	0.95	88.35
TELE/DATA	T165	111	0.95	105.45
TELE/DATA	T116	97	0.95	92.15
TICKETING	150	137	1.68	230.16
TICKETING OFFICE	150B	126	1.68	211.68
TREATMENT & BIKE ROOM	111	871	1.66	1445.86
TREATMENT ROOM	165B	112	1.66	185.92
VAULT	150A	121	0.63	76.23
VEST.	157C	36	0.66	23.76
VEST.	F156	106	0.66	69.96
VESTIBULE	F105	210	0.66	138.6
VESTIBULE	F101	216	0.66	142.56
VESTIBULE	F103	178	0.66	117.48
VESTIBULE	105	277	0.66	182.82
VESTIBULE	F102	138	0.66	91.08
VIDEO EDITING	155C	127	1.11	140.97
VIDEO STORAGE	155B	118	0.63	74.34
VIDEO/STUDY	105A	329	1.11	365.19
VIDEO/STUDY	115	264	1.11	293.04
VISITING TEAM LOCKER ROOM	165	733	0.75	549.75
VISITING TEAM STORAGE	165A	153	0.63	96.39
VOMITORY	132	515	0.66	339.9
VOMITORY	119	423	0.66	279.18
VOMITORY	164	429	0.66	283.14
WMN DIR HOCKEY OPS	150K	112	1.11	124.32
WMNS ASST COACH	150J	157	1.11	174.27
WMNS ASST COACH	150L	158	1.11	175.38
WMNS ASST COACH	150M	112	1.11	124.32
WMNS HEAD COACH	150Q	320	1.11	355.2
WMNS RECRUIT LOUNGE	150N	153	0.73	111.69
WOMEN'S COACHES LOUNGE	118	204	0.73	148.92
WOMEN'S EQUIPMENT ROOM	113	318	0.63	200.34
WOMENS LOCKER ROOM	112D	1391	0.75	1043.25



WOMEN'S RESTROOM	R129	264	0.98	258.72
WOMEN'S RESTROOM	R154	160	0.98	156.8
WOMENS TEAM LOUNGE	114	631	0.73	460.63
WORK ROOM	156A	457	0.63	287.91
	Totals	**106160**		**169734.5**

Notes: ASHRAE Standard 90.1-2010
Class I Arena used

MAIN CONCOURSE LEVEL POWER DENSITY

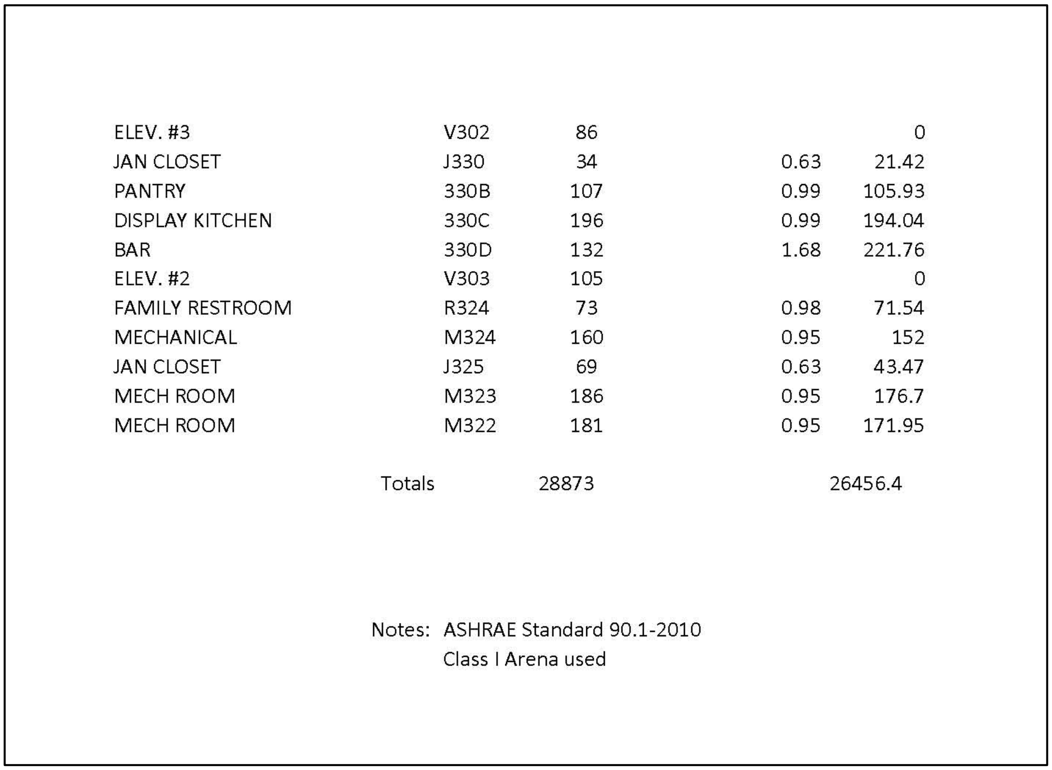
Room Name	Room #	Room NSF	Code Allowable W/SF	Code Allowable Wattage
BAND STORAGE	208	258	0.63	162.54
CONCESSION	228A	211	1.68	354.48
CONCESSION	221A	190	1.68	319.2
CONCESSION	217A	243	1.68	408.24
CONCESSION	210A	178	1.68	299.04
CONCESSION	202A	204	1.68	342.72
CONCESSION	214A	207	1.68	347.76
CONCESSION B.O.H.	228	338	1.68	567.84
CONCESSION B.O.H.	221	308	1.68	517.44
CONCESSION B.O.H.	217	277	1.68	465.36
CONCESSION B.O.H.	210	316	1.68	530.88
CONCESSION B.O.H.	202	291	1.68	488.88
CONCESSION B.O.H.	214	295	1.68	495.6
CONCESSION STORAGE	228B	113	0.63	71.19
CONCIERGE	201	148	1.68	248.64
CURTAIN	213	46	0.63	28.98
CURTAIN	218	46	0.63	28.98
EAST CONCOURSE	Q214	3237	0.66	2136.42
ELECTRICAL	P227	162	0.95	153.9
ELECTRICAL	P222	191	0.95	181.45
ELECTRICAL	P209	92	0.95	87.4
ELECTRICAL	P203	254	0.95	241.3
ELEV. #1	E1.2	72		0
ELEV. #2	V203	109		0
ELEV. #3	V202	84		0
ELEVATOR LOBBY	F203	235	0.64	150.4
FAMILY RESTROOM	R206	65	0.98	63.7
FAMILY RESTROOM	R224	98	0.98	96.04
FIRST AID	J232	312	1.66	517.92
JANITOR	J233	237	0.63	149.31
JANITOR	J215	92	0.63	57.96
LOBBY	F202	3534.4	0.73	2580.112
LOBBY	F205	3166	0.9	2849.4
LOBBY	F219	4078	0.9	3670.2
MAIN ARENA	372	0	3.01	0
MECH.	T209	80	0.95	76
MECHANICAL	212	274	0.95	260.3
MENS RESTROOM	R234	307	0.98	300.86
MEN'S RESTROOM	R226	763	0.98	747.74
MEN'S RESTROOM	R215	248	0.98	243.04
MEN'S RESTROOM	R205	659	0.98	645.82
MT. NITTANY ROOM	230	1559	1.31	2042.29
NORTH CONCOURSE	Q201	4226	0.66	2789.16

NOVELTY SALES	231A	160	1.68	268.8
NOVELTY STORAGE	231	344	0.63	216.72
PANTRY	229	285	0.99	282.15
RESTAURANT SERVICE	220	1945	0.99	1925.55
SOUTH CONCOURSE	Q209	4264	0.66	2814.24
STAIR	Z202	245	0.69	169.05
STAIR	Z201	413	0.69	284.97
STAIR	Z203	234	0.69	161.46
STAIR	Z205	173	0.69	119.37
TICKETING	201A	215	1.68	361.2
TICKETING	211	174	1.68	292.32
VESTIBULE	F201	520	0.66	343.2
VESTIBULE	F204	374	0.66	246.84
VOM	Q207	166	0.66	109.56
VOMITORY	Q205	100	0.66	66
VOMITORY	Q204	98	0.66	64.68
VOMITORY	Q203	101	0.66	66.66
VOMITORY	Q202	99	0.66	65.34
VOMITORY	Q217	70	0.66	46.2
VOMITORY	Q216	75	0.66	49.5
VOMITORY	Q213	100	0.66	66
VOMITORY	Q215	109	0.66	71.94
VOMITORY	Q211	99	0.66	65.34
VOMITORY	Q212	100	0.66	66
VOMITORY	Q210	99	0.66	65.34
VOMITORY	Q208	167	0.66	110.22
WEST CONCOURSE	Q206	1653	0.66	1090.98
WOMEN'S R.R.	R204	771	0.98	755.58
WOMEN'S RESTROOM	R233	372	0.98	364.56
WOMEN'S RESTROOM	R223	764	0.98	748.72
WOMEN'S RESTROOM	R216	262	0.98	256.76
WOMEN'S RESTROOM	R207	707	0.98	692.86
	Totals	43061.4		38026.602

Notes: ASHRAE Standard 90.1-2010
Class I Arena used

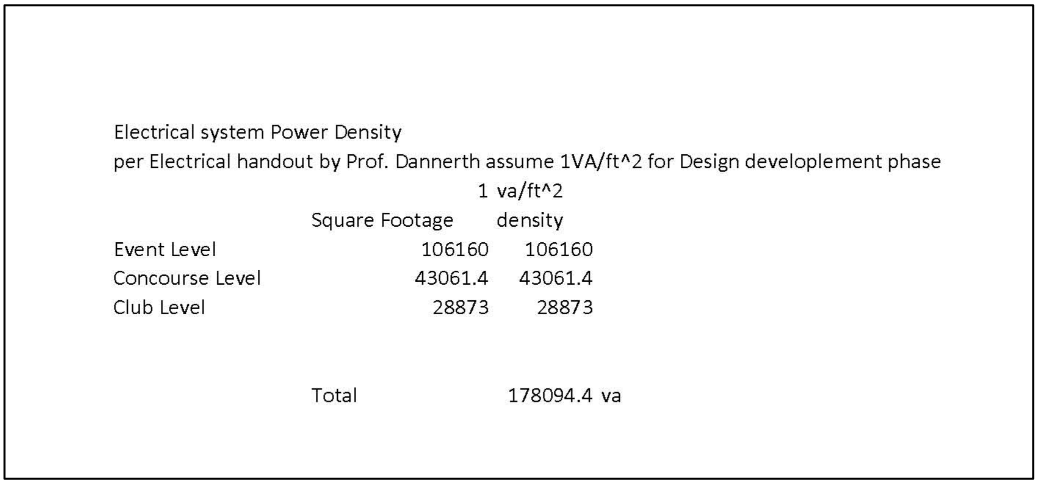
CLUB LEVEL POWER DENSITY

Room Name	Room #	Room NSF	Code Allowable W/SF	
VISITING COACH	225A	98	1.11	108.78
BROADCAST BOOTH	225B	227	1.11	251.97
COACH	225C	161	1.11	178.71
PRESS ROOM	225	494	1.11	548.34
STAIR	Z303	234	0.69	161.46
MEN'S RESTROOM	R327	223	0.98	218.54
WOMEN'S RESTOOM	R326	222	0.98	217.56
ELECTRICAL	P324	127	0.95	120.65
KITCHEN	330	2749	0.99	2721.51
MEN'S RESTROOM	R306	185	0.98	181.3
TELE/DATA	T306	142	0.95	134.9
SUITE 1A	321	448	0.82	367.36
SUITE 1B	320	552	0.82	452.64
SUITE 2	317	477	0.82	391.14
SUITE 3	316	495	0.82	405.9
SUITE 4	314	495	0.82	405.9
SUITE 5	313	495	0.82	405.9
SUITE 6	312	495	0.82	405.9
SUITE 7	311	495	0.82	405.9
SUITE 8	310	495	0.82	405.9
SUITE 9	309	495	0.82	405.9
SUITE 10	308	495	0.82	405.9
SUITE LOUNGE	306	718	0.73	524.14
PANTRY	302	212	0.99	209.88
CONTROL ROOM	301	225	1.11	249.75
SUITE 11	307	477	0.82	391.14
SUITE 12A	305	588	0.82	482.16
SUITE 12B	304	624	0.82	511.68
WOMEN'S RESTROOM	R303	171	0.98	167.58
ELEV. #1	V301	71		0
TELE/DATA	T315	130	0.95	123.5
ELECTRICAL	P315	123	0.95	116.85
MEN'S RESTROOM	R318	156	0.98	152.88
WOMEN'S RESTROOM	R319	154	0.98	150.92
JANITOR	J318	46	0.63	28.98
STAIR	Z302	266	0.69	183.54
CLUB DINING ROOM	332	5330	1.31	6982.3
CLUB LOUNGE	334	1991	0.73	1453.43
STAIR	Z304	246	0.69	169.74
NORTH CONCOURSE	Q301	2425	0.66	1600.5
EAST CONCOURSE	Q304	1268	0.66	836.88
LOGE BOX	322	1016	0.82	833.12
LOGE BOX	323	1008	0.82	826.56



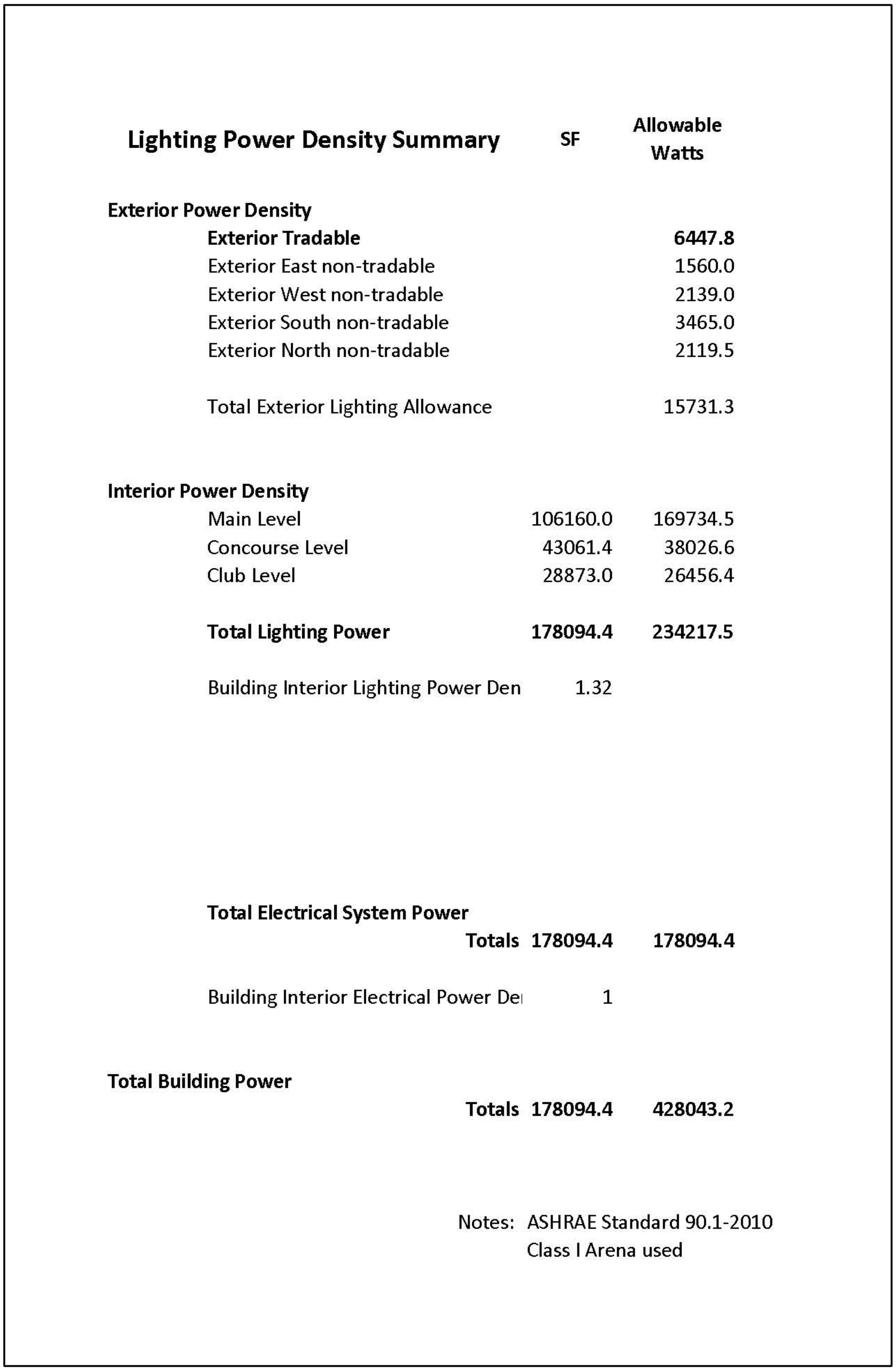
ELEV. #3	V302	86		0
JAN CLOSET	J330	34	0.63	21.42
PANTRY	330B	107	0.99	105.93
DISPLAY KITCHEN	330C	196	0.99	194.04
BAR	330D	132	1.68	221.76
ELEV. #2	V303	105		0
FAMILY RESTROOM	R324	73	0.98	71.54
MECHANICAL	M324	160	0.95	152
JAN CLOSET	J325	69	0.63	43.47
MECH ROOM	M323	186	0.95	176.7
MECH ROOM	M322	181	0.95	171.95
	Totals	28873		26456.4

Notes: ASHRAE Standard 90.1-2010
Class I Arena used



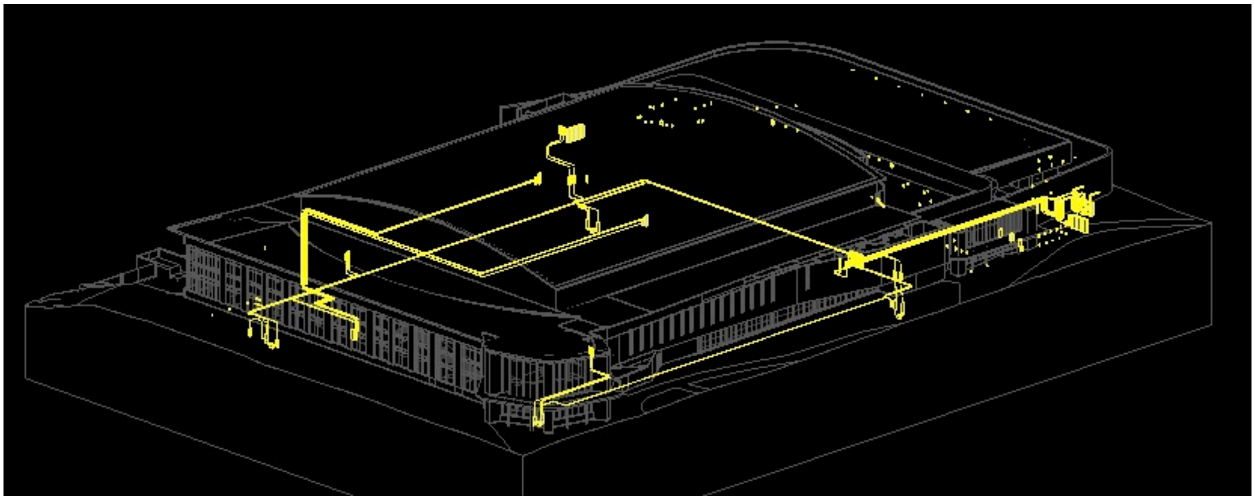
Electrical system Power Density
per Electrical handout by Prof. Dannerth assume 1VA/ft^2 for Design developlement phase

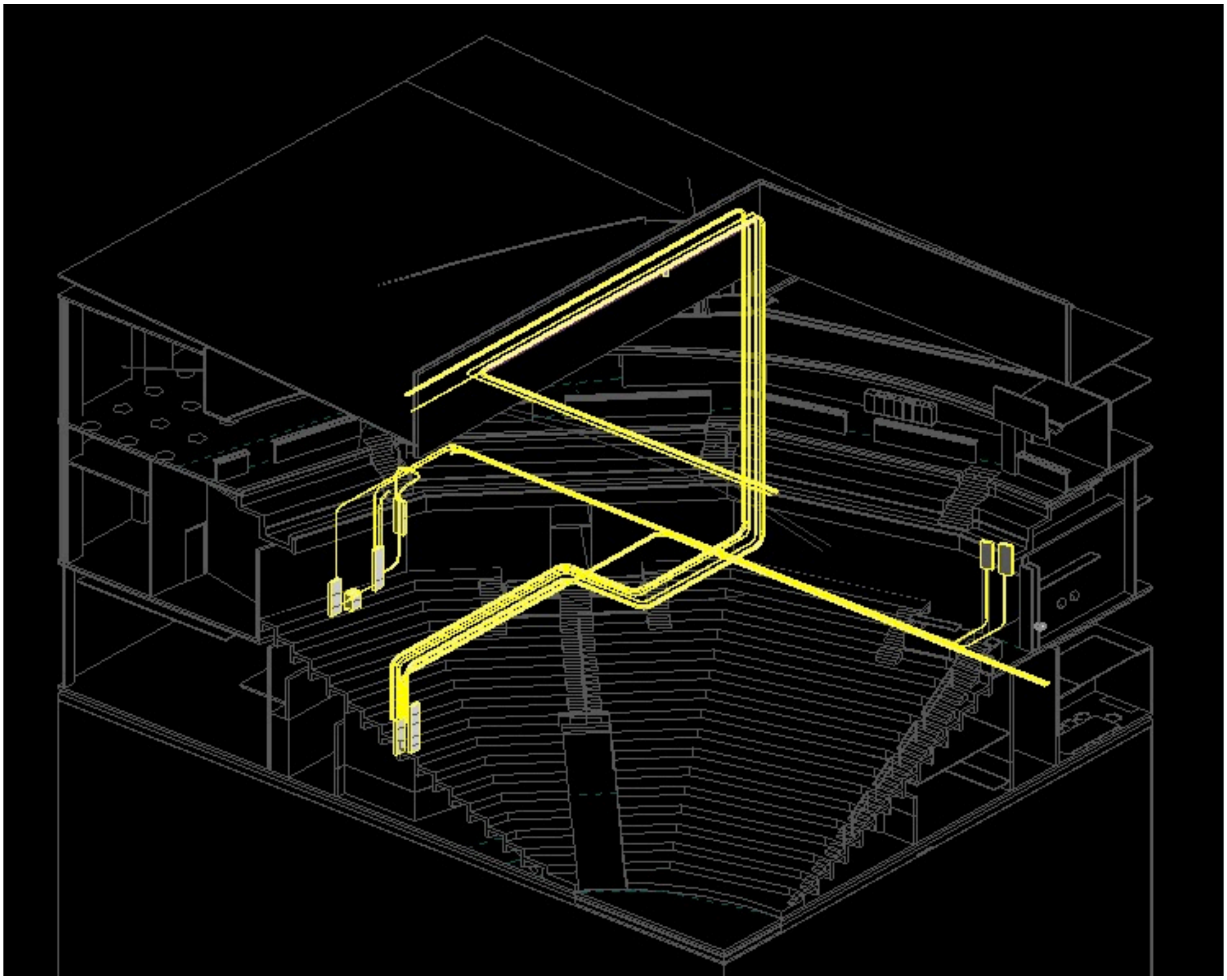
	Square Footage	1 va/ft^2 density
Event Level	106160	106160
Concourse Level	43061.4	43061.4
Club Level	28873	28873
	Total	178094.4 va

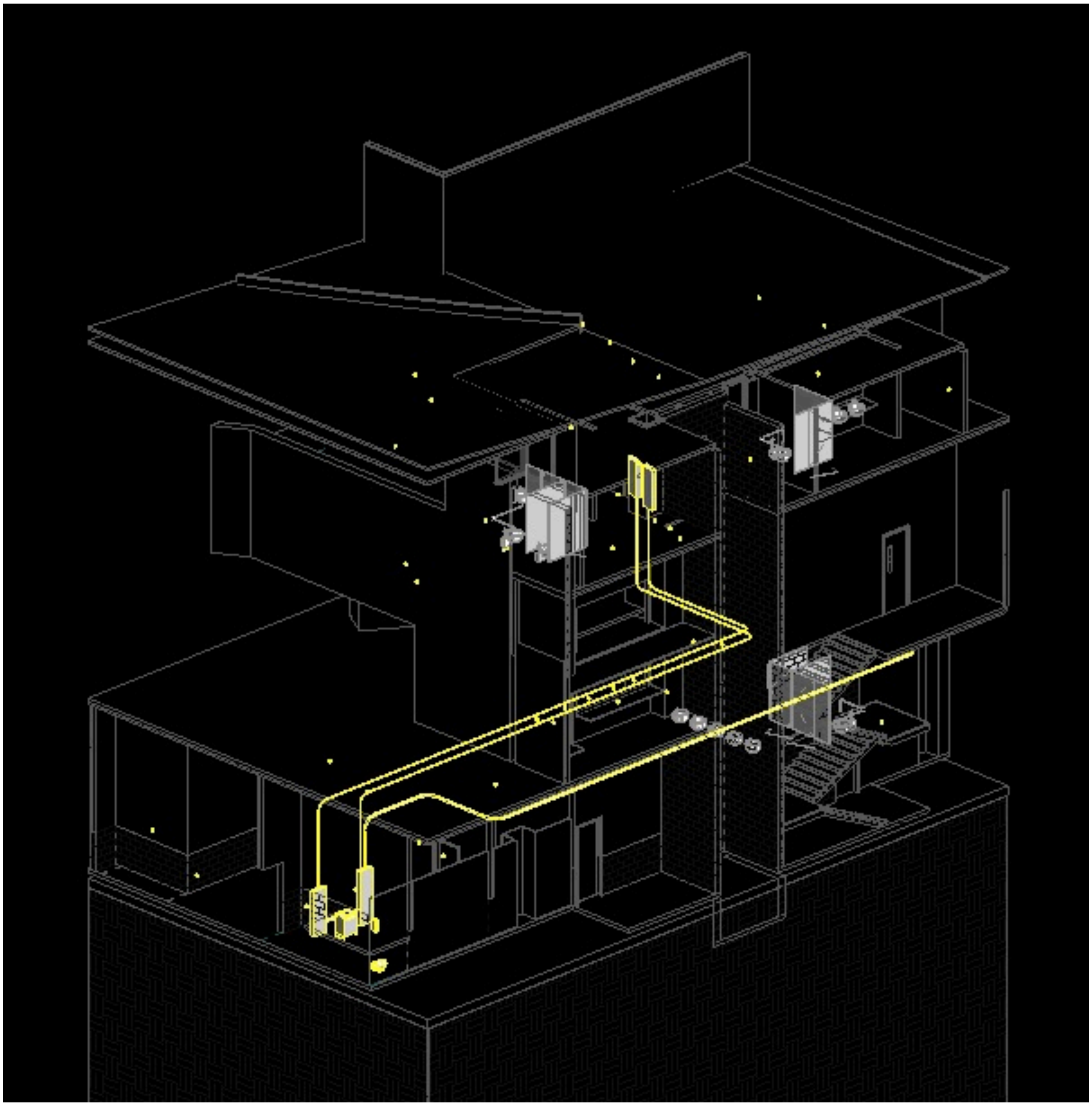


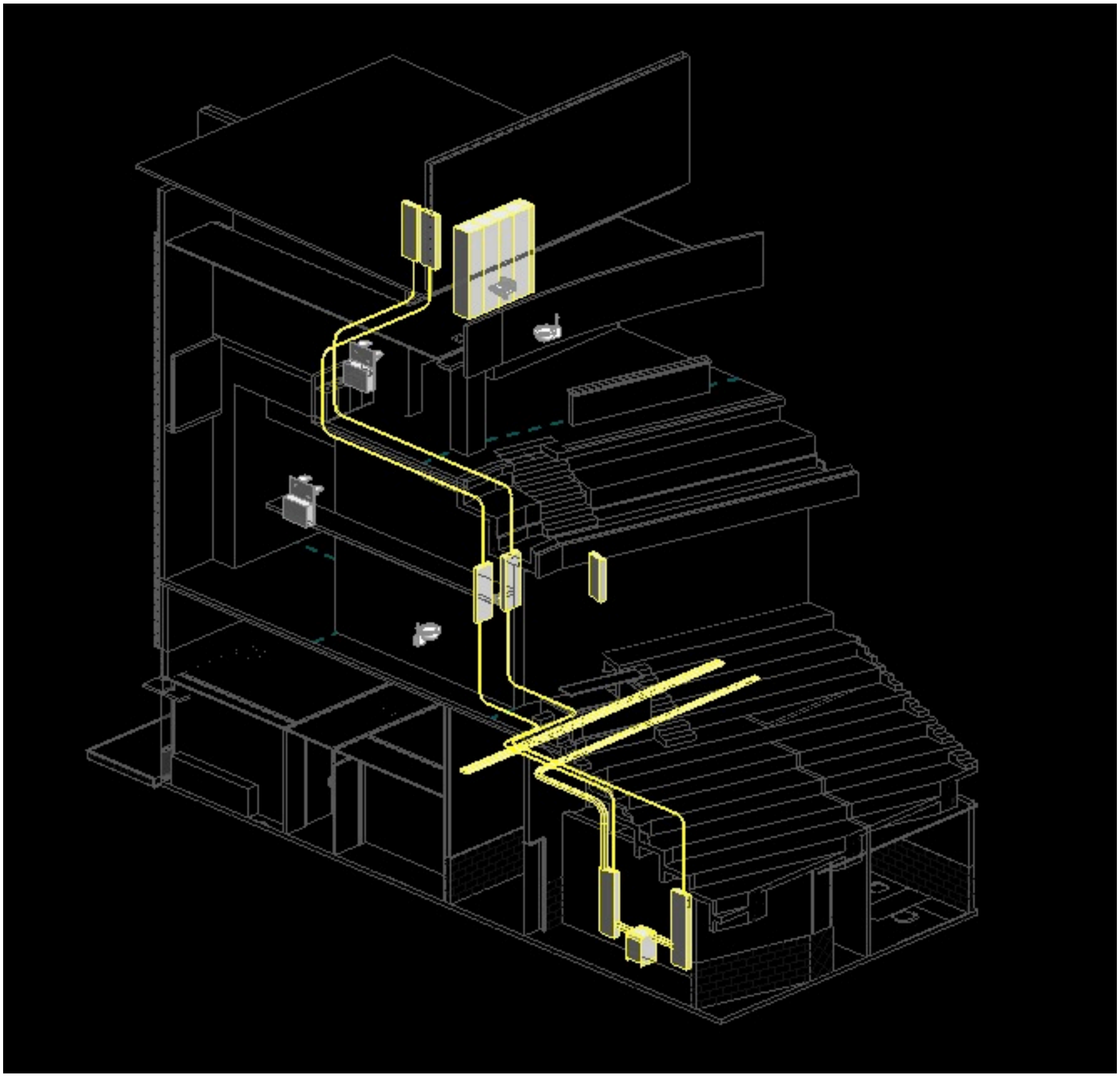
Lighting Power Density Summary		SF	Allowable Watts
Exterior Power Density			
Exterior Tradable			**6447.8**
Exterior East non-tradable			1560.0
Exterior West non-tradable			2139.0
Exterior South non-tradable			3465.0
Exterior North non-tradable			2119.5
Total Exterior Lighting Allowance			15731.3
Interior Power Density			
Main Level		106160.0	169734.5
Concourse Level		43061.4	38026.6
Club Level		28873.0	26456.4
Total Lighting Power		**178094.4**	**234217.5**
Building Interior Lighting Power Den		1.32	
Total Electrical System Power			
	Totals	**178094.4**	**178094.4**
Building Interior Electrical Power De		1	
Total Building Power			
	Totals	**178094.4**	**428043.2**

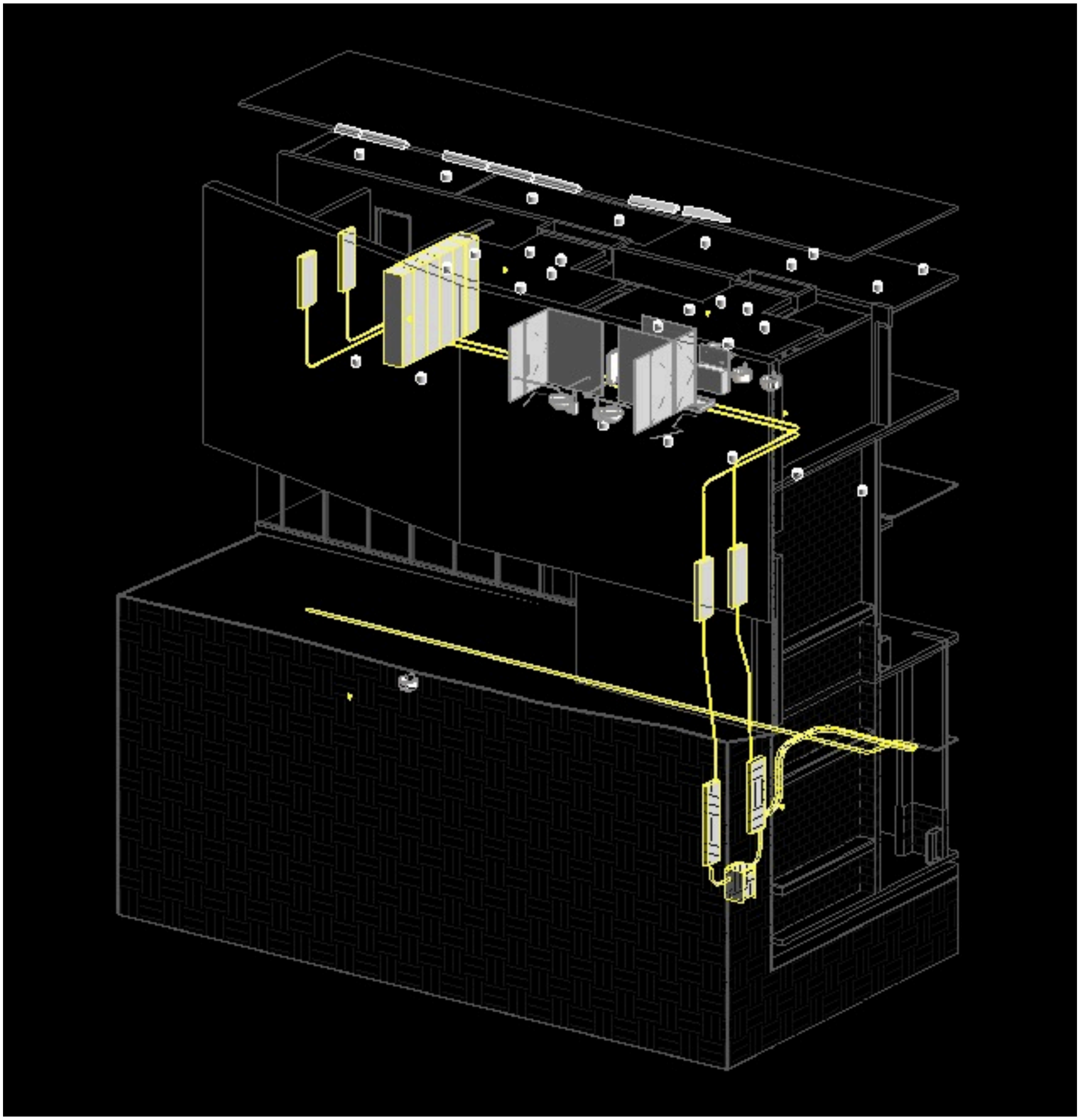
Notes: ASHRAE Standard 90.1-2010
Class I Arena used











APPENDIX L: General Lighting Information

EXTERIOR LIGHTING POWER DENSITY	Code Allowable W, W/f, W/sf, Amount	Approximate: Area, Linear footage, amount	Total
Base Site Allowance	750	1	750
Tradable Surfaces			0
Uncovered Parking Area	0.1	33790	3379
Building Grounds			0
Walkways less than 10 feet wide	0.08	1397	111.76
walkways 10 feet or greater	0.16	2919	467.04
stairways	1	0	0
pedestrian tunnels	0.2	0	0
landscaping	0.05	0	0
Building Entrances			0
Main Entries	30	54	1620
Other Doors	20	6	120
Entry Canopies	0.4	0	0
Sales Canopies	0.8	0	0
Outdoor Sales			0
Open Areas	0.5	0	0
Street Frontage fore vehicle sales	10	0	0
			6447.8
Nontradable Surfaces			
Building Façade			0
East	0.15	10400	1560
West	0.15	14260	2139
North	0.15	14130	2119.5
South	0.15	23100	3465
ATM	270	0	0
Entrances at guarded facilites	0.75	0	0
Loading Area for Emergency Service Vehicles	0.5	0	0
Drive-through Windows	400	0	0
Parking near 24-hour retail	800	0	0
Roadway/Parking	-	0	

Notes: ASHRAE Standard 90.1-2010
Assumed Lighting Zone 3 from table 9.4.3A in ASHRAE Standard 90.1-2

Luminaire Schedule

	Style	Manufacturer	CATALOG #	QUANTITY	DESCRIPTION	LAMP	BALLAST	INPUTS WATTS
A1	Arena Lights	Philips - Widelite	AE2M-1-A-MADJ-MW10-CBLKMP		Indoor Sports light with 1000 watt metal halide lamp. Beam spread is NEMA 5x4. Fixture should be equiped with shutters with full black-out capability. Lamp mounted horizontally, Remote ballast	(1) Philips - MS1000/BU/BT37/PS	Philips - 78E65F3	1075
A2	Arena Lights	Philips - Widelite	AE2M-1-B-MADJ-MW10-CBLKMP		Indoor Sports light with 1000 watt metal halide lamp. Beam spread is NEMA 4x2. Fixture should be equiped with shutters with full black-out capability. Lamp mounted horizontally, Remote ballast	(1) Philips - MS1000/BU/BT37/PS	Philips - 78E65F3	1075
B	LED Downlight	Zumtobel	BR6LED-25W-K35-MS45-DH2-XX	-	6" round aperature LED downlight housed in a galvanized steel case, shallow integral heat sink. Upper reflector is spun anodized aluminum, a lens is placed to obscure direct view of the LEDs. The lower reflector is a compound parabolic shape also spun anodized aluminum.	LED, 2700k, 85 CRI	Lutron HiLume A-series	25
C	LED Linear Wall Grazer	Amerlux	LWG-B-LED-E-PAL-B-IND-277-2700-XX	-	Extruded aluminum housing, die-formed aluminum, glavanized, and coldrolled steel internal components. Extruded aluminum optic reflector, 1 LED linear array module per 1" section	Linear LED array, 2700k, 80 CRI	Integral	74
D	HID Track Mounted Floodlight	Zumtobel	VIVO L1/150W HIT G12 EVG 3CV WFL-S	-	Line voltage track mounted floodlight, contains a 150 watt ceramic metal halide lamp. The reflector is rotationally symmetrical. Ballast is housed in a trackbox located on the track.	(1) Sylvania - MC150T7.5/U/G12/940PB	Integral	162
F	Cantilever Mounted LED assymetric wallwasher	The Lighting Quotie	5099-LA07-X-02-N-V0-O-30	-	LED linear array with precision made optical surround utilizing refaction to distribute light. Extruded aluminum heat sink and optic housing. Extruded impact resistant acrylic outer protective lens. Provide with acessory cantilever part number VCP-02-300.	Linear LED array, 85 CRI, 3000k	RDLI-0350-A-00-277-00-O-0C	9
G	Ground recessed assymetrica	designplan	CSL-B-6D4-550-C-T-00	-	Ingrade linear flourescent fixture. Extruded aluminum body with lower copper die cast ends. Stainless steel frame and screws. Capable of supporting 11,000 lb. Housing is gasketed with silicone rubber throughout.	(1) Sylvania - FP14/835/ECO	QTP 1X28T5/UNV PSN NL	
H	Wall mounted HID Spot	Zumtobel	MIROS 1/150W HIT G12 EVG IP54	-	Housing made of extruded aluminum and diecast aluminum. Reflector is highly specular anodised parabolic shape. Circular louvers with integral lamp shelding provide precise glare control.	(1) Sylvania - MC150T7.5/U/G12/940PB	Integral	162
I	Ingrade Round LED fixture	Winona Lighting	HEBRLEB-9000-12V-14-00-SHO-TF	-	Ingrade mounted round LED fixture, IP68 rated. Separate seiled wireing compartment to prevent water intrusion inot lamp compartment. 12v magnetric transfomer required to function properly.	LED module	12v magnetic transformer	15
J	4.5" LED round wallwashing r	Lightolier	C4L10-WW-30K-CL-W-00	-	Recessed 4.5" round downlight with reflecting kicker plate to achieve wall washing distribution.	LED module	LED Driver	19.8
K	Linear flourescent cover	Mark Architectural l	CG2-4-1-T5-EBPR-277-XX	-	Cold-rolled stell housing and ballast compartment. Matte white finish. Die-formed 20 gauge steel specular alumium reflector.	(1) Sylvania - FP28/830/ECO	Sylvania - QTP 1X28T5/UNV I	32
E1	LED Floodlight	Lightolier	UF2-06-U-TSA-030-4K-4X4-7	-	LED floodlight on emergency circuit in main arena. Diecast aluminum construction. 3/4" arm with serrated teeth lock arm mouing unit for precision mounting	30 High output LEDs	integral LED driver	63

Table 89: Light Loss Factors

Light Loss Factor									
Luminaire Type	A1	A2	B	C	D	F	G	H	E1
Luminaire Ambient Temperature	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lamp Lumen Depreciation	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Luminaire Dirt Depreciation	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Ballast Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Equipment Operating Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total Light Loss Factor	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73

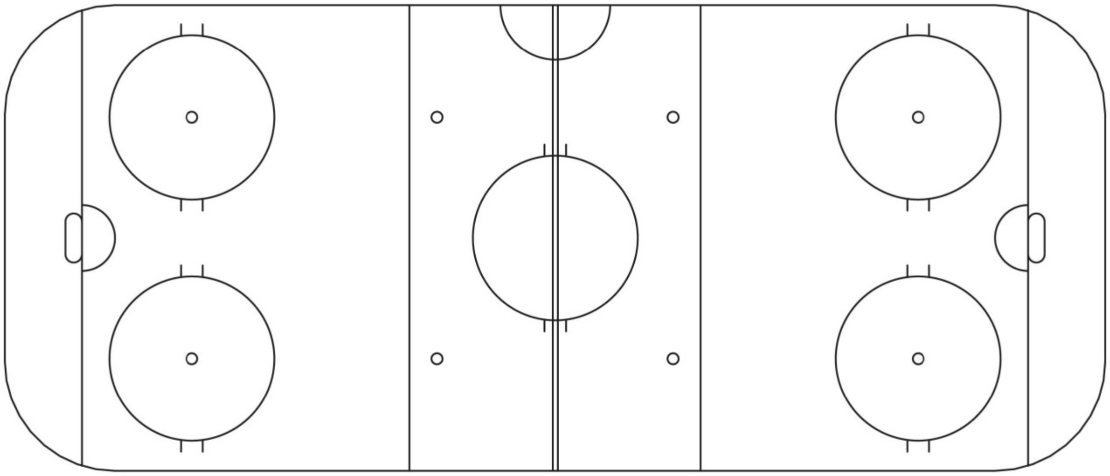
Best Lighting Practices: Ice Hockey/Roller Hockey

National Championship Final Site

Summary: Following these recommended best practices will help ensure quality of light needed for safety of participants, enjoyment of spectators, and quality national championship final site television broadcasts, as required.

Horizontal light levels:	125 footcandles
Horizontal uniformity:	1.5:1
Vertical light levels:	125 footcandles to center main side high camera 75 footcandles to end line camera
Vertical uniformity:	1.5:1 to main camera 2.5:1 to end line camera
Grid spacing:	14 ft x 14 ft

Typical facility layout:



1. For new facilities or upgrades, it is recommended to consult a lighting professional for optimal luminaire placement and catwalk locations.
2. Optimal luminaire placement, mounting heights, and catwalk locations will impact playability and minimize glare and skip glare.
3. To achieve required vertical footcandles, some lights must be mounted beyond the sides and ends of boards.
4. As a general rule, due to mounting heights, lower wattage luminaires are used, commonly 1000 watt.

APPENDIX M: Catalog Information

Kawneer Wall System

1600 Wall System®3

Design with Innovation, Imagination and Inside/Outside Glazing

Medical College of Georgia Children's Medical Center, Augusta, GA
Architect: Stanley, Beaman & Sears Architecture, Atlanta, GA
Glazing Contractor: T & L Services, Inc., Palmetto, GA

Inside/outside-glazed 1600 Wall System®3 from yesterday's pioneer and today's leader provides everything you ever wanted in curtain wall systems. 1600 Wall System®3 incorporates inside glazing and the patented IsoStrut® Thermal Break to provide first-rate structural capability, outstanding thermal performance and installation economies. And it's versatile enough for low-rise, high-rise and monumental curtain wall applications – from offices to hospitals and government buildings to art centers.

Performance

Thermal and wind-load requirements are increasing at both federal and state levels. 1600 Wall System®3 has been developed as a response to the need for a true thermally broken system with greater structural performance. The patented IsoStrut® method is used within the mullions of the inside or outside glazed curtain wall system to create a continuous thermal barrier, which substantially reduces thermal transmission and improves condensation resistance and

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structural performance. IsoStrut® achieves a high-strength bond between the interior and exterior aluminum and the thermal isolator, which creates a composite assembly for increased structural performance. 1600 Wall System®3 has been tested in accordance with all major standards for curtain walls:

Air Infiltration	ASTM E283
Static Water Penetration	ASTM E331
Dynamic Water Penetration	AAMA 501.2
Thermal Transmittance	AAMA 1503.1
Structural Performance	ASTM E330
Seismic	UBC Section No. 2334, (H) 2 (Phase I, Phase II)

Economy

Inside-glazed 1600 Wall System®3 provides a major reduction in installation costs and re-glazing is much easier and less costly. 1600 Wall System®3 is part of Kawneer's 1600 Wall series and is fully compatible and interchangeable with 1600 Wall System®1 and 1600 Wall System®2. Standardization of overall depths to 6" (152.4) and 7-1/2" (190.5) means fewer parts to inventory and simplified work for architects.

In addition, the IsoStrut® vertical mullion reduces labor costs because the mullion, cover and thermal isolator are integral. There are no vertical pressure plates, screws, thermal separators or snap-on covers to install. Further labor savings can be gained by pre-installing horizontal pressure plates. Outside glazing can easily be achieved by installing the pressure plates from the outside after the glass is in place. This option is often used in spandrel areas, and re-glazing can be done from the outside without disrupting the building occupants.

One Ballantyne, Ballantyne Corporate Park, Charlotte, NC
Architect: TBA² Architects, Charlotte, NC
Glazing Contractor: Cabarrus Glass Company, Inc., Concord, NC

Aesthetics

1600 Wall System®3 gives designers the greater flexibility of a true inside/outside glazed system, which allows for different exterior and interior finishes, and creates unlimited design possibilities with associated cost savings. Construction flexibility allows a structural silicone glazing option. 1600 Wall System®3 has no exposed fasteners, and a 1600 GLASSvent™ option offers designers a concealed ventilator with uninterrupted sightlines.

For the Finishing Touch

Permanodic® Anodized finishes are available in Class I and Class II in seven different color choices.

Painted finishes, including fluoropolymer, that meet or exceed AAMA 2605 are offered in many standard choices and an unlimited number of specially-designed colors.

Solvent-free powder coatings add the "green" element with high performance, durability and scratch resistance that meet the standards of AAMA 2604.

Note: Numbers in parentheses ( ) are millimeters unless otherwise noted.

Kawneer Company, Inc.
Technology Park / Atlanta
555 Guthridge Court
Norcross, GA 30092

kawneer.com
770 . 449 . 5555

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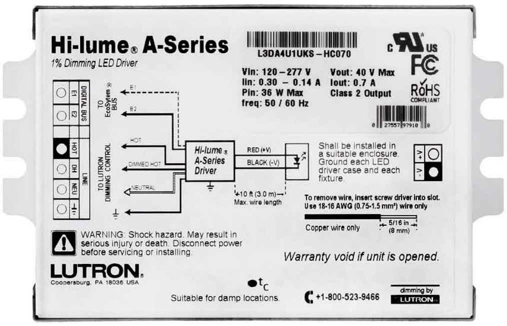
Hi-lume® A-Series Driver Overview
EcoSystem® or 3-wire control

Hi-lume® A-Series Driver is a high-performance LED driver that provides smooth, continuous 1% dimming for virtually any LED fixture, whether it requires constant current or constant voltage. It is the most versatile LED driver offered today due to its compatibility with a wide variety of LED arrays, multiple form factors, and numerous control options.

Features

- Continuous, flicker-free dimming from 100% to 1%.
- Compatible with Energi Savr Node™ with EcoSystem® unit, GRAFIK Eye® QS control unit, PowPak™ dimming module with EcoSystem®, and Quantum® systems, allowing for integration into a planned or existing EcoSystem® lighting control solution. Please see chart at the end of this document or contact Lutron for details regarding compatible controls.
- Standard 3-wire line-voltage phase-control technology for consistent dimming performance and compatibility with all Lutron® 3-wire fluorescent controls.
- Protected from miswires of input power to EcoSystem® control inputs.
- 100% performance tested at factory.
- 100% burned in at factory.
- A rated lifetime of 50,000 hours @ t_C = 149 °F (65 °C).
- UL recognized for United States and Canada.
- FCC Part 15 compliant for commercial applications at 120 V∼ or 277 V∼.
- Pulse Width Modulation (PWM) or Constant Current Reduction (CCR) dimming methods available. See Application Note #360 for details.
- For more information please go to: www.lutron.com/HilumeLED



Hi-lume® A-Series, case type K

3.00 in (76 mm) W x 1.00 in (25 mm) H x 4.90 in (124 mm) L

Hi-lume® A-Series, case type M

1.18 in (30 mm) W x 1.00 in (25 mm) H x 14.25 in (362 mm) L

For Fixture type B

LUTRON® SPECIFICATION SUBMITTAL Page 1

Job Name:	Model Numbers:
Job Number:	

Specifications

Performance

- Dimming Range: 100% to 1%
- Operating Voltage: 120-277 V∼ at 50/60 Hz
- A rated lifetime of 50,000 hours @ t_c = 149 °F (65 °C). Contact Lutron for derating information.
- Patented thermal foldback protection
- LEDs turn on to any dimmed level without going to full brightness.
- Nonvolatile memory restores all driver settings after power failure.
- Power Factor: >0.90 at 40 W
- Standby Power Consumption: <1.0 W
- Total Harmonic Distortion (THD): <20% at 40 W
- Inrush Current: <2 A
- Inrush Current Limiting Circuitry: eliminates circuit breaker tripping, switch arcing and relay failure.
- Open circuit protected
- Short circuit protected
- Turn-on time: ≤ 1 second
- PWM Dimming Frequency: 550 Hz

Environmental

- Sound Rating: Class A.
- Relative Humidity: Maximum 90% non-condensing.
- Minimum operating ambient temperature t_a = 32 °F (0 °C).

Standards

- Meets ANSI C62.41 category A surge protection standards up to and including 4 kV.
- FCC Part 15 compliant for commercial applications at 120 V∼ or 277 V∼.
- Manufacturing facilities employ ESD reduction practices that comply with the requirements of ANSI/ESD S20.20.
- Lutron® Quality Systems registered to ISO 9001.2008.
- UL 8750 recognized.
- Class 2 output available.
- Models available to meet LED Driver requirements for Energy Star 1.1.

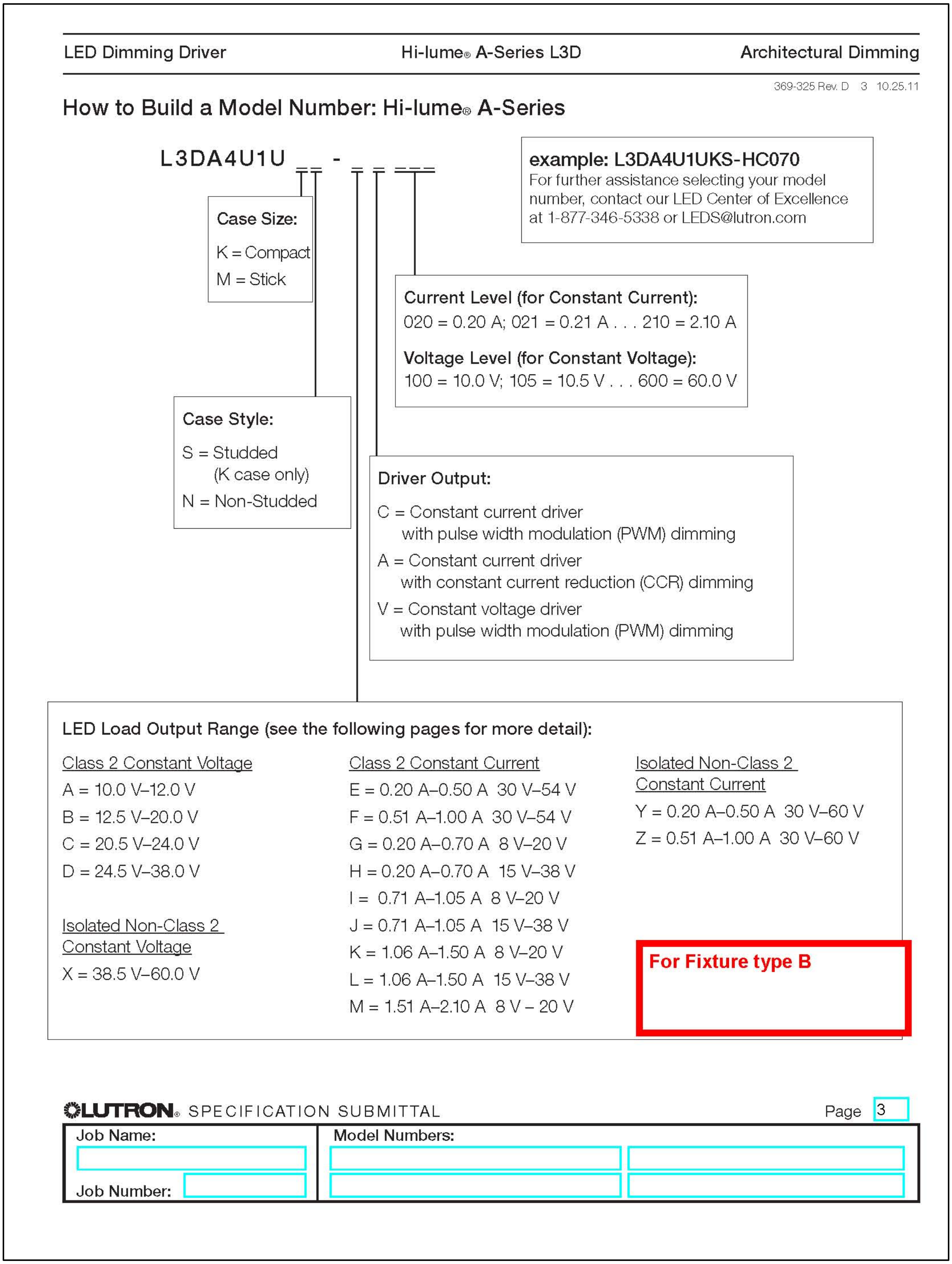
Driver Wiring & Mounting

- Driver is grounded by a mounting screw to the grounded fixture (or by terminal connection on the K case).
- Terminal blocks on the driver accept one solid wire per terminal from 18 to 16 AWG (0.75 to 1.5 mm²).
- Fixture must be grounded in accordance with local and national electrical codes.
- Maximum driver–to–LED light engine wire length is 10 ft (3.0 m).

For Fixture type B

LUTRON® SPECIFICATION SUBMITTAL Page 2

Job Name:	Model Numbers:	
Job Number:		



How to Build a Model Number: Hi-lume® A-Series

L3DA4U1U _ _ - _ _ _ _ _

example: L3DA4U1UKS-HC070
For further assistance selecting your model number, contact our LED Center of Excellence at 1-877-346-5338 or LEDS@lutron.com

Case Size:
K = Compact
M = Stick

Case Style:
S = Studded (K case only)
N = Non-Studded

Current Level (for Constant Current):
020 = 0.20 A; 021 = 0.21 A . . . 210 = 2.10 A

Voltage Level (for Constant Voltage):
100 = 10.0 V; 105 = 10.5 V . . . 600 = 60.0 V

Driver Output:
C = Constant current driver with pulse width modulation (PWM) dimming
A = Constant current driver with constant current reduction (CCR) dimming
V = Constant voltage driver with pulse width modulation (PWM) dimming

LED Load Output Range (see the following pages for more detail):

Class 2 Constant Voltage
A = 10.0 V–12.0 V
B = 12.5 V–20.0 V
C = 20.5 V–24.0 V
D = 24.5 V–38.0 V

Isolated Non-Class 2 Constant Voltage
X = 38.5 V–60.0 V

Class 2 Constant Current
E = 0.20 A–0.50 A 30 V–54 V
F = 0.51 A–1.00 A 30 V–54 V
G = 0.20 A–0.70 A 8 V–20 V
H = 0.20 A–0.70 A 15 V–38 V
I = 0.71 A–1.05 A 8 V–20 V
J = 0.71 A–1.05 A 15 V–38 V
K = 1.06 A–1.50 A 8 V–20 V
L = 1.06 A–1.50 A 15 V–38 V
M = 1.51 A–2.10 A 8 V – 20 V

Isolated Non-Class 2 Constant Current
Y = 0.20 A–0.50 A 30 V–60 V
Z = 0.51 A–1.00 A 30 V–60 V

For Fixture type B

LUTRON® SPECIFICATION SUBMITTAL

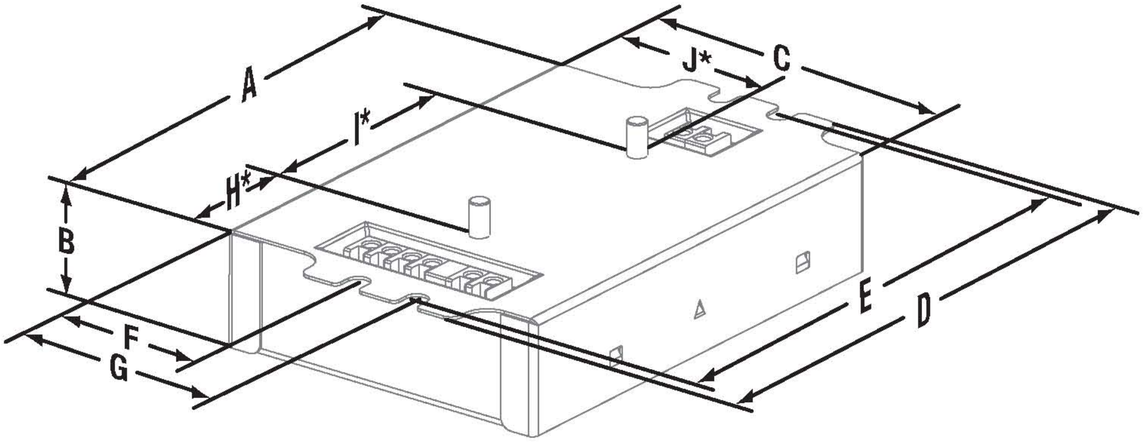
Page 3

Job Name:

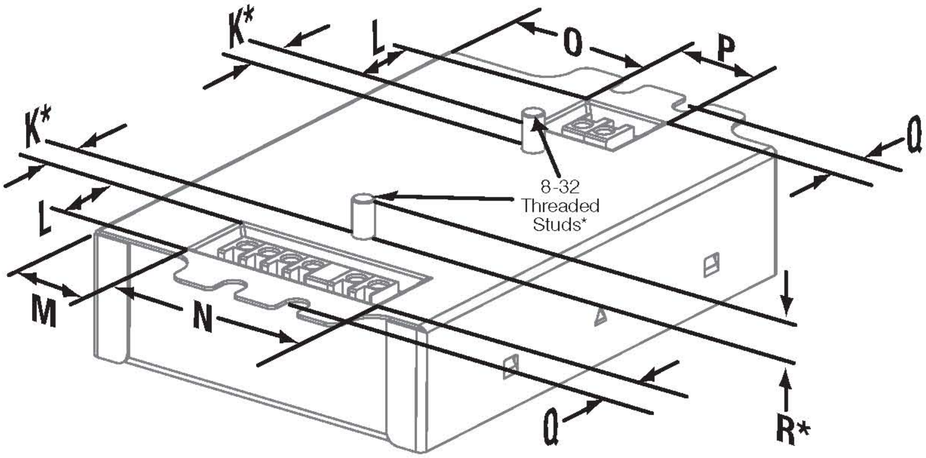
Job Number:

Model Numbers:

K Case: Case Dimensions



K Case: Connector Location Dimensions



A	4.20 in (107 mm)	F	1.42 in (36 mm)	L	0.65 in (16.5 mm)	R*	0.29 in (7 mm)
B	1.00 in (25 mm)	G	1.99 in (51 mm)	M	0.75 in (19 mm)		
C	3.00 in (76 mm)	H*	1.11 in (28 mm)	N	1.73 in (44 mm)		
D	4.90 in (124 mm)	I*	2.00 in (51 mm)	O	1.33 in (34 mm)		
E	4.60 in (117 mm) (mounting center)	J*	1.60 in (41 mm)	P	0.74 in (19 mm)		
		K*	0.33 in (8.3 mm)	Q	0.32 in (8 mm)		

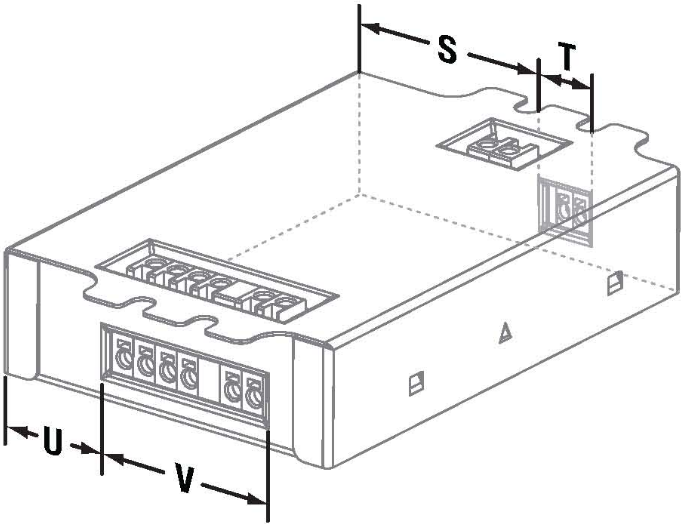
For Fixture type B

* Applies to studded K case only.

LUTRON® SPECIFICATION SUBMITTAL Page 20

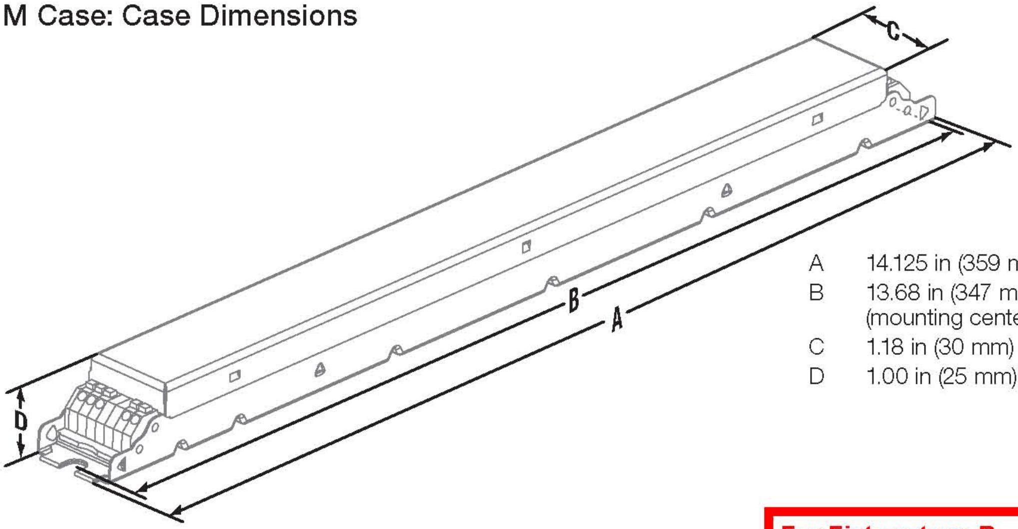
Job Name:	Model Numbers:
Job Number:	

K Case: Side Entry Connector Location Dimensions (Non-Studded)



S	1.38 in (35 mm)
T	0.64 in (16 mm)
U	0.88 in (22 mm)
V	1.53 in (39 mm)

M Case: Case Dimensions



A	14.125 in (359 mm)
B	13.68 in (347 mm) (mounting center)
C	1.18 in (30 mm)
D	1.00 in (25 mm)

For Fixture type B

LUTRON® SPECIFICATION SUBMITTAL Page 21

Job Name:

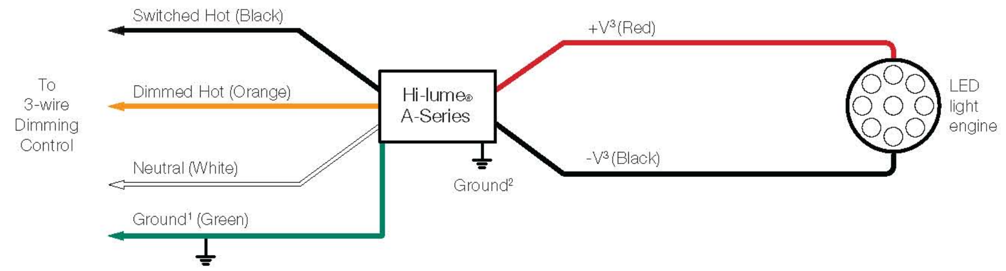
Job Number:

Model Numbers:

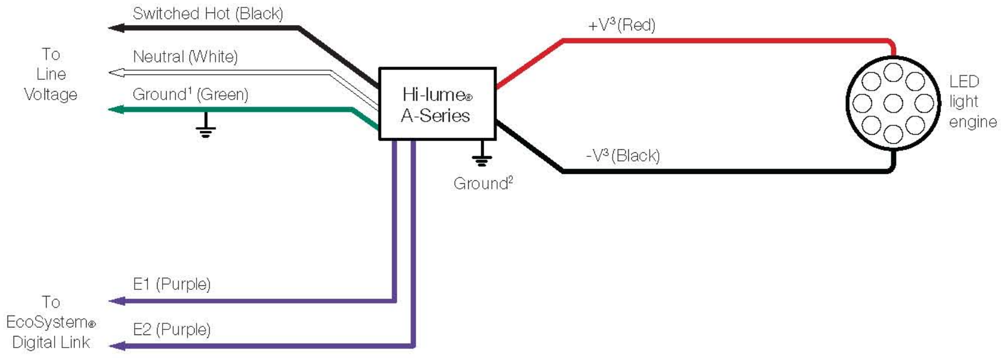
LED Dimming Driver | Hi-lume® A-Series L3D | Architectural Dimming

369-325 Rev. D 22 10.25.11

Wiring Diagram for 3-Wire Control



Wiring Diagram for EcoSystem® Digital Control



Note: Colors shown correspond to terminal blocks on driver.

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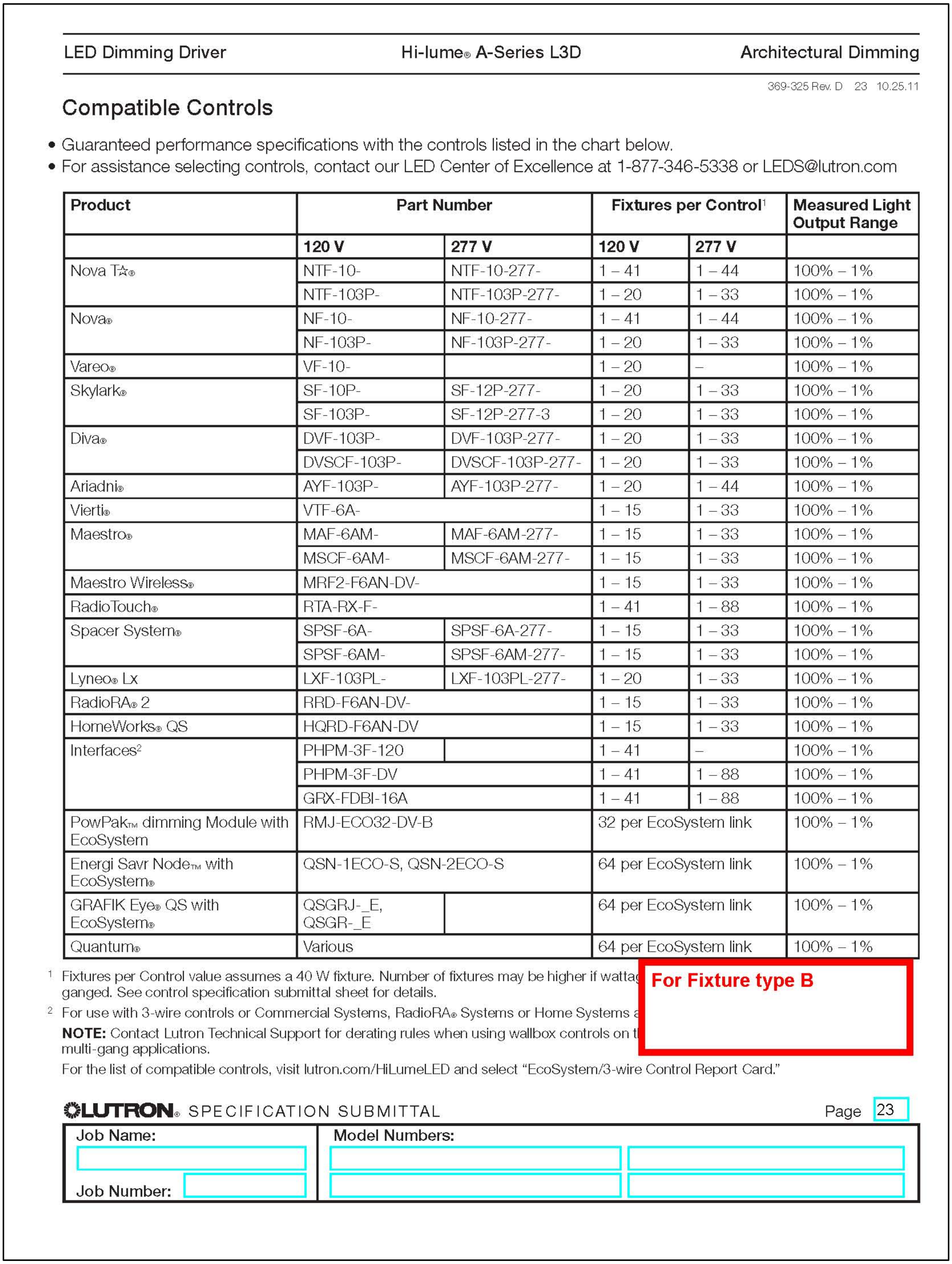
[1] Ground wire connection available on K case models only.
[2] Fixture and driver case must be grounded in accordance with local and national electrical codes.
[3] Maximum driver–to–LED light engine wire length is 10 ft (3.0 m).

For Fixture type B

LUTRON® SPECIFICATION SUBMITTAL

Page 22

Job Name:	Model Numbers:
Job Number:	



LED Dimming Driver Hi-lume® A-Series L3D Architectural Dimming

369-325 Rev. D 23 10.25.11

Compatible Controls

- Guaranteed performance specifications with the controls listed in the chart below.
- For assistance selecting controls, contact our LED Center of Excellence at 1-877-346-5338 or LEDS@lutron.com

Product	Part Number		Fixtures per Control[1]		Measured Light Output Range
	120 V	**277 V**	**120 V**	**277 V**	
Nova T☆®	NTF-10-	NTF-10-277-	1 – 41	1 – 44	100% – 1%
	NTF-103P-	NTF-103P-277-	1 – 20	1 – 33	100% – 1%
Nova®	NF-10-	NF-10-277-	1 – 41	1 – 44	100% – 1%
	NF-103P-	NF-103P-277-	1 – 20	1 – 33	100% – 1%
Vareo®	VF-10-		1 – 20	–	100% – 1%
Skylark®	SF-10P-	SF-12P-277-	1 – 20	1 – 33	100% – 1%
	SF-103P-	SF-12P-277-3	1 – 20	1 – 33	100% – 1%
Diva®	DVF-103P-	DVF-103P-277-	1 – 20	1 – 33	100% – 1%
	DVSCF-103P-	DVSCF-103P-277-	1 – 20	1 – 33	100% – 1%
Ariadni®	AYF-103P-	AYF-103P-277-	1 – 20	1 – 44	100% – 1%
Vierti®	VTF-6A-		1 – 15	1 – 33	100% – 1%
Maestro®	MAF-6AM-	MAF-6AM-277-	1 – 15	1 – 33	100% – 1%
	MSCF-6AM-	MSCF-6AM-277-	1 – 15	1 – 33	100% – 1%
Maestro Wireless®	MRF2-F6AN-DV-		1 – 15	1 – 33	100% – 1%
RadioTouch®	RTA-RX-F-		1 – 41	1 – 88	100% – 1%
Spacer System®	SPSF-6A-	SPSF-6A-277-	1 – 15	1 – 33	100% – 1%
	SPSF-6AM-	SPSF-6AM-277-	1 – 15	1 – 33	100% – 1%
Lyneo® Lx	LXF-103PL-	LXF-103PL-277-	1 – 20	1 – 33	100% – 1%
RadioRA® 2	RRD-F6AN-DV-		1 – 15	1 – 33	100% – 1%
HomeWorks® QS	HQRD-F6AN-DV		1 – 15	1 – 33	100% – 1%
Interfaces[2]	PHPM-3F-120		1 – 41	–	100% – 1%
	PHPM-3F-DV		1 – 41	1 – 88	100% – 1%
	GRX-FDBI-16A		1 – 41	1 – 88	100% – 1%
PowPak™ dimming Module with EcoSystem	RMJ-ECO32-DV-B		32 per EcoSystem link		100% – 1%
Energi Savr Node™ with EcoSystem®	QSN-1ECO-S, QSN-2ECO-S		64 per EcoSystem link		100% – 1%
GRAFIK Eye® QS with EcoSystem®	QSGRJ-_E, QSGR-_E		64 per EcoSystem link		100% – 1%
Quantum®	Various		64 per EcoSystem link		100% – 1%

[1] Fixtures per Control value assumes a 40 W fixture. Number of fixtures may be higher if wattag ganged. See control specification submittal sheet for details.

[2] For use with 3-wire controls or Commercial Systems, RadioRA® Systems or Home Systems a

NOTE: Contact Lutron Technical Support for derating rules when using wallbox controls on t multi-gang applications.

For the list of compatible controls, visit lutron.com/HiLumeLED and select "EcoSystem/3-wire Control Report Card."

For Fixture type B

LUTRON® SPECIFICATION SUBMITTAL Page 23

Job Name:

Job Number:

Model Numbers:

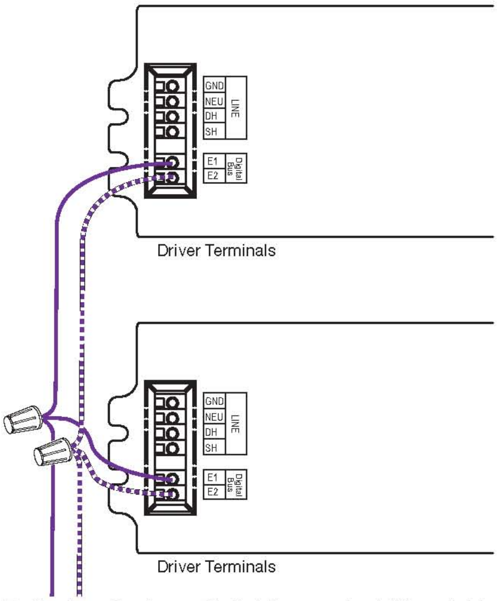
EcoSystem® Wiring Diagrams

EcoSystem® Digital Link Overview

- The EcoSystem® Digital Link wiring (E1 and E2) connects the digital ballasts and drivers together to form a lighting control system.
- Each EcoSystem® Digital Link supports up to 64 digital ballasts, LED drivers or EcoSystem® Modules (e.g. C5-BMJ-16A, C5-XPJ-16A), 32 occupancy sensors (64 occupancy sensors with Energi Savr Node™ with EcoSystem®), 16 daylight sensors, and 64 wallstations or IR receivers.*
- Sensors do not directly connect to Hi-Lume® A-Series LED drivers.
- E1 and E2 (EcoSystem® digital link wires) are polarity insensitive and can be wired in any topology.
- An Energi Savr Node™ with EcoSystem® unit, GRAFIK Eye® QS control unit with EcoSystem®, PowPak™ dimming module with EcoSystem®, or Quantum® system provides power for the EcoSystem® Digital Link and supports system programming.*
- All EcoSystem® Digital Link programming is completed by using the Energi Savr App for *Apple iPad, iPod Touch* or *iPhone* mobile digital devices, GRAFIK Eye® QS with EcoSystem®, PowPak™ dimming module with EcoSystem®, or Quantum® System.

EcoSystem® Digital Link Wiring

- Driver EcoSystem® Digital Link terminals only accept one 18 to 16 AWG (0.75 to 1.5 mm²) solid copper wire per terminal.
- Make sure that the supply breaker to the Digital Driver and EcoSystem® Digital Link Supply is OFF when wiring.
- Connect the two conductors to the two Digital Driver terminals E1 and E2 as shown.
- Using two different colors for E1 and E2 will reduce confusion when wiring several drivers together.
- The EcoSystem® Digital Link may be wired Class 1 or IEC/PELV NEC® Class 2. Consult applicable electrical codes for proper wiring practices.



To the EcoSystem® Digital Bus and additional drivers and/or ballasts

Notes

- The EcoSystem® Digital Link Supply does not have to be located at the end of the Digital Link.
- EcoSystem® Digital Link length is limited by the wire gauge used for E1 and E2 as follows:

Wire Gauge	Digital Link Length (max)
12 AWG	2200 ft
14 AWG	1400 ft
16 AWG	900 ft
18 AWG	550 ft

Wire Size	Digital Link Length (max)
4.0 mm²	828 m
2.5 mm²	
1.5 mm²	
1.0 mm²	
0.75 mm²	

For Fixture type B

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* PowPak™ dimming module with EcoSystem® provides power for the EcoSystem® Digital Link and can support 32 digital ballasts, LED drivers or EcoSystem® Modules, 6 Wireless Occupancy Sensors, 1 Wireless Daylight Sensor, and 9 Pico Wireless Controllers.

LUTRON® SPECIFICATION SUBMITTAL Page 24

Job Name:	Model Numbers:	
Job Number:		

ELECTRICIANS AND CONTRACTORS

Driver Leads

Maximum driver–to–LED light engine wire length is 10 ft (3.0 m).

Wiring and Grounding

Driver and lighting fixture must be grounded. Drivers must be installed per national and local electrical codes.

LED Load Replacement

For Class 2 rated drivers, the LED load can be changed while the driver is installed and powered.

Maximum Driver Operating Temperature

Driver case temperature (t_C) must not exceed UL conditions of acceptability in end product.

For 50,000 hour lifetime, driver case temperature (t_C) must not exceed 149 °F (65 °C).

FACILITIES MANAGERS

SERVICE

Warranty

For warranty information, please visit http://www.lutron.com/TechnicalDocumentLibrary/Ballast%20and%20Driver%20Warranty.pdf

Replacement Parts

When ordering Lutron® replacement parts please provide the full model number. Consult Lutron if you have any questions.

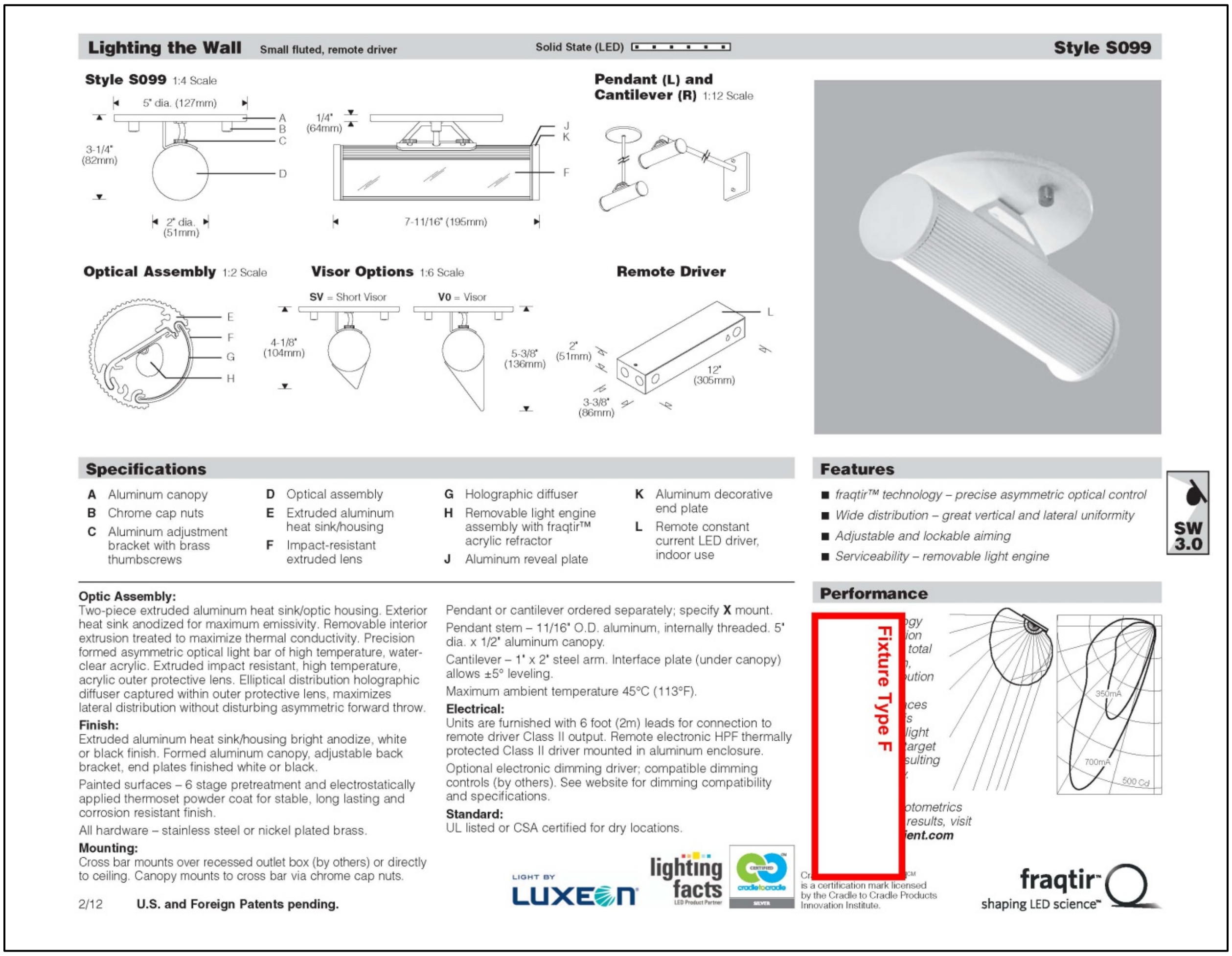
Further Information

For further information, please visit us at www.lutron.com/hilumeLED or contact our LED Control Center of Excellence at 1.877.346.5338 or LEDs@lutron.com

For Fixture type B

LUTRON® SPECIFICATION SUBMITTAL Page 25

Job Name:	Model Numbers:
Job Number:	



Lighting the Wall

Small fluted, remote driver

Solid State (LED)

Style S099

Style S099 1:4 Scale

Pendant (L) and Cantilever (R) 1:12 Scale

Optical Assembly 1:2 Scale

Visor Options 1:6 Scale

Remote Driver

Specifications

A	Aluminum canopy	**D**	Optical assembly	**G**	Holographic diffuser	**K**	Aluminum decorative end plate
B	Chrome cap nuts	**E**	Extruded aluminum heat sink/housing	**H**	Removable light engine assembly with fraqtir™ acrylic refractor	**L**	Remote constant current LED driver, indoor use
C	Aluminum adjustment bracket with brass thumbscrews	**F**	Impact-resistant extruded lens	**J**	Aluminum reveal plate		

Optic Assembly:
Two-piece extruded aluminum heat sink/optic housing. Exterior heat sink anodized for maximum emissivity. Removable interior extrusion treated to maximize thermal conductivity. Precision formed asymmetric optical light bar of high temperature, water-clear acrylic. Extruded impact resistant, high temperature, acrylic outer protective lens. Elliptical distribution holographic diffuser captured within outer protective lens, maximizes lateral distribution without disturbing asymmetric forward throw.

Finish:
Extruded aluminum heat sink/housing bright anodize, white or black finish. Formed aluminum canopy, adjustable back bracket, end plates finished white or black.

Painted surfaces – 6 stage pretreatment and electrostatically applied thermoset powder coat for stable, long lasting and corrosion resistant finish.

All hardware – stainless steel or nickel plated brass.

Mounting:
Cross bar mounts over recessed outlet box (by others) or directly to ceiling. Canopy mounts to cross bar via chrome cap nuts.

Pendant or cantilever ordered separately; specify **X** mount.

Pendant stem – 11/16" O.D. aluminum, internally threaded. 5" dia. x 1/2" aluminum canopy.

Cantilever – 1" x 2" steel arm. Interface plate (under canopy) allows ±5° leveling.

Maximum ambient temperature 45°C (113°F).

Electrical:
Units are furnished with 6 foot (2m) leads for connection to remote driver Class II output. Remote electronic HPF thermally protected Class II driver mounted in aluminum enclosure.

Optional electronic dimming driver; compatible dimming controls (by others). See website for dimming compatibility and specifications.

Standard:
UL listed or CSA certified for dry locations.

2/12 **U.S. and Foreign Patents pending.**

Features

- *fraqtir™ technology – precise asymmetric optical control*
- *Wide distribution – great vertical and lateral uniformity*
- *Adjustable and lockable aiming*
- *Serviceability – removable light engine*

Performance

Fixture Type F

gy
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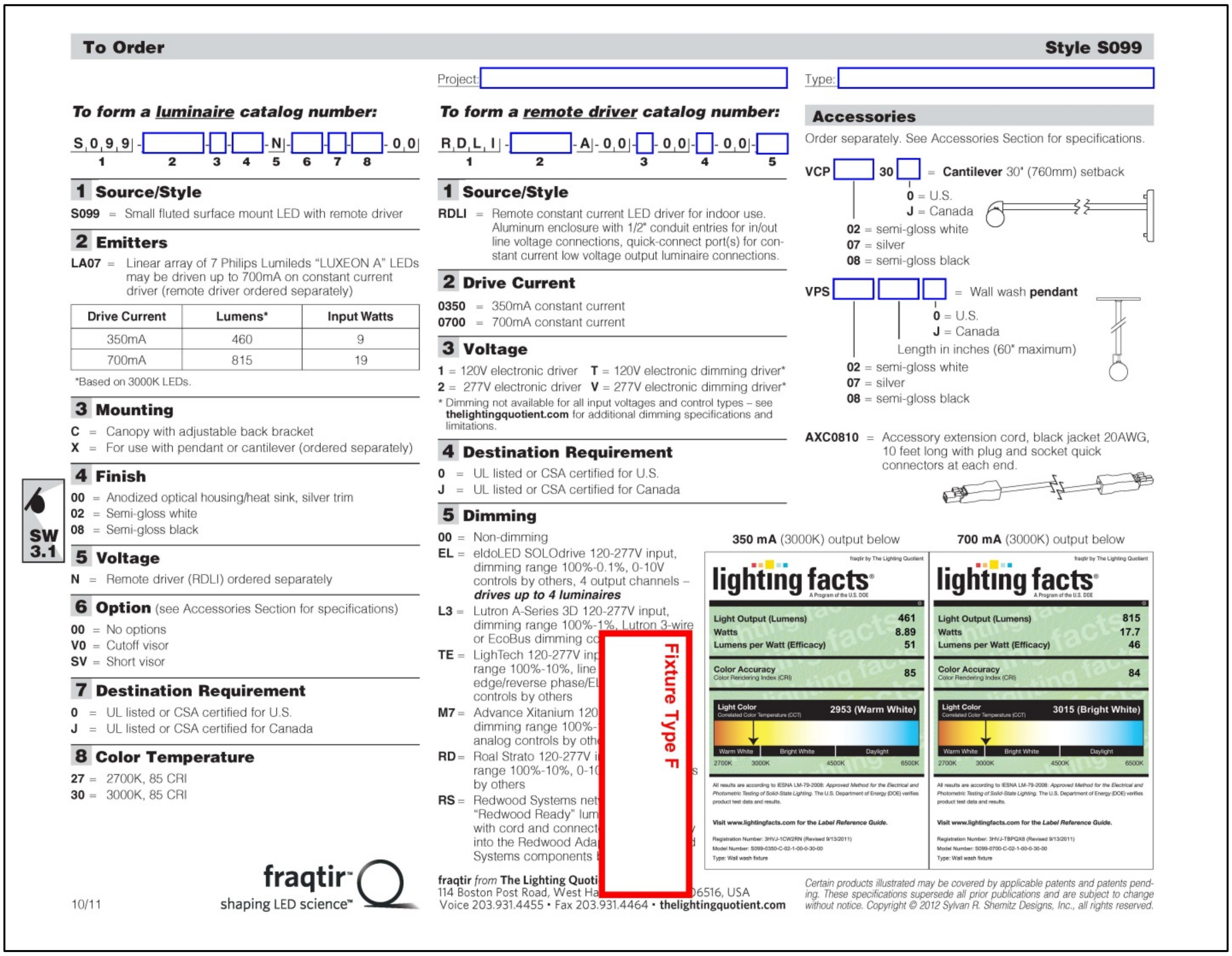
otometrics
results, visit
ient.com

Cr ℠
is a certification mark licensed by the Cradle to Cradle Products Innovation Institute.

fraqtir™
shaping LED science™



To Order

Style S099

Project: ☐

Type: ☐

To form a luminaire catalog number:

S099 - ☐ - ☐ - ☐ - N - ☐ - ☐ - ☐ - 00
1 2 3 4 5 6 7 8

1 Source/Style

S099 = Small fluted surface mount LED with remote driver

2 Emitters

LA07 = Linear array of 7 Philips Lumileds "LUXEON A" LEDs may be driven up to 700mA on constant current driver (remote driver ordered separately)

Drive Current	Lumens*	Input Watts
350mA	460	9
700mA	815	19

*Based on 3000K LEDs.

3 Mounting

C = Canopy with adjustable back bracket
X = For use with pendant or cantilever (ordered separately)

4 Finish

00 = Anodized optical housing/heat sink, silver trim
02 = Semi-gloss white
08 = Semi-gloss black

SW 3.1

5 Voltage

N = Remote driver (RDLI) ordered separately

6 Option (see Accessories Section for specifications)

00 = No options
V0 = Cutoff visor
SV = Short visor

7 Destination Requirement

0 = UL listed or CSA certified for U.S.
J = UL listed or CSA certified for Canada

8 Color Temperature

27 = 2700K, 85 CRI
30 = 3000K, 85 CRI

10/11

fraqtir™
shaping LED science™

To form a remote driver catalog number:

RDLI - ☐ - A - 00 - ☐ - 00 - ☐ - 00 - ☐
1 2 3 4 5

1 Source/Style

RDLI = Remote constant current LED driver for indoor use. Aluminum enclosure with 1/2" conduit entries for in/out line voltage connections, quick-connect port(s) for constant current low voltage output luminaire connections.

2 Drive Current

0350 = 350mA constant current
0700 = 700mA constant current

3 Voltage

1 = 120V electronic driver **T** = 120V electronic dimming driver*
2 = 277V electronic driver **V** = 277V electronic dimming driver*

* Dimming not available for all input voltages and control types – see **thelightingquotient.com** for additional dimming specifications and limitations.

4 Destination Requirement

0 = UL listed or CSA certified for U.S.
J = UL listed or CSA certified for Canada

5 Dimming

00 = Non-dimming
EL = eldoLED SOLOdrive 120-277V input, dimming range 100%-0.1%, 0-10V controls by others, 4 output channels – ***drives up to 4 luminaires***
L3 = Lutron A-Series 3D 120-277V input, dimming range 100%-1%, Lutron 3-wire or EcoBus dimming co
TE = LighTech 120-277V inp range 100%-10%, line edge/reverse phase/EL controls by others
M7 = Advance Xitanium 120 dimming range 100%- analog controls by oth
RD = Roal Strato 120-277V i range 100%-10%, 0-10 s by others
RS = Redwood Systems net "Redwood Ready" lum with cord and connect y into the Redwood Ada d Systems components

Fixture Type F

fraqtir *from* **The Lighting Quoti**
114 Boston Post Road, West Ha 06516, USA
Voice 203.931.4455 • Fax 203.931.4464 • **thelightingquotient.com**

Accessories

Order separately. See Accessories Section for specifications.

VCP ☐ **30** ☐ = **Cantilever** 30" (760mm) setback
0 = U.S.
J = Canada
02 = semi-gloss white
07 = silver
08 = semi-gloss black

VPS ☐ ☐ ☐ = Wall wash **pendant**
0 = U.S.
J = Canada
Length in inches (60" maximum)
02 = semi-gloss white
07 = silver
08 = semi-gloss black

AXC0810 = Accessory extension cord, black jacket 20AWG, 10 feet long with plug and socket quick connectors at each end.

350 mA (3000K) output below

fraqtir by The Lighting Quotient
lighting facts®
A Program of the U.S. DOE

Light Output (Lumens)	461
Watts	8.89
Lumens per Watt (Efficacy)	51
Color Accuracy Color Rendering Index (CRI)	85
Light Color Correlated Color Temperature (CCT)	2953 (Warm White)

Warm White | Bright White | Daylight
2700K 3000K 4500K 6500K

All results are according to IESNA LM-79-2008: *Approved Method for the Electrical and Photometric Testing of Solid-State Lighting.* The U.S. Department of Energy (DOE) verifies product test data and results.

Visit www.lightingfacts.com for the *Label Reference Guide.*

Registration Number: 3HVJ-1CW2RN (Revised 9/13/2011)
Model Number: S099-0350-C-02-1-00-0-30-00
Type: Wall wash fixture

700 mA (3000K) output below

fraqtir by The Lighting Quotient
lighting facts®
A Program of the U.S. DOE

Light Output (Lumens)	815
Watts	17.7
Lumens per Watt (Efficacy)	46
Color Accuracy Color Rendering Index (CRI)	84
Light Color Correlated Color Temperature (CCT)	3015 (Bright White)

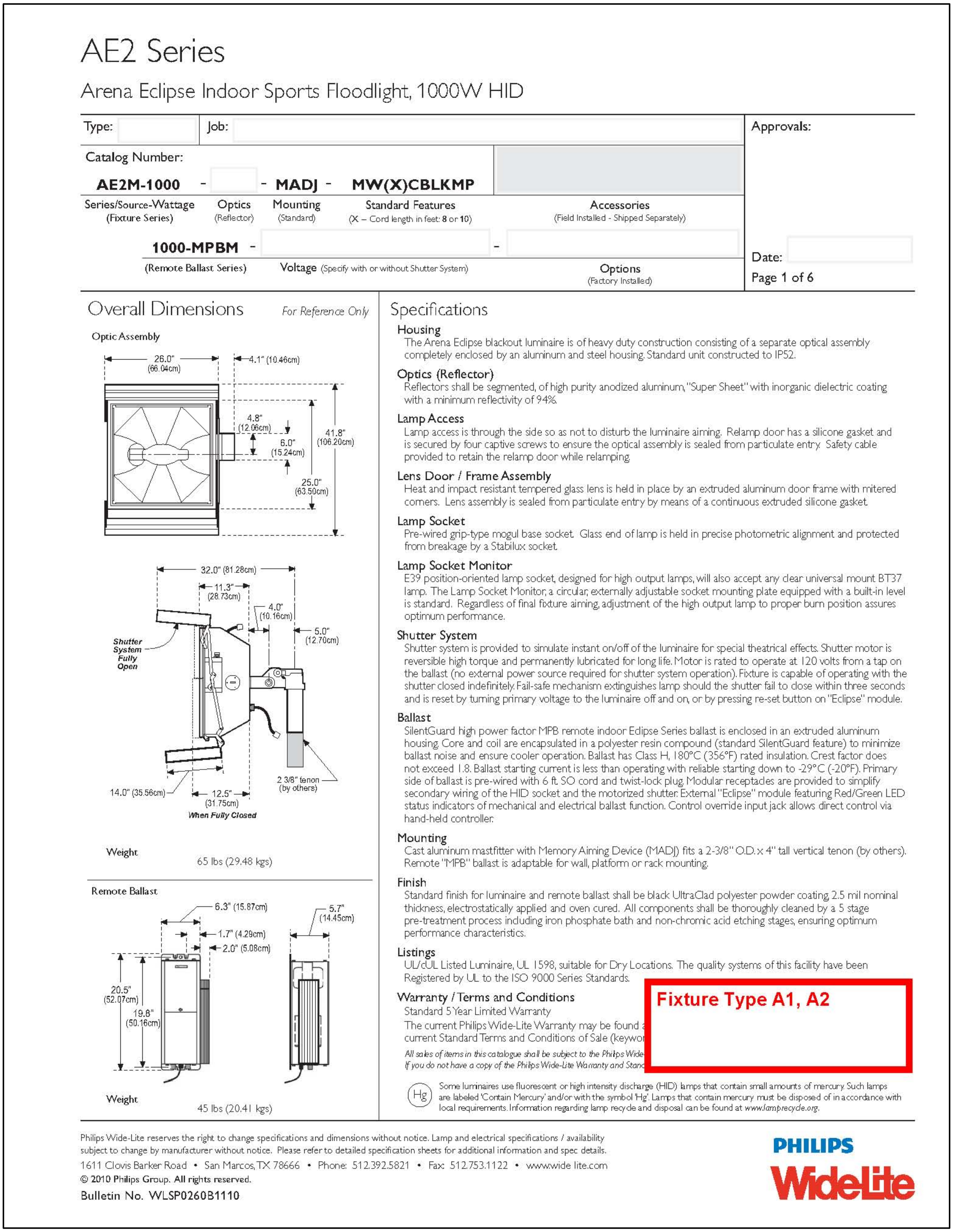
Warm White | Bright White | Daylight
2700K 3000K 4500K 6500K

All results are according to IESNA LM-79-2008: *Approved Method for the Electrical and Photometric Testing of Solid-State Lighting.* The U.S. Department of Energy (DOE) verifies product test data and results.

Visit www.lightingfacts.com for the *Label Reference Guide.*

Registration Number: 3HVJ-TBPQX8 (Revised 9/13/2011)
Model Number: S099-0700-C-02-1-00-0-30-00
Type: Wall wash fixture

Certain products illustrated may be covered by applicable patents and patents pending. These specifications supersede all prior publications and are subject to change without notice.



AE2 Series

Arena Eclipse Indoor Sports Floodlight, 1000W HID

Type: | Job: | Approvals:

Catalog Number:

AE2M-1000 - - **MADJ** - **MW(X)CBLKMP**

Series/Source-Wattage (Fixture Series) | Optics (Reflector) | Mounting (Standard) | Standard Features (X – Cord length in feet: 8 or 10) | Accessories (Field Installed - Shipped Separately)

1000-MPBM - -

(Remote Ballast Series) | Voltage (Specify with or without Shutter System) | Options (Factory Installed)

Date:

Page 1 of 6

Overall Dimensions

For Reference Only

Optic Assembly

Weight

65 lbs (29.48 kgs)

Remote Ballast

Weight

45 lbs (20.41 kgs)

Specifications

Housing

The Arena Eclipse blackout luminaire is of heavy duty construction consisting of a separate optical assembly completely enclosed by an aluminum and steel housing. Standard unit constructed to IP52.

Optics (Reflector)

Reflectors shall be segmented, of high purity anodized aluminum, "Super Sheet" with inorganic dielectric coating with a minimum reflectivity of 94%.

Lamp Access

Lamp access is through the side so as not to disturb the luminaire aiming. Relamp door has a silicone gasket and is secured by four captive screws to ensure the optical assembly is sealed from particulate entry. Safety cable provided to retain the relamp door while relamping.

Lens Door / Frame Assembly

Heat and impact resistant tempered glass lens is held in place by an extruded aluminum door frame with mitered corners. Lens assembly is sealed from particulate entry by means of a continuous extruded silicone gasket.

Lamp Socket

Pre-wired grip-type mogul base socket. Glass end of lamp is held in precise photometric alignment and protected from breakage by a Stabilux socket.

Lamp Socket Monitor

E39 position-oriented lamp socket, designed for high output lamps, will also accept any clear universal mount BT37 lamp. The Lamp Socket Monitor, a circular, externally adjustable socket mounting plate equipped with a built-in level is standard. Regardless of final fixture aiming, adjustment of the high output lamp to proper burn position assures optimum performance.

Shutter System

Shutter system is provided to simulate instant on/off of the luminaire for special theatrical effects. Shutter motor is reversible high torque and permanently lubricated for long life. Motor is rated to operate at 120 volts from a tap on the ballast (no external power source required for shutter system operation). Fixture is capable of operating with the shutter closed indefinitely. Fail-safe mechanism extinguishes lamp should the shutter fail to close within three seconds and is reset by turning primary voltage to the luminaire off and on, or by pressing re-set button on "Eclipse" module.

Ballast

SilentGuard high power factor MPB remote indoor Eclipse Series ballast is enclosed in an extruded aluminum housing. Core and coil are encapsulated in a polyester resin compound (standard SilentGuard feature) to minimize ballast noise and ensure cooler operation. Ballast has Class H, 180°C (356°F) rated insulation. Crest factor does not exceed 1.8. Ballast starting current is less than operating with reliable starting down to -29°C (-20°F). Primary side of ballast is pre-wired with 6 ft. SO cord and twist-lock plug. Modular receptacles are provided to simplify secondary wiring of the HID socket and the motorized shutter. External "Eclipse" module featuring Red/Green LED status indicators of mechanical and electrical ballast function. Control override input jack allows direct control via hand-held controller.

Mounting

Cast aluminum mastfitter with Memory Aiming Device (MADJ) fits a 2-3/8" O.D. x 4" tall vertical tenon (by others). Remote "MPB" ballast is adaptable for wall, platform or rack mounting.

Finish

Standard finish for luminaire and remote ballast shall be black UltraClad polyester powder coating, 2.5 mil nominal thickness, electrostatically applied and oven cured. All components shall be thoroughly cleaned by a 5 stage pre-treatment process including iron phosphate bath and non-chromic acid etching stages, ensuring optimum performance characteristics.

Listings

UL/cUL Listed Luminaire, UL 1598, suitable for Dry Locations. The quality systems of this facility have been Registered by UL to the ISO 9000 Series Standards.

Warranty / Terms and Conditions

Standard 5 Year Limited Warranty

The current Philips Wide-Lite Warranty may be found a

current Standard Terms and Conditions of Sale (keywor

All sales of items in this catalogue shall be subject to the Philips Wide-

If you do not have a copy of the Philips Wide-Lite Warranty and Stand

Fixture Type A1, A2

Hg Some luminaires use fluorescent or high intensity discharge (HID) lamps that contain small amounts of mercury. Such lamps are labeled 'Contain Mercury' and/or with the symbol 'Hg'. Lamps that contain mercury must be disposed of in accordance with local requirements. Information regarding lamp recycle and disposal can be found at *www.lamprecycle.org*.

Philips Wide-Lite reserves the right to change specifications and dimensions without notice. Lamp and electrical specifications / availability subject to change by manufacturer without notice. Please refer to detailed specification sheets for additional information and spec details.

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Bulletin No. WLSP0260B1110

AE2 Series

Arena Eclipse Indoor Sports Floodlight, 1000W HID

Type:	Job:	Page 2 of 6

Fixture Series/Source-Wattage

Metal Halide
☑ **AE2M-1000**

Optics *(Reflector)*

with Shutter System	less Shutter System
☐ **A**	☐ **ALS**
☐ **B**	☐ **BLS**
☐ **N**	☐ **NLS**
☐ **U**	☐ **ULS**

Mounting

☑ **MADJ**	Mastfitter

Cast aluminum mastfitter with Memory Aiming Device

Remote Ballast Series

Metal Halide
☑ **1000-MPBM**

Fixtures are furnished with regulating HPF single voltage ballasts: 120V, 208V, 277V, 347V or 480V.

Voltage

with Shutter System	less Shutter System
☐ **120ESCM-MW-6C-L2320P**	☐ **120-MW-6C-L2320P**
☐ **208ESCM-MW-6C-L2320P**	☐ **208-MW-6C-L2320P**
☐ **277ESCM-MW-6C-L2320P**	☐ **277-MW-6C-L2320P**
☐ **347ESCM-MW-6C-L2320P**	☐ **347-MW-6C-L2320P**
☐ **480ESCM-MW-6C-L2320P**	☐ **480-MW-6C-L2320P**

Options (Factory Installed)

☐ **BL**	Bi-Level (for Less Shutter System)
☐ **BLEM**	Bi-Level (for Shutter System)
☐ **F1**	Single Fuse (120/277/347V)
☐ **F2**	Double Fuse (208/240/480V)

Accessories (Field Installed - Shipped Separately)

☐ **F1-KIT**	Single Fuse Kit (120/277/347V)
☐ **F2-KIT**	Double Fuse Kit (208/240/480V)
☐ **AMB-S**	Single Fixture Mounting Bracket
☐ **AMB-D**	Double Fixture Mounting Bracket
☐ **AE2-STY-CBL**	Fixture Safety Cable
☐ **SRB**	Strain Relief Bracket

Fixture Type A1, A2

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PHILIPS WideLite

AE2 Series

Arena Eclipse Indoor Sports Floodlight, 1000W HID

Type:	Job:	Page 3 of 6

Distribution Guide & Ballast Data [1, 2]

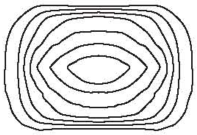
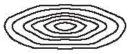
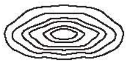
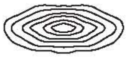
Source Type [1]	Catalog Number	Reflector Type	Lamp [2] Envelope	.ies File Name	Ballast Type [3]	ANSI Code	Line Current 120 / 208 / 277 / 347 / 480	Line Watts
MH	**AE2M-1000**	A	BT37	Consult factory	CWA	M47 / H36	9.2 / 5.6 / 4.7 / 4.1 / 3.2 / 2.4	1080
	AE2M-1000	B	BT37	Consult factory	CWA	M47 / H36	9.2 / 5.6 / 4.7 / 4.1 / 3.2 / 2.4	1080
	AE2M-1000	N	BT37	Consult factory	CWA	M47 / H36	9.2 / 5.6 / 4.7 / 4.1 / 3.2 / 2.4	1080
	AE2M-1000	U	BT37	Consult factory	CWA	M47 / H36	9.2 / 5.6 / 4.7 / 4.1 / 3.2 / 2.4	1080

1) MH = Metal Halide.

2) The Arena Eclipse is designed and installed using high output BT37 clear lamps. Lamp socket will accept any universal burn BT37 clear lamp, however performance will be negatively affected.

3) CWA = Constant Wattage Autotransformer.

Beam Spreads and Distribution Patterns

BEAM PATTERNS Reflector Type	**Wattage/ Source**	**Max Candle Power**	**H x V NEMA**	**BEAM SPREADS Horizontal X Vertical** 10% Field Angle	50% Beam Angle
A 	1000W **MH**	210,981	5 x 4	86° x 62°	44° x 23°
B 	1000W **MH**	399,650	4 x 2	67° x 26°	27° x 11°
N 	1000W **MH**	432,750	4 x 3	66° x 31°	27° x 12°
U 	1000W **MH**	115,000	4 x 2	67° x 28°	27° x 11°

Fixture Type A1, A2

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PHILIPS
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AE2 Series

Arena Eclipse Indoor Sports Floodlight, 1000W HID

Type: Job: Page 4 of 6

Option details (Factory Installed)

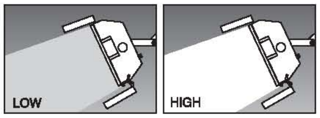
BL *Bi-Level dimming ballast for Less Shutter Systems*

BLEM *Bi-Level dimming ballast for Shutter Systems*

Bi-Level feature is specified as a Ballast Option.

Bi-Level provides high/low level of lamp output with up to 50% power consumption.

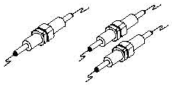
Zero crossover network avoids strobing and lamp dropout.



F1 *Single fuse (120/277/347V)*

F2 *Double fuse (208/240/480V)*

Fuses are DTK/KLK 30 amp unless otherwise specified.



Fixture Type A1, A2

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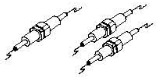
AE2 Series

Arena Eclipse Indoor Sports Floodlight, 1000W HID

Type: Job: Page 5 of 6

Accessory details (Field Installed - Shipped Separately)

F1-KIT	*Single fuse kit (120/277/347V)*	*Consists of 1 or 2 fuse holders and 1 or 2 KTK 20 amp fuses. Field installed.*
F2-KIT	*Double fuse kit (208/240/480V)*	

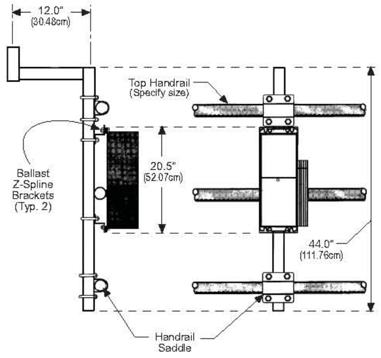


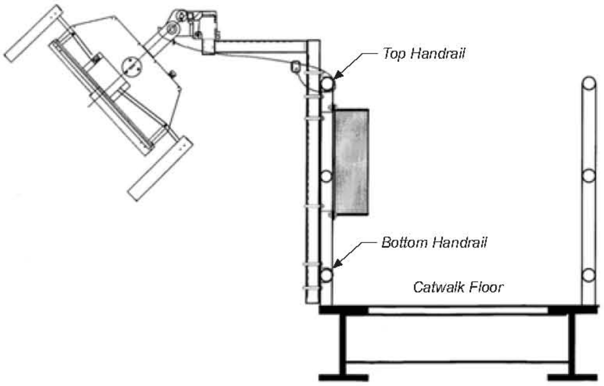
AMB-S *Single fixture mounting bracket*

Bracket for mounting single fixture to catwalk.

Handrail size must be specified. Consult factory.

Shown with Fixture Safety Cables securing fixture at yoke to handrail of catwalk.





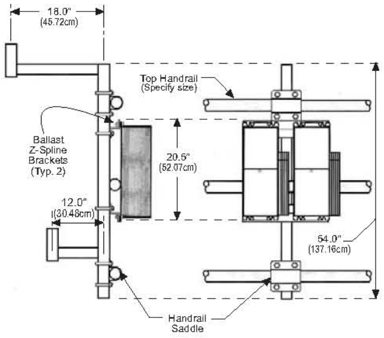
All steel parts are finished Semi-gloss Black.
All hardware zinc plated.
Ends of all exposed tubes are fitted with plastic closures.
Ballasts mount to "Z-Spline" Brackets, attached to fixture mounting bar by U Bolts.
Shipping Wt: 18 lbs. Shipped Unassembled.

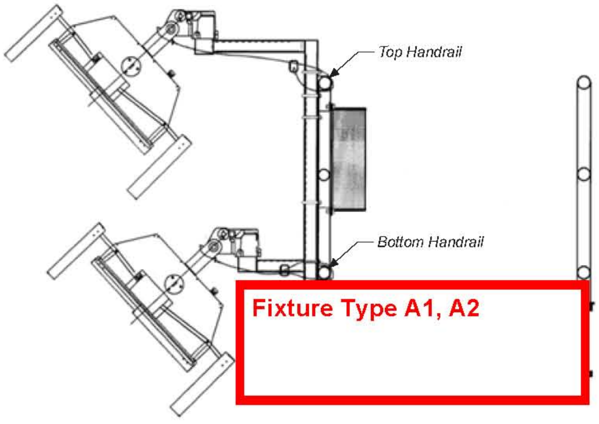
AMB-D *Double fixture mounting bracket*

Bracket for mounting two stacked fixtures to catwalk.

Handrail size must be specified. Consult factory.

Shown with Fixture Safety Cables securing fixture at yoke to handrail of catwalk.





Fixture Type A1, A2

All steel parts are finished Semi-gloss Black.
All hardware zinc plated.
Ends of all exposed tubes are fitted with plastic closures.
Ballasts mount to "Z-Spline" Brackets, attached to fixture mounting bar by U Bolts.
Shipping Wt: 20 lbs. Shipped Unassembled.

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AE2 Series

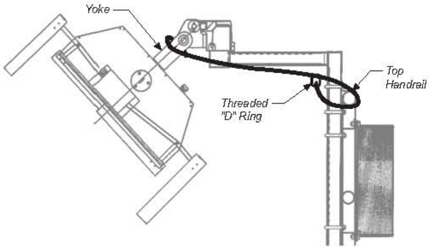
Arena Eclipse Indoor Sports Floodlight, 1000W HID

Type:		Job:		Page 6 of 6

Accessory details continued (Field Installed - Shipped Separately)

AE2-STY-CBL *Fixture Safety Cable*

1/8" stainless steel aircraft cable for securing fixture head to catwalk handrail.



SRB	*Strain relief bracket*	*Provides strain relief and shielding for modular wiring cable protection. Also provides convenient handling of ballast.*

Notes

Fixture Type A1, A2

ISO 9001 Certified

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PHILIPS WideLite

MARK®
ARCHITECTURAL
LIGHTING

The CVG2 Series

With its extremely shallow profile (2 inches deep), CVG2 is a perfect fit for most cove projects. Its forward-throw optics provide maximum ceiling illumination, while its white deflector reduces socket shadowing to a minimum.

CVG2 is available in T8, T5 or T5HO lamp configurations and in lengths from 2 to 8 feet.

Type:

Project:

Catalog Number:
DO NOT TYPE HERE. Autopopulated field.

Specification Features

Housing
Fabricated from 20-gauge, cold-rolled steel. Ballast compartments provided with 7/8"-diameter KOs at either end of housing for through wiring.

Finish
Matte white.

Reflector
Die-formed specular aluminum/matte white combination.

Deflector
20-gauge steel; matte white; tapered ends to reduce socket shadowing.

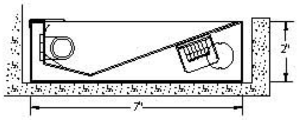
Lamps
(1) T5, T5HO or T8 lamp. Consult factory for other lamps.

Ballast
Thermally protected Class P energy-saving electronic ballast.

Mounting
Recessed indirect cove in 8', 6', 4', 3' and 2' sections. When required, housings are sized downward to accommodate T5 and T5HO lamps. (See chart.)

Certification
UL Listed, IBEW (Local 3) Union-made in the USA.

Technical Drawings



Fixture Type K

Ordering

Example: CG2 6 1T5HO EBPR 120

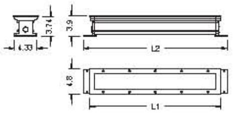
Series		Length[1]		No. of lamps/Lamp type[2]		Ballast		Voltage	Options	
CG2	CVG2	2	Nominal 2'	Number of lamps	Lamp type[2]	EBPR	Program rapid start (standard)	120	EMPK	Emergency battery pack
		3	Nominal 3'	1	T5	EBIS	Instant start	277		
		4	Nominal 4'		T5HO	EDB	Dimming (specify)	347[3]		
		6	Nominal 6'		T8	EDHL	Lutron Hi-Lume® dimming			
		8	Nominal 8'			EDE10	Lutron Eco-10® dimming			
						EDES	Lutron Eco System®			

HOUSING LENGTHS BY LAMP TYPE

NOMINAL LENGTH	ACTUAL LENGTH (T8)	ACTUAL LENGTH (T5/T5HO)
2'	24"	22 1/2"
3'	36"	34 5/16"
4'	48"	46 1/8"
6'	72"	68 5/8"
8'	96"	92 1/4"

Notes
1 See housing-length/lamp chart.
2 Consult factory for other lamps.
3 Consult factory for lamp and ballast compatibility.

marklighting.com 3 Kilmer Rd, Edison NJ 08817 T (732) 985 2600 F (732) 985 8441

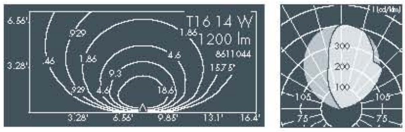


c5l ground-recessed single luminaire Asymmetrical, wide beam

.T5 and T5HO lamps
.Extruded aluminum body with low copper die cast ends.
.UL listed wet label IP67
.Stainless Steel frame and screws
.Electrophoretic dipcoated and polyester powder coated
.Capable of supporting 11,000 pounds
.Silicone rubber gasket
.suitable for through wiring

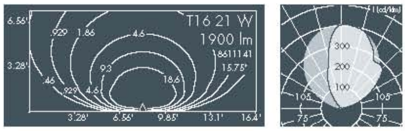
Single luminaire, asymmetrical, L1= 25", L2=27.3"

Part Number	Lamp	Lampholder	Voltage	Beam angle C0-180	C90-270
C5L-8-6D-4-SS-0-C-T-00	14W T5 2 Foot body	G5	Universal	74°	105°
C5L-8-06-4-SS-0-C-T-00	24W T5HO 2 Foot body	G5	Universal	74°	105°



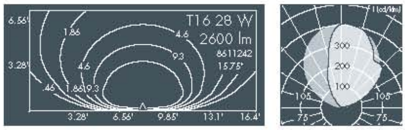
Single luminaire, asymmetrical, L1= 36.93", L2=39.09"

Part Number	Lamp	Lampholder	Voltage	Beam angle C0-180	C90-270
C5L-8-6K-4-SS-0-C-T-00	21W T5 3 Foot body	G5	Universal	74°	105°
C5L-8-07-4-SS-0-C-T-00	39W T5HO 3 Foot body	G5	Universal	74°	105°



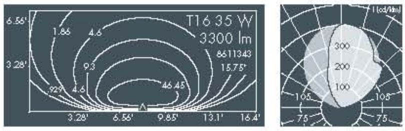
Single luminaire, asymmetrical, L1= 48.74", L2=50.91"

Part Number	Lamp	Lampholder	Voltage	Beam angle C0-180	C90-270
C5L-8-7E-4-SS-0-C-T-00	28W T5 4 Foot body	G5	Universal	74°	105°
C5L-8-08-4-SS-0-C-T-00	54W T5HO 4 Foot body	G5	Universal	74°	105°



Single luminaire, asymmetrical, L1= 60.55", L2=62.72"

Part Number	Lamp	Lampholder	Voltage	Beam angle C0-180	C90-270
C5L-8-Z5-4-SS-0-C-T-00	35W T5 5 Foot body	G5	Universal	74°	105°
C5L-8-09-4-SS-0-C-T-00	80W T5HO 5 Foot body	G5	Universal	74°	105°

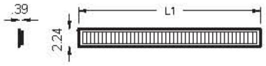


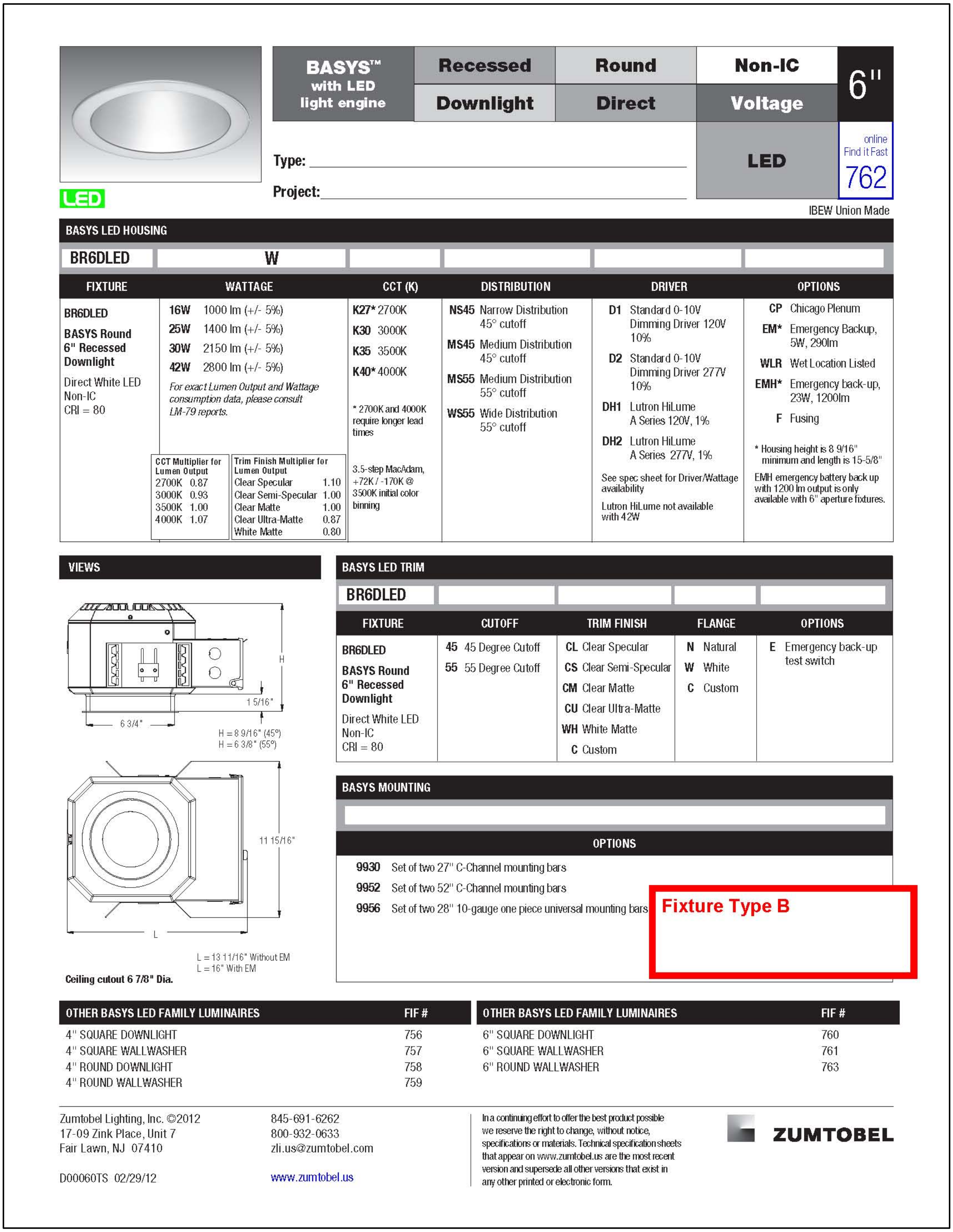
Fixture Type G

Accessories

Part number	Length*	L1	Description
126 0 129 940	25"	23.6"	**Louvre,** stainless steel, to avoid glare from the lamp
126 0 130 940	36.8"	35.4"	
126 0 131 940	48.6"	47.2"	
126 0 132 940	60.4"	59"	

* Length of the corresp. luminaire.





BASYS™ with LED light engine | **Recessed Downlight** | **Round Direct** | **Non-IC Voltage** | **LED** | **6"**

online Find it Fast 762

LED

Type: ____________________

Project: ____________________

IBEW Union Made

BASYS LED HOUSING

BR6DLED | W

FIXTURE	WATTAGE	CCT (K)	DISTRIBUTION	DRIVER	OPTIONS
BR6DLED **BASYS Round 6" Recessed Downlight** Direct White LED Non-IC CRI = 80	**16W** 1000 lm (+/- 5%) **25W** 1400 lm (+/- 5%) **30W** 2150 lm (+/- 5%) **42W** 2800 lm (+/- 5%) *For exact Lumen Output and Wattage consumption data, please consult LM-79 reports.*	**K27*** 2700K **K30** 3000K **K35** 3500K **K40*** 4000K * 2700K and 4000K require longer lead times 3.5-step MacAdam, +72K / -170K @ 3500K initial color binning	**NS45** Narrow Distribution 45° cutoff **MS45** Medium Distribution 45° cutoff **MS55** Medium Distribution 55° cutoff **WS55** Wide Distribution 55° cutoff	**D1** Standard 0-10V Dimming Driver 120V 10% **D2** Standard 0-10V Dimming Driver 277V 10% **DH1** Lutron HiLume A Series 120V, 1% **DH2** Lutron HiLume A Series 277V, 1% See spec sheet for Driver/Wattage availability Lutron HiLume not available with 42W	**CP** Chicago Plenum **EM*** Emergency Backup, 5W, 290lm **WLR** Wet Location Listed **EMH*** Emergency back-up, 23W, 1200lm **F** Fusing * Housing height is 8 9/16" minimum and length is 15-5/8" EMH emergency battery back up with 1200 lm output is only available with 6" aperture fixtures.

CCT Multiplier for Lumen Output	
2700K	0.87
3000K	0.93
3500K	1.00
4000K	1.07

Trim Finish Multiplier for Lumen Output	
Clear Specular	1.10
Clear Semi-Specular	1.00
Clear Matte	1.00
Clear Ultra-Matte	0.87
White Matte	0.80

VIEWS

H
1 5/16"
6 3/4"
H = 8 9/16" (45°)
H = 6 3/8" (55°)

11 15/16"
L
L = 13 11/16" Without EM
L = 16" With EM

Ceiling cutout 6 7/8" Dia.

BASYS LED TRIM

BR6DLED

FIXTURE	CUTOFF	TRIM FINISH	FLANGE	OPTIONS
BR6DLED **BASYS Round 6" Recessed Downlight** Direct White LED Non-IC CRI = 80	**45** 45 Degree Cutoff **55** 55 Degree Cutoff	**CL** Clear Specular **CS** Clear Semi-Specular **CM** Clear Matte **CU** Clear Ultra-Matte **WH** White Matte **C** Custom	**N** Natural **W** White **C** Custom	**E** Emergency back-up test switch

BASYS MOUNTING

OPTIONS

9930	Set of two 27" C-Channel mounting bars
9952	Set of two 52" C-Channel mounting bars
9956	Set of two 28" 10-gauge one piece universal mounting bars

Fixture Type B

OTHER BASYS LED FAMILY LUMINAIRES	FIF #
4" SQUARE DOWNLIGHT	756
4" SQUARE WALLWASHER	757
4" ROUND DOWNLIGHT	758
4" ROUND WALLWASHER	759

OTHER BASYS LED FAMILY LUMINAIRES	FIF #
6" SQUARE DOWNLIGHT	760
6" SQUARE WALLWASHER	761
6" ROUND WALLWASHER	763

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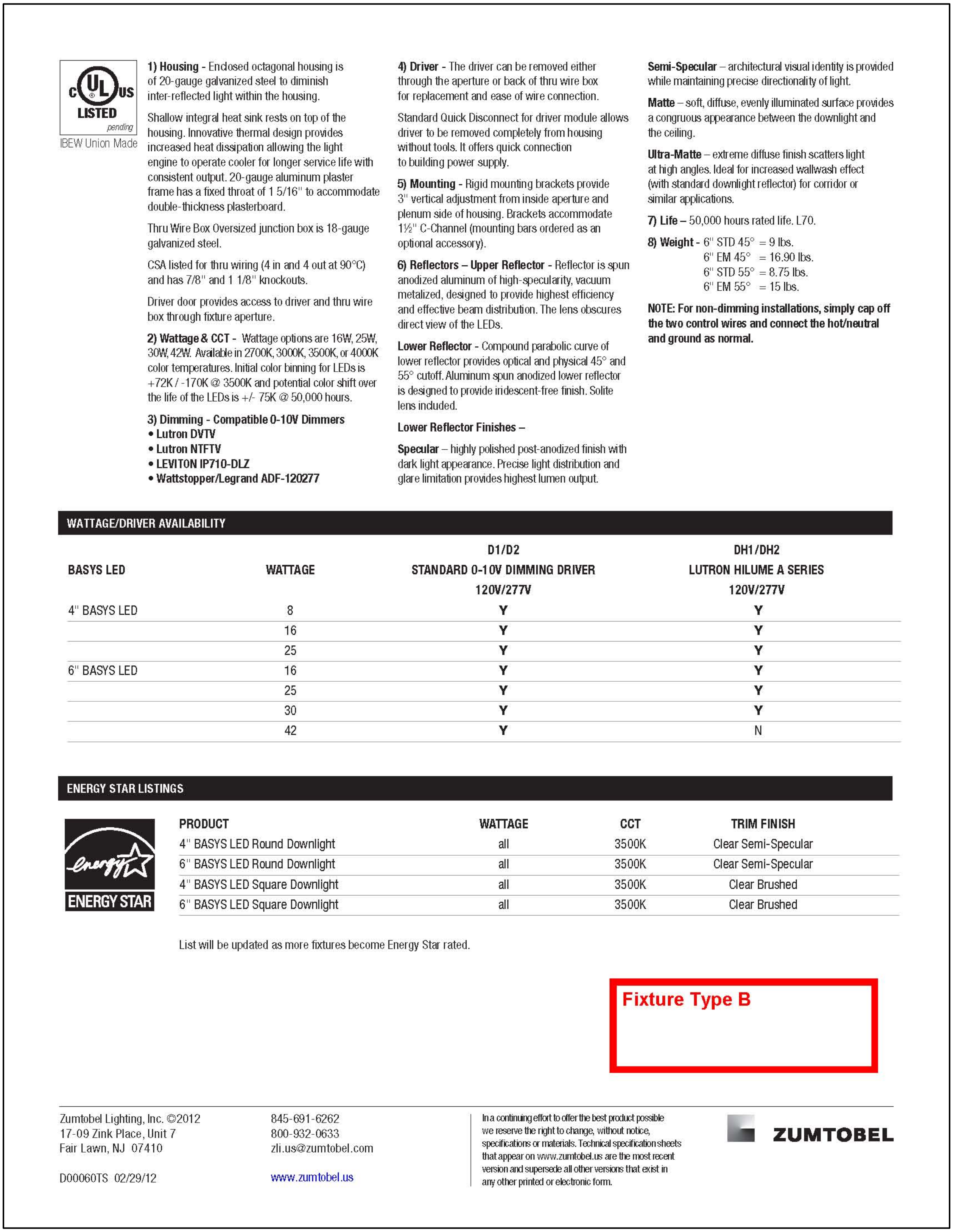
zli.us@zumtobel.com

D00060TS 02/29/12

www.zumtobel.us

In a continuing effort to offer the best product possible we reserve the right to change, without notice, specifications or materials. Technical specification sheets that appear on www.zumtobel.us are the most recent version and supersede all other versions that exist in any other printed or electronic form.

ZUMTOBEL



IBEW Union Made

1) Housing - Enclosed octagonal housing is of 20-gauge galvanized steel to diminish inter-reflected light within the housing.

Shallow integral heat sink rests on top of the housing. Innovative thermal design provides increased heat dissipation allowing the light engine to operate cooler for longer service life with consistent output. 20-gauge aluminum plaster frame has a fixed throat of 1 5/16" to accommodate double-thickness plasterboard.

Thru Wire Box Oversized junction box is 18-gauge galvanized steel.

CSA listed for thru wiring (4 in and 4 out at 90°C) and has 7/8" and 1 1/8" knockouts.

Driver door provides access to driver and thru wire box through fixture aperture.

2) Wattage & CCT - Wattage options are 16W, 25W, 30W, 42W. Available in 2700K, 3000K, 3500K, or 4000K color temperatures. Initial color binning for LEDs is +72K / -170K @ 3500K and potential color shift over the life of the LEDs is +/- 75K @ 50,000 hours.

3) Dimming - Compatible 0-10V Dimmers

- **Lutron DVTV**
- **Lutron NTFTV**
- **LEVITON IP710-DLZ**
- **Wattstopper/Legrand ADF-120277**

4) Driver - The driver can be removed either through the aperture or back of thru wire box for replacement and ease of wire connection.

Standard Quick Disconnect for driver module allows driver to be removed completely from housing without tools. It offers quick connection to building power supply.

5) Mounting - Rigid mounting brackets provide 3" vertical adjustment from inside aperture and plenum side of housing. Brackets accommodate 1½" C-Channel (mounting bars ordered as an optional accessory).

6) Reflectors – Upper Reflector - Reflector is spun anodized aluminum of high-specularity, vacuum metalized, designed to provide highest efficiency and effective beam distribution. The lens obscures direct view of the LEDs.

Lower Reflector - Compound parabolic curve of lower reflector provides optical and physical 45° and 55° cutoff. Aluminum spun anodized lower reflector is designed to provide iridescent-free finish. Solite lens included.

Lower Reflector Finishes –

Specular – highly polished post-anodized finish with dark light appearance. Precise light distribution and glare limitation provides highest lumen output.

Semi-Specular – architectural visual identity is provided while maintaining precise directionality of light.

Matte – soft, diffuse, evenly illuminated surface provides a congruous appearance between the downlight and the ceiling.

Ultra-Matte – extreme diffuse finish scatters light at high angles. Ideal for increased wallwash effect (with standard downlight reflector) for corridor or similar applications.

7) Life – 50,000 hours rated life. L70.

8) Weight - 6" STD 45° = 9 lbs.
6" EM 45° = 16.90 lbs.
6" STD 55° = 8.75 lbs.
6" EM 55° = 15 lbs.

NOTE: For non-dimming installations, simply cap off the two control wires and connect the hot/neutral and ground as normal.

WATTAGE/DRIVER AVAILABILITY

BASYS LED	WATTAGE	D1/D2 STANDARD 0-10V DIMMING DRIVER 120V/277V	DH1/DH2 LUTRON HILUME A SERIES 120V/277V
4" BASYS LED	8	Y	Y
	16	Y	Y
	25	Y	Y
6" BASYS LED	16	Y	Y
	25	Y	Y
	30	Y	Y
	42	Y	N

ENERGY STAR LISTINGS

PRODUCT	WATTAGE	CCT	TRIM FINISH
4" BASYS LED Round Downlight	all	3500K	Clear Semi-Specular
6" BASYS LED Round Downlight	all	3500K	Clear Semi-Specular
4" BASYS LED Square Downlight	all	3500K	Clear Brushed
6" BASYS LED Square Downlight	all	3500K	Clear Brushed

List will be updated as more fixtures become Energy Star rated.

Fixture Type B

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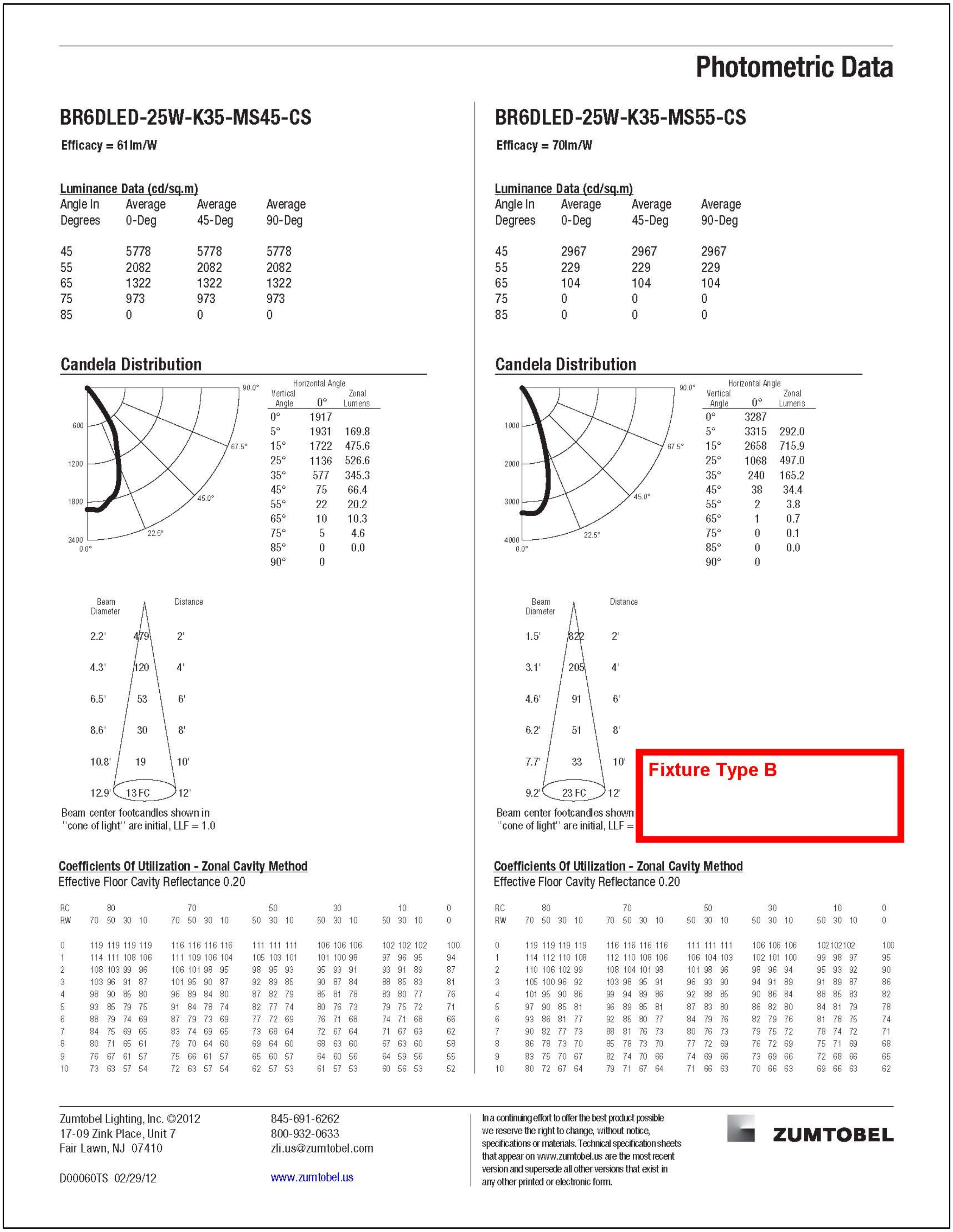

Photometric Data

BR6DLED-25W-K35-MS45-CS

Efficacy = 61lm/W

Luminance Data (cd/sq.m)

Angle In Degrees	Average 0-Deg	Average 45-Deg	Average 90-Deg
45	5778	5778	5778
55	2082	2082	2082
65	1322	1322	1322
75	973	973	973
85	0	0	0

Candela Distribution

	Horizontal Angle	
Vertical Angle	0°	Zonal Lumens
0°	1917	
5°	1931	169.8
15°	1722	475.6
25°	1136	526.6
35°	577	345.3
45°	75	66.4
55°	22	20.2
65°	10	10.3
75°	5	4.6
85°	0	0.0
90°	0	

Beam Diameter		Distance
2.2'	479	2'
4.3'	120	4'
6.5'	53	6'
8.6'	30	8'
10.8'	19	10'
12.9'	13 FC	12'

Beam center footcandles shown in "cone of light" are initial, LLF = 1.0

Coefficients Of Utilization - Zonal Cavity Method

Effective Floor Cavity Reflectance 0.20

RC	80				70				50			30			10			0
RW	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
0	119	119	119	119	116	116	116	116	111	111	111	106	106	106	102	102	102	100
1	114	111	108	106	111	109	106	104	105	103	101	101	100	98	97	96	95	94
2	108	103	99	96	106	101	98	95	98	95	93	95	93	91	93	91	89	87
3	103	96	91	87	101	95	90	87	92	89	85	90	87	84	88	85	83	81
4	98	90	85	80	96	89	84	80	87	82	79	85	81	78	83	80	77	76
5	93	85	79	75	91	84	78	74	82	77	74	80	76	73	79	75	72	71
6	88	79	74	69	87	79	73	69	77	72	69	76	71	68	74	71	68	66
7	84	75	69	65	83	74	69	65	73	68	64	72	67	64	71	67	63	62
8	80	71	65	61	79	70	64	60	69	64	60	68	63	60	67	63	60	58
9	76	67	61	57	75	66	61	57	65	60	57	64	60	56	64	59	56	55
10	73	63	57	54	72	63	57	54	62	57	53	61	57	53	60	56	53	52

BR6DLED-25W-K35-MS55-CS

Efficacy = 70lm/W

Luminance Data (cd/sq.m)

Angle In Degrees	Average 0-Deg	Average 45-Deg	Average 90-Deg
45	2967	2967	2967
55	229	229	229
65	104	104	104
75	0	0	0
85	0	0	0

Candela Distribution

	Horizontal Angle	
Vertical Angle	0°	Zonal Lumens
0°	3287	
5°	3315	292.0
15°	2658	715.9
25°	1068	497.0
35°	240	165.2
45°	38	34.4
55°	2	3.8
65°	1	0.7
75°	0	0.1
85°	0	0.0
90°	0	

Beam Diameter		Distance
1.5'	822	2'
3.1'	205	4'
4.6'	91	6'
6.2'	51	8'
7.7'	33	10'
9.2'	23 FC	12'

Beam center footcandles shown "cone of light" are initial, LLF =

Fixture Type B

Coefficients Of Utilization - Zonal Cavity Method

Effective Floor Cavity Reflectance 0.20

RC	80				70				50			30			10			0
RW	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
0	119	119	119	119	116	116	116	116	111	111	111	106	106	106	102	102	102	100
1	114	112	110	108	112	110	108	106	106	104	103	102	101	100	99	98	97	95
2	110	106	102	99	108	104	101	98	101	98	96	98	96	94	95	93	92	90
3	105	100	96	92	103	98	95	91	96	93	90	94	91	89	91	89	87	86
4	101	95	90	86	99	94	89	86	92	88	85	90	86	84	88	85	83	82
5	97	90	85	81	96	89	85	81	87	83	80	86	82	80	84	81	79	78
6	93	86	81	77	92	85	80	77	84	79	76	82	79	76	81	78	75	74
7	90	82	77	73	88	81	76	73	80	76	73	79	75	72	78	74	72	71
8	86	78	73	70	85	78	73	70	77	72	69	76	72	69	75	71	69	68
9	83	75	70	67	82	74	70	66	74	69	66	73	69	66	72	68	66	65
10	80	72	67	64	79	71	67	64	71	66	63	70	66	63	69	66	63	62

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In a continuing effort to offer the best product possible we reserve the right to change, without notice, specifications or materials. Technical specification sheets that appear on www.zumtobel.us are the most recent version and supersede all other versions that exist in any other printed or electronic form.

ZUMTOBEL

Photometric Data

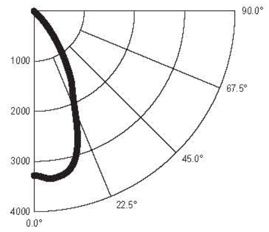
BR6DLED-42W-K35-MS55-CS

Efficacy = 69lm/W

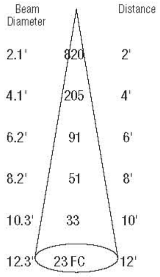
Luminance Data (cd/sq.m)

Angle In Degrees	Average 0-Deg	Average 45-Deg	Average 90-Deg
45	14949	15956	14949
55	477	477	477
65	130	130	130
75	0	0	0
85	0	0	0

Candela Distribution



Vertical Angle	Horizontal Angle 0°	45°	90°	Zonal Lumens
0°	3280	3280	3280	
5°	3355	3364	3355	301.0
15°	3106	3127	3106	848.1
25°	1830	1891	1830	866.7
35°	875	928	875	567.9
45°	193	206	193	171.5
55°	5	5	5	10.5
65°	1	1	1	1.4
75°	0	0	0	0.1
85°	0	0	0	0.0
90°	0	0	0	



Beam center footcandles shown in
''cone of light'' are initial, LLF = 1.0

Coefficients Of Utilization - Zonal Cavity Method

Effective Floor Cavity Reflectance 0.20

RC	80				70				50			30			10			0
RW	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
0	119	119	119	119	116	116	116	116	111	111	111	106	106	106	102	102	102	100
1	114	111	109	106	111	109	107	105	105	103	102	101	100	98	98	97	96	94
2	108	104	100	96	106	102	98	95	99	96	93	96	93	91	93	91	89	88
3	103	97	92	88	101	95	91	87	93	89	86	90	87	85	88	86	83	82
4	98	91	85	81	96	90	85	81	87	83	80	85	82	79	84	80	78	76
5	93	85	79	75	92	84	79	75	82	78	74	81	77	74	79	76	73	71
6	89	80	74	70	87	79	74	70	78	73	69	76	72	69	75	71	68	67
7	84	75	70	65	83	75	69	65	73	68	65	72	68	65	71	67	64	63
8	80	71	65	61	79	71	65	61	69	64	61	68	64	61	68	63	60	59
9	77	67	62	58	76	67	61	58	66	61	57	65	60	57	64	60	57	56
10	73	64	58	54	72	63	58	54	63	58	54	62	57	54	61	57	54	53

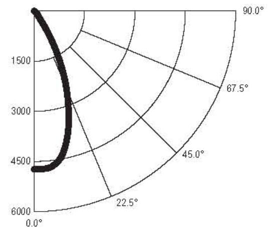
BR6DLED-42W-K35-NS45-CL

Efficacy = 69lm/W

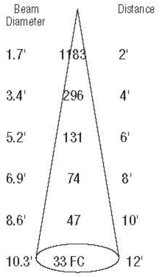
Luminance Data (cd/sq.m)

Angle In Degrees	Average 0-Deg	Average 45-Deg	Average 90-Deg
45	11425	11425	11425
55	1509	1509	1509
65	894	894	894
75	614	614	614
85	440	440	440

Candela Distribution



Vertical Angle	Horizontal Angle 0°	Zonal Lumens
0°	4730	
5°	4716	414.3
15°	3840	1052.
25°	2045	918.1
35°	397	300.8
45°	148	92.2
55°	16	14.8
65°	7	7.0
75°	3	3.1
85°	1	0.6
90°	0	



Beam center footcandles shown in
''cone of light'' are initial, LLF = 1.0

Fixture Type B

Coefficients Of Utilization - Zonal Cavity Method

Effective Floor Cavity Reflectance 0.20

RC	80				70				50			30			10			0
RW	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
0	119	119	119	119	116	116	116	116	111	111	111	106	106	106	102	102	102	100
1	114	112	109	107	112	109	107	106	105	104	102	102	100	99	98	97	96	95
2	109	105	101	98	107	103	100	97	100	97	95	97	95	93	94	92	91	89
3	104	99	94	91	103	97	93	90	95	91	89	92	90	87	90	88	86	84
4	100	93	88	85	98	92	88	84	90	86	83	88	85	82	86	84	81	80
5	96	88	83	79	94	87	83	79	86	81	78	84	80	78	83	79	77	76
6	92	84	78	75	90	83	78	74	82	77	74	80	76	73	79	76	73	72
7	88	80	74	71	87	79	74	70	78	73	70	77	73	70	76	72	69	68
8	84	76	71	67	83	75	70	67	74	70	66	73	69	66	72	69	66	65
9	81	72	67	64	80	72	67	63	71	66	63	70	66	63	69	66	63	62
10	78	69	64	61	77	69	64	60	68	63	60	67	63	60	67	63	60	59

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The fascination
of reflected light

Contemporary architecture calls out for modern lighting systems that can meet both aesthetic and functional requirements. Open, lofty interiors place particularly high demands on form and function. Projector-mirror technology offers the optimum solution to this lighting challenge.

We can send light into places that are difficult for us to access, in order to distribute this light evenly back into the room. Fascination, functionality and efficiency were the themes of our Miros development. Equally important to us were clear lines, universal adjustability and high system quality.

The reflector unit has a very flat design and can be supplied in various sizes depending on the task. The circular or square design of the mirror means it is easy to fit in any ceiling construction. Unwanted glare is prevented by the multi-spherical surface structure of the mirror.

The multifunctional housing enables straightforward mounting even in awkward positions.

Projector – wallmounted version

Fixture Type H

MIROS DESIGN CHARLES KELLER

"The spatial separation of light source and reflecting surface opens up new lighting dimensions for architectures. High-ceilinged rooms and large spaces can have focussed lighting – simply fascinating."
Charles Keller,
Designer of the MIROS projector-mirror `satelighting` system.

The projector
Technology and perfection

Concentration of the light

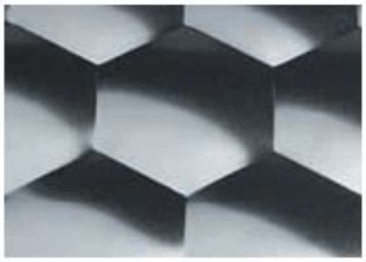
The high technical quality of the projector makes it an impressive light source, as does the attractive, minimalist design with its functional outlines. The light from the projector is highly concentrated, minimising scattering losses when reflected from the mirror.

Perfect focussing and low beam divergence are guaranteed by an exact computer-designed reflector structure. The circular louvres and integrated lamp shielding element prevent glare from the extremely bright light source.

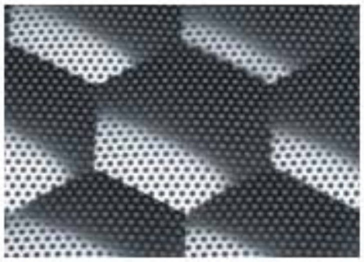
The ballast housing and reflector unit are designed to IP 54 protection, and can therefore also be used outdoors as well.

Fixture Type H

Highly specular surface
Exclusively directional reflection of light. Outside the light cone, the reflector appears "dark".



Semi-matt surface
Slightly diffuse component of reflected light for soft transitions. Luminance levels are perceptible on the reflector even with oblique light incidence.

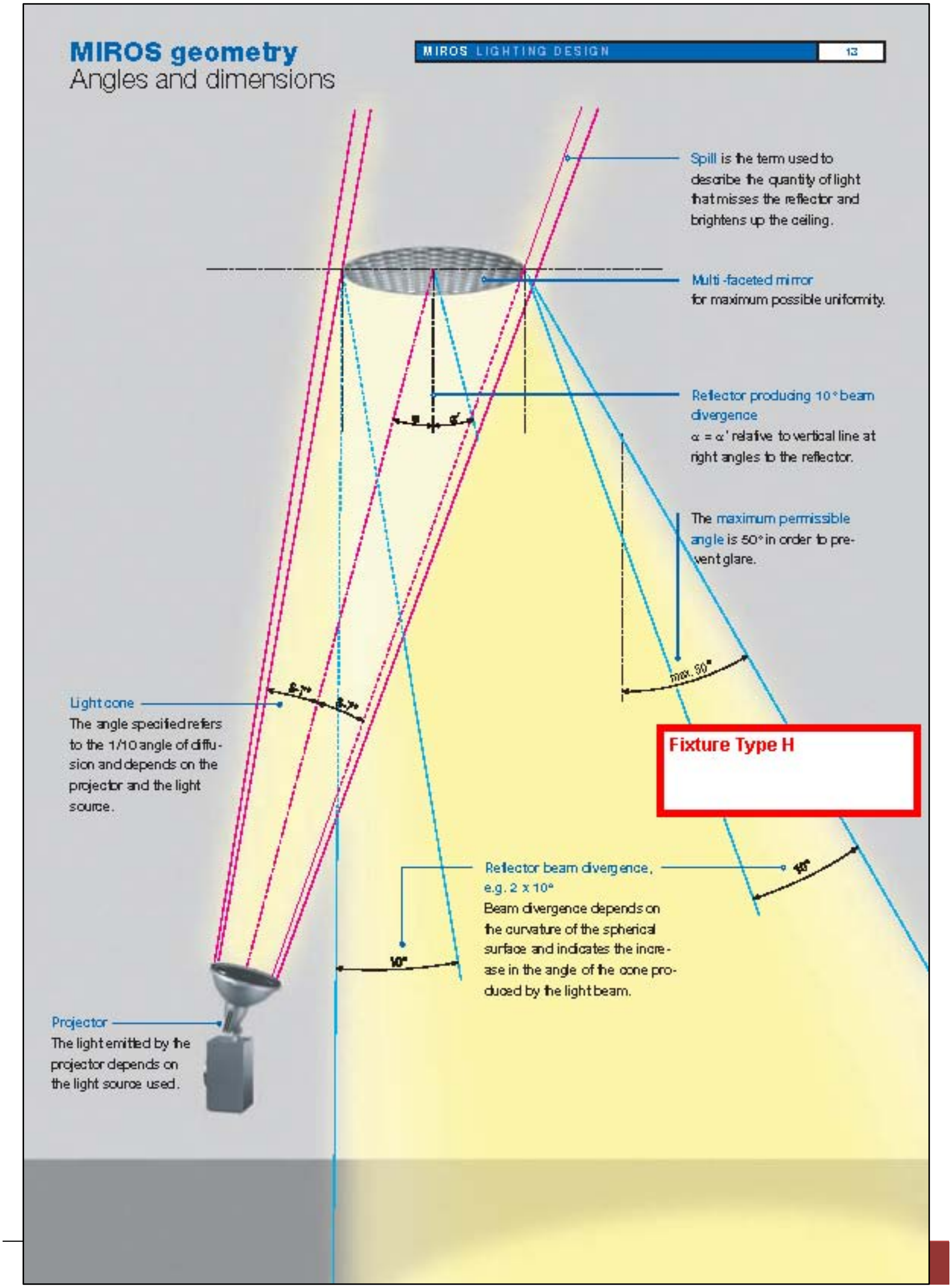


Perforated sheet steel optic
Same properties as for semi-matt version but with 20 % transmission component. Light for brightening up the ceiling and throwing soft shadows behind the reflector.

Mounting method
The reflectors are practically maintenance-free, and can be fixed onto any standard supporting surface because of their low intrinsic weight.
The mounting plate is made of die-cast aluminium in RAL 9006, with two fixing points, and three-point support. Comes with a screw-in suspension tube of various lengths to suit the reflector diameter.

Adjustment
The reflectors are easy to align and secure. The reflector angle is adjusted via a ball-and-socket joint integrated into the suspension tube, and can be fixed with a screw. The risk of the reflector shifting out of alignment is minimal, even during cleaning.

Fixture Type H



MIROS geometry
Angles and dimensions

Spill is the term used to describe the quantity of light that misses the reflector and brightens up the ceiling.

Multi-faceted mirror for maximum possible uniformity.

Reflector producing 10° beam divergence
α = α' relative to vertical line at right angles to the reflector.

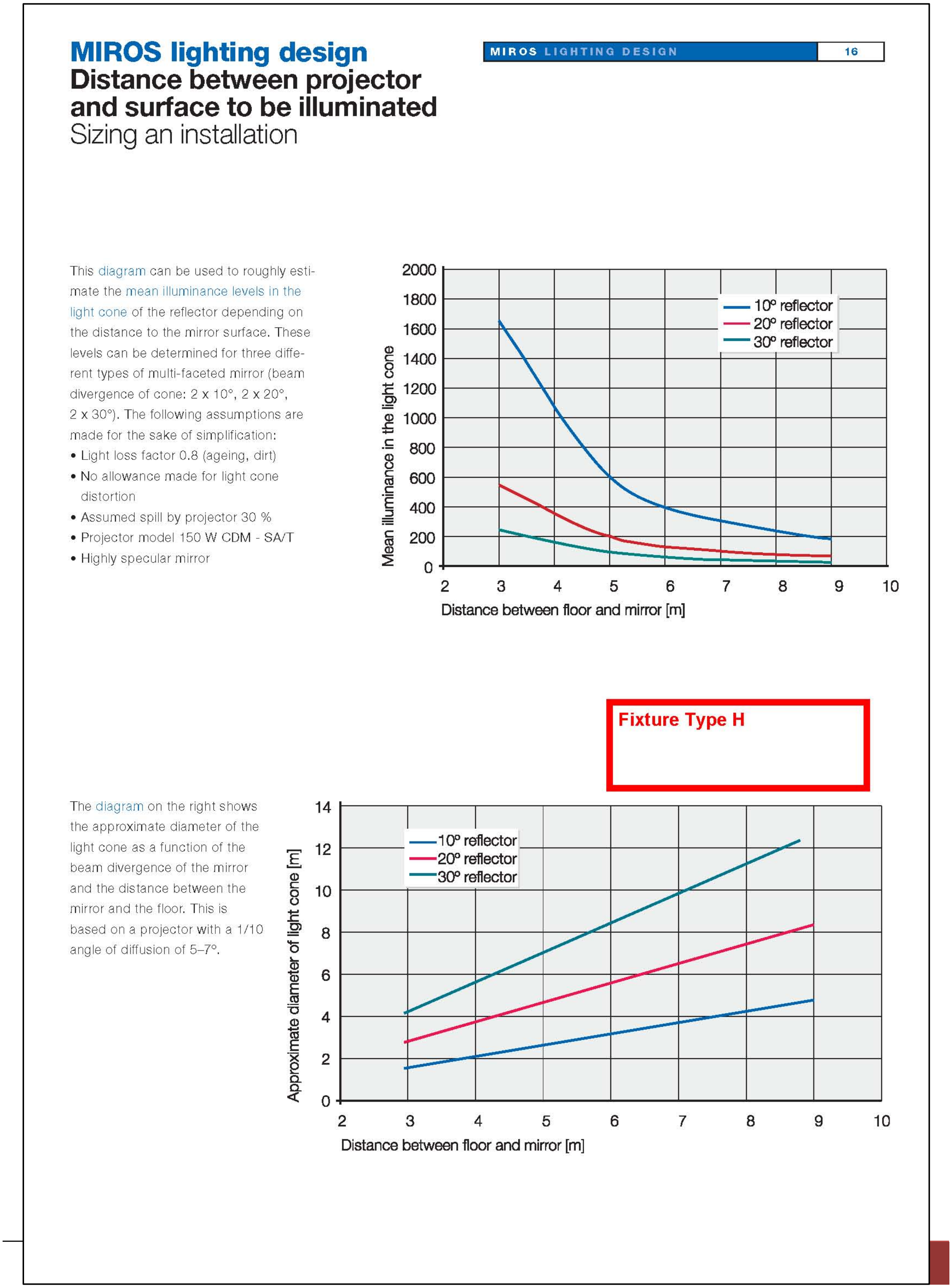
The **maximum permissible angle** is 50° in order to prevent glare.

Fixture Type H

Light cone
The angle specified refers to the 1/10 angle of diffusion and depends on the projector and the light source.

Reflector beam divergence, e.g. 2 x 10°
Beam divergence depends on the curvature of the spherical surface and indicates the increase in the angle of the cone produced by the light beam.

Projector
The light emitted by the projector depends on the light source used.



MIROS lighting design

Distance between projector and surface to be illuminated

Sizing an installation

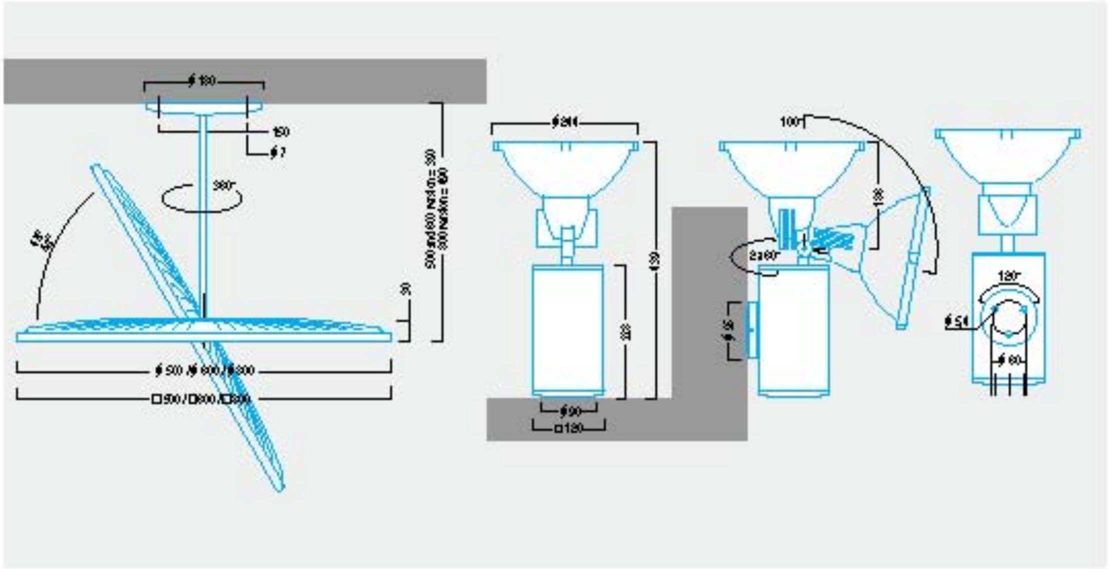
This diagram can be used to roughly estimate the mean illuminance levels in the light cone of the reflector depending on the distance to the mirror surface. These levels can be determined for three different types of multi-faceted mirror (beam divergence of cone: 2 x 10°, 2 x 20°, 2 x 30°). The following assumptions are made for the sake of simplification:

- Light loss factor 0.8 (ageing, dirt)
- No allowance made for light cone distortion
- Assumed spill by projector 30 %
- Projector model 150 W CDM - SA/T
- Highly specular mirror

Fixture Type H

The diagram on the right shows the approximate diameter of the light cone as a function of the beam divergence of the mirror and the distance between the mirror and the floor. This is based on a projector with a 1/10 angle of diffusion of 5–7°.

MIROS



MIROS IP 54 projector

IP54

Projector
- Pin spot with symmetrical highly specular reflector
- Housing made of extruded aluminium section, painted in RAL 9006
- Circular vane louvre with built-in lamp shielding element
- Electrical connection in separate ballast housing
- Easy installation method

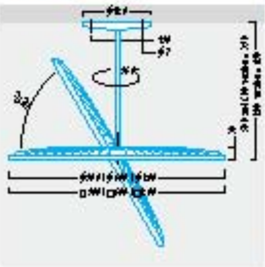
Cat. no.	L/W/H	kg	Order no.
for metal halide lamp* on electronic ballast			
1/70 W HIT	244/244/460	4.1	42122854
1/150 W HIT	244/244/460	4.2	42122867
for metal halide lamp* on low-loss ballast			
1/70 W HIT I	244/244/460	4.9	82122814
1/70 W HIT KSP	244/244/460	5.3	82122830
1/150 W HIT I	244/244/460	6.2	82122838
1/150 W HIT KSP	244/244/460	6.6	82122842
for LV			
1/150 W QT16	244/244/460	5.5	22122780

KSP = hpf, with blocking inductor for HIT and HIT-CRI lamps.
** For suitable lamps, please consult the section on design*

Fixture Type H

To specify e.g.: MIROS IP 54 projector 1/70 W HIT 42 122 854

MIROS square mirror with multi-faceted surface



Cat. no.	L	kg	Order no.
highly specular finish			
SQD 500 2x10°	506	2.0	22122515
SQD 500 2x20°	506	2.0	22122521
SQD 500 2x30°	506	2.0	22122537
SQD 600 2x10°	606	2.8	22122548
SQD 600 2x20°	606	2.8	22122559
SQD 600 2x30°	606	2.8	22122562
SQD 800 2x10°	806	4.2	22122578
SQD 800 2x20°	806	4.2	22122584
SQD 800 2x30°	806	4.2	22122590
semi-matt finish			
SQC 500 2x10°	506	2.0	22122601
SQC 500 2x20°	506	2.0	22122610
SQC 500 2x30°	506	2.0	22122626
SQC 600 2x10°	606	2.8	22122632
SQC 600 2x20°	606	2.9	22122648
SQC 600 2x30°	606	2.9	22122654
SQC 800 2x10°	806	4.4	22122667
SQC 800 2x20°	806	4.4	22122673
SQC 800 2x30°	806	4.4	22122689
perforated sheet steel optic			
SQG 500 2x10°	506	1.5	22122695
SQG 500 2x20°	506	1.5	22122702
SQG 500 2x30°	506	1.5	22122711
SQG 600 2x10°	606	2.0	22122727
SQG 600 2x20°	606	2.0	22122733
SQG 600 2x30°	606	2.0	22122749
SQG 800 2x10°	806	3.3	22122755
SQG 800 2x20°	606	3.3	22122768
SQG 800 2x30°	606	3.3	22122774

Multi-faceted reflector
- High level of uniformity at working plane thanks to multi-faceted surface
- One-piece reflector element
- Simple adjustment using ball-and-socket-joint and single-point fixing
- Rotates through 360° and tilts through 45°/60°
- Variable expansion, surface and dimensions for different lighting tasks

MIROS adjustment unit

Cat. no.	W/H	kg	Order no.
accessories			
Adjusting device	190/42	0.3	22126482

Adjusting device
- Adjustment kit with laser pointer in order to align projector with mirror
- Enables adjustment without switching on projectors
- Can be snapped on and removed from projector head without the use of tools, via three fixing clips

Fixture Type H

To specify e.g.: MIROS square mirror SQD 500 2x10° 22 122 515

MIROS multi-faceted mirror

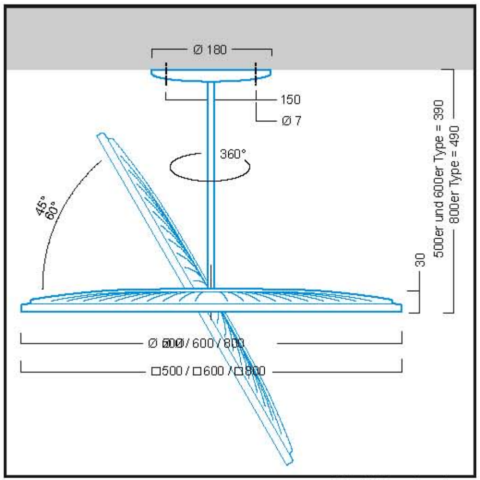
ZUMTOBEL

SQC 800 2x30° 22122689

square mirror matt bivergent

Square mirror matt bivergent; multi-faceted deflecting mirror multi-faceted surface, matt made of one piece; light spot dispersion for optimised glare removal; mounted on stable plastic plate in RAL 7000 grey; 1-point adjustment using ball-and-socket joint in mirror; rotates through 360° rotation and tilts through 45/60°; light distribution depends on beam angle; mounting plate with 2-point fixing for installation on ceilings of any type; dimensions: Ø 806 mm, height 505 mm, extremely low weight: 4.4 kg.

ZS_MOS_F_Spiegel_matt.jpg



ZS_MOS_spiegel.wmf

Fixture Type H

LINEAR WALL GRAZER

LED

LWG
LED

APPLICATIONS:
Wall grazing for commercial, retail and hospitality spaces

CONSTRUCTION:
Extruded aluminum housing
Die-formed aluminum, galvanized and coldrolled steel internal components
Die-formed aluminum module bracket painted black
Stamped steel end cap painted black
Housing lengths are 4′ or 8′ nominal for individual fixtures

MOUNTING:
Sheet rock ceilings
Fixtures may be continuously row-mounted

OPTICS:
Extruded aluminum optic-custom polished finish
4 LED linear array modules per nominal 4′ section, 2700°K, 85 CRI

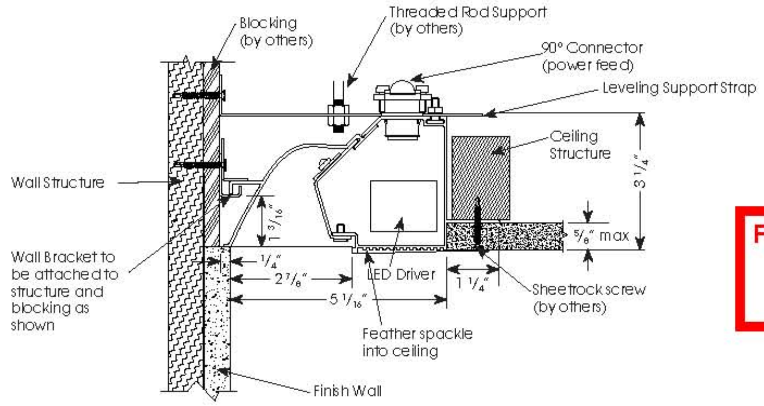
ELECTRICAL:
Electronic constant voltage 24v DC LED driver, 120v
Dimming: 0-10v dimming equipment and relay module by others, consult factory
This product complies with IEEE C62.41 for surge endurance up to 1KV. Amerlux recommends using additional surge protection with this unit (supplied by others), surge damage is not covered by warranty.

LABELING:

c UL us

PROJECT:

TYPE:



Electrostatic sensitive device, observe precautions for handling

Fixture Type C

LED
5-YEAR WARRANTY

Amerlux reserves the right to change details that do not affect overall function and performance.

ELECTRICAL

			Lamping 4′		8′	
Driver	Wattage per foot		Input watts	Amps	Input watts	Amps
Electronic	8	120v	37	.31	74	.62
		277v	37	.13	74	.26

ORDERING INFORMATION:

Model	Wattage per Foot	Lamp Type	Driver	Finish	Length	Length	Voltage	Color Temp	Options/ Accessories
LWG	8	LED	E - electronic	PAL - polished aluminum	4 - 4′ individual 8 - 8′ individual ___ run length in increments of 1′ (consult factory)	IND - individual BOR - beginning of run EOR - end of run MOR - middle of run	120 277	2700 Consult factory for other color temperature options	DIM - dimming

Example: LWG-8-LED-E-PAL-4-IND-120-2700

Cat #:

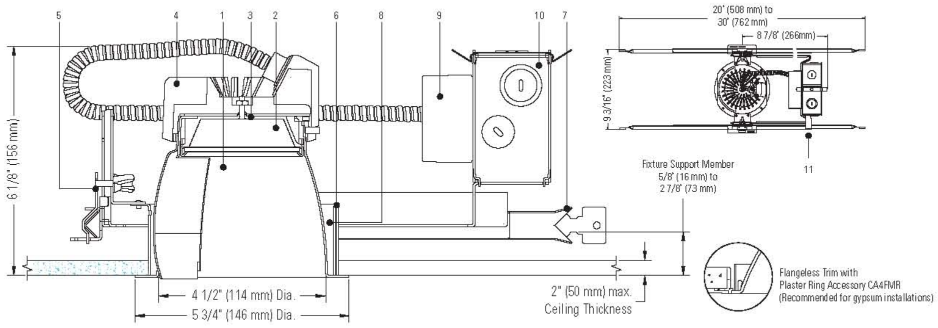
amerlux
GLOBAL LIGHTING SOLUTIONS

23 daniel road east, fairfield, nj 07044 • P: 973-882-5010 F: 973-882-2605 • www.amerlux.com

C4L10WW

Calculite LED 4 1/2" Wall Washer

Page 1 of 4



Ordering Guide: Light Engines

Light Engine Series	Style	Color Temperature	Reflector Finish	Flange	Options
C4L10	**WW** (Open wall wash)	**27K** (2700K) **30K** (3000K) **35K** (3500K) **40K** (4000K)	**CL** (Clear) **CCL** (Comfort Clear) **CCD** (Comfort Clear Diffuse) **CCZ** (Champagne Bronze) **WH** (Painted White)	**W** (Painted white) **P** (Aperture-matching/polished) **FT** (Flush-mount/flangeless)[1]	**EM** (Integral emergency test switch)

Example: C4L10LW35KCCLWEM | [1]Accessory CA4FMR recommended for gypsum applications. Reflector flange is 1/4".

Ordering Guide: Frame-in Kits

Frame-in Kit Series	Installation Options	Input Voltage	Options
C4L10	**N** (New construction) **R** (Remodeler)	**1** (120V) **2** (277V)*	**Blank** (Electronic low voltage dimming) **EM** (Emergency) **LD** (Lutron driver) **Z10V** (0-10V dimming)
CUL10	**J** (J-box mount retrofit) **S** (Screw-in base retrofit (120V only)	**1** (120V) **2** (277V)*	**Blank** (Electronic low voltage dimming)

Example: C4L10N1EM

*277V dimming applications require LD or Z10V option.

Fixture Type J

Job Inform

Job Name:

Cat. No.:

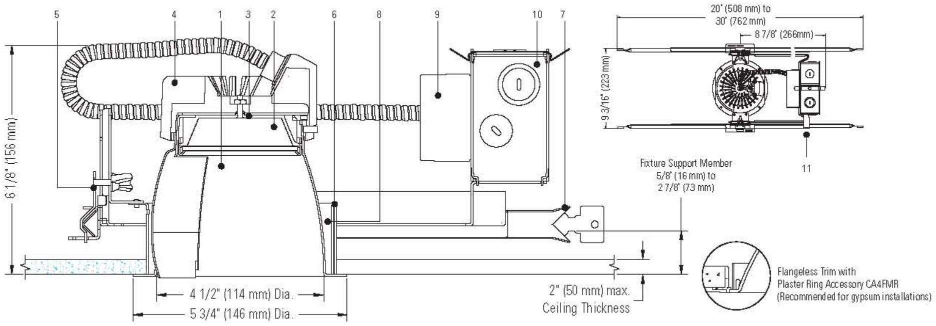
Notes:

PHILIPS
LIGHTOLIER

C4L10WW

Calculite LED 4 1/2" Wall Washer

Page 2 of 4



Features

Aperture: 4 1/2" (114mm) I.D., 5 3/4" (146mm) O.D.

Input Wattage: 20W (+/- 5%)

Reflector Cone: Aluminum. Provides 50° cutoff to source & source image. Self-flanged.

Depth (including Frame-in kit): 6 1/8" (156mm)

Power Connection: Attaches to frame-in kit via push-in connector (on frame). Removable cover provides access.

Technology

LED Board: Array of high brightness royal blue LED's.

Remote Phosphor Technology: Remote phosphor technology provides increased efficiency and color consistency. Phosphor lens assembly positioned in front of LED array converts blue light to white. Color shift will not exceed +/- 100K over life.

Optical Mixing Chamber: Lightolier-specific mixing chamber redirects back-reflected light through aperture resulting in 20% increase in efficiency.

Thermal Management: Heat sink and thermal design along with clean room assembly ensures specified performance.

Technology (continued)

Rated Life: Based on IESNA LM-80-2008 50,000 hours at 70% lumen maintenance.

Photometric Performance: Tested in accordance to IESNA LM-79-2008

Options

Dimming Capability: See LED-DIM specification sheet

Emergency Capability (Integral): Add "EM" suffix.
See LED-EM spec sheet.

Emergency Capability (Inverter): See LED-LMI specification sheet

Labels

UL (suitable for wet locations), cUL, I.B.E.W.
5 Year Wa

Fixture Type J

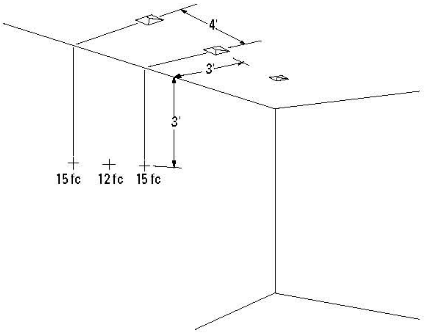
Job Information	**Type:**

PHILIPS
LIGHTOLIER

C4L10WW

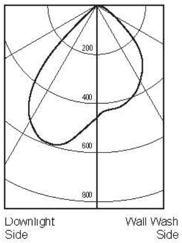
Calculite LED 4 1/2" Wall Washer

Page 3 of 4



Lighting Data - Example
C420LEDWW30KCLW illumination on the wall 4' down from the ceiling is 12 f.c. beneath and 13 f.c. between fixtures.

20W LED, 2700K, CL FINISH TRIM



Trim:
C420LEDWW27KCLW

Reflector Finish:
Specular Clear

Correlated Color Temp[1]**:**
2700K

Input Watts[2]**:**
19.8 w

CRI[4]**:**
80

Multiple Units - Footcandles On Wall
2' from Wall - 3' On Center

Distance from ceiling in feet	○	3'	○
1	14	9	14
2	26	17	26
3	19	22	19
4	16	16	16
5	13	13	13
6	10	10	10
7	8	8	8
8	7	7	7
9	6	6	6
10	6	6	6
12	5	5	5
14	4	4	4

Multiple Units - Footcandles On Wall
3' from Wall - 3' On Center

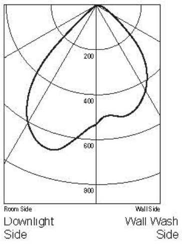
Distance from ceiling in feet	○	3'	○
1	6	6	6
2	11	10	11
3	15	14	15
4	14	15	14
5	13	13	13
6	11	11	11
7	10	10	10
8	9	9	9
9	8	8	8
10	7	7	7
12	6	6	6
14	5	5	5

Multiple Units - Footcandles On Wall
3' from Wall - 4' On Center

Distance from ceiling in feet	○	4'	○
1	5	4	5
2	9	7	9
3	12	9	12
4	10	11	10
5	9	10	9
6	8	8	8
7	7	7	7
8	6	6	6
9	5	5	5
10	5	5	5
12	4	4	4
14	3	3	3

CERTIFIED TEST REPORT NO. F09937[3]

20W LED, 3000K, CL FINISH TRIM



Trim:
C420LEDWW30KCLW

Reflector Finish:
Specular Clear

Correlated Color Temp[1]**:**
3000K

Input Watts[2]**:**
19.8 w

CRI[4]**:**
79

Multiple Units - Footcandles On Wall
2' from Wall - 3' On Center

Distance from ceiling in feet	○	3'	○
1	14	11	14
2	29	19	29
3	23	25	23
4	19	20	19
5	15	15	15
6	12	12	12
7	10	10	10
8	8	8	8
9	7	7	7
10	6	6	6
12	5	5	5
14	5	5	5

Multiple Units - Footcandles On Wall
3' from Wall - 3' On Center

Distance from ceiling in feet	○	3'	○
1	7	7	7
2	12	12	12
3	17	17	17
4	17	18	17
5	16	16	16
6	14	14	14
7	12	[illegible]	[illegible]
8	10	[illegible]	[illegible]
9	9	[illegible]	[illegible]
10	8	[illegible]	[illegible]
12	7	[illegible]	[illegible]
14	6	[illegible]	[illegible]

Multiple Units - Footcandles On Wall
3' from Wall - 4' On Center

Distance from ceiling in feet	○	4'	○
1	5	4	5
2	9	8	9
3	14	11	14
4	12	13	12
5	11	12	11
6	10	10	10
[illegible]	[illegible]	[illegible]	[illegible]

Fixture Type J

CERTIFIED TEST REPORT NO. 15737[3]

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[1] Color temperature controlled within specifications as defined by ANSI_NEMA_ANSLG C78.377-2008: Specifications for the Chromaticity of Solid State Lighting Products.
[2] Wattage controlled to within 65%.
[3] Tested using absolute photometry as specified in LM79: IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products.
[4] Color Rendering Index within +/- 2%.

Job Information	Type:

PHILIPS
LIGHTOLIER

C4L10WW

Calculite LED 4 1/2" Wall Washer

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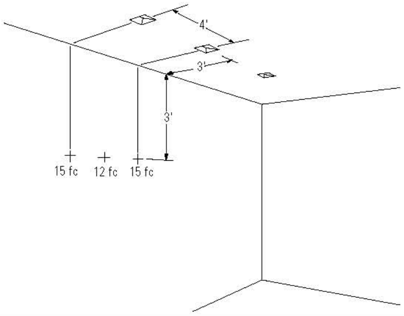
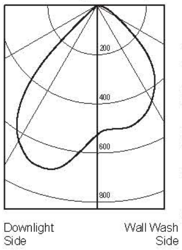


Lighting Data - Example
C420LEDWW30KCLW illumination on the wall 4' down from the ceiling is 12 f.c. beneath and 13 f.c. between fixtures.

20W LED, 3500K, CL FINISH TRIM



Trim:
C420LEDWW35KCLW

Reflector Finish:
Specular Clear

Correlated Color Temp[1]**:**
3500K

Input Watts[2]**:**
19.8 w

CRI[4]**:**
76

Multiple Units - Footcandles On Wall
2' from Wall - 3' On Center

Distance from ceiling in feet	○	3'	○
1	17	11	17
2	32	20	32
3	23	27	23
4	20	20	20
5	16	16	16
6	13	13	13
7	10	10	10
8	9	9	9
9	8	8	8
10	7	7	7
12	6	6	6
14	5	5	5

Multiple Units - Footcandles On Wall
3' from Wall - 3' On Center

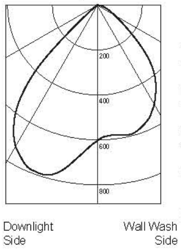
Distance from ceiling in feet	○	3'	○
1	8	7	8
2	13	13	13
3	19	18	19
4	18	19	18
5	17	16	17
6	14	14	14
7	12	12	12
8	10	10	10
9	9	9	9
10	8	8	8
12	7	7	7
14	6	6	6

Multiple Units - Footcandles On Wall
3' from Wall - 4' On Center

Distance from ceiling in feet	○	4'	○
1	6	5	6
2	11	8	11
3	15	11	15
4	13	14	13
5	11	12	11
6	10	10	10
7	9	9	9
8	7	8	7
9	7	7	7
10	6	6	6
12	5	5	5
14	4	4	4

CERTIFIED TEST REPORT NO. F09954[3]

20W LED, 4000K, CL FINISH TRIM



Trim:
C420LEDWW40KCLW

Reflector Finish:
Specular Clear

Correlated Color Temp[1]**:**
4000K

Input Watts[2]**:**
19.8 w

CRI[4]**:**
76

Multiple Units - Footcandles On Wall
2' from Wall - 3' On Center

Distance from ceiling in feet	○	3'	○
1	16	11	16
2	32	20	32
3	26	27	26
4	21	22	21
5	17	17	17
6	14	14	14
7	11	11	11
8	9	10	9
9	8	8	8
10	7	7	7
12	6	6	6
14	6	6	6

Multiple Units - Footcandles On Wall
3' from Wall - 3' On Center

Distance from ceiling in feet	○	3'	○
1	7	7	7
2	13	12	13
3	19	18	19
4	19	20	19
5	18	17	18
6	16	15	16
7	13	13	13
8	11	12	11
9	10	10	10
10	9	9	[illegible]
12	8	8	[illegible]
14	7	7	[illegible]

Multiple Units - Footcandles On Wall
3' from Wall - 4' On Center

Distance from ceiling in feet	○	4'	○
1	5	4	5
2	10	8	10
3	15	11	15
4	14	14	14
5	12	13	12
6	11	11	11
7	10	9	10
8	8	8	8
9	7	7	7
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

CERTIFIED TEST REPORT NO. F09323[3]

Fixture Type J

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[1] Color temperature controlled within specifications as defined by ANSI_NEMA_ANSLG C78.377-2008: Specifications for the Chromaticity of

[2] Wattage controlled to within 6.5%.

[3] Tested using absolute photometry as specified in LM79: IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products.

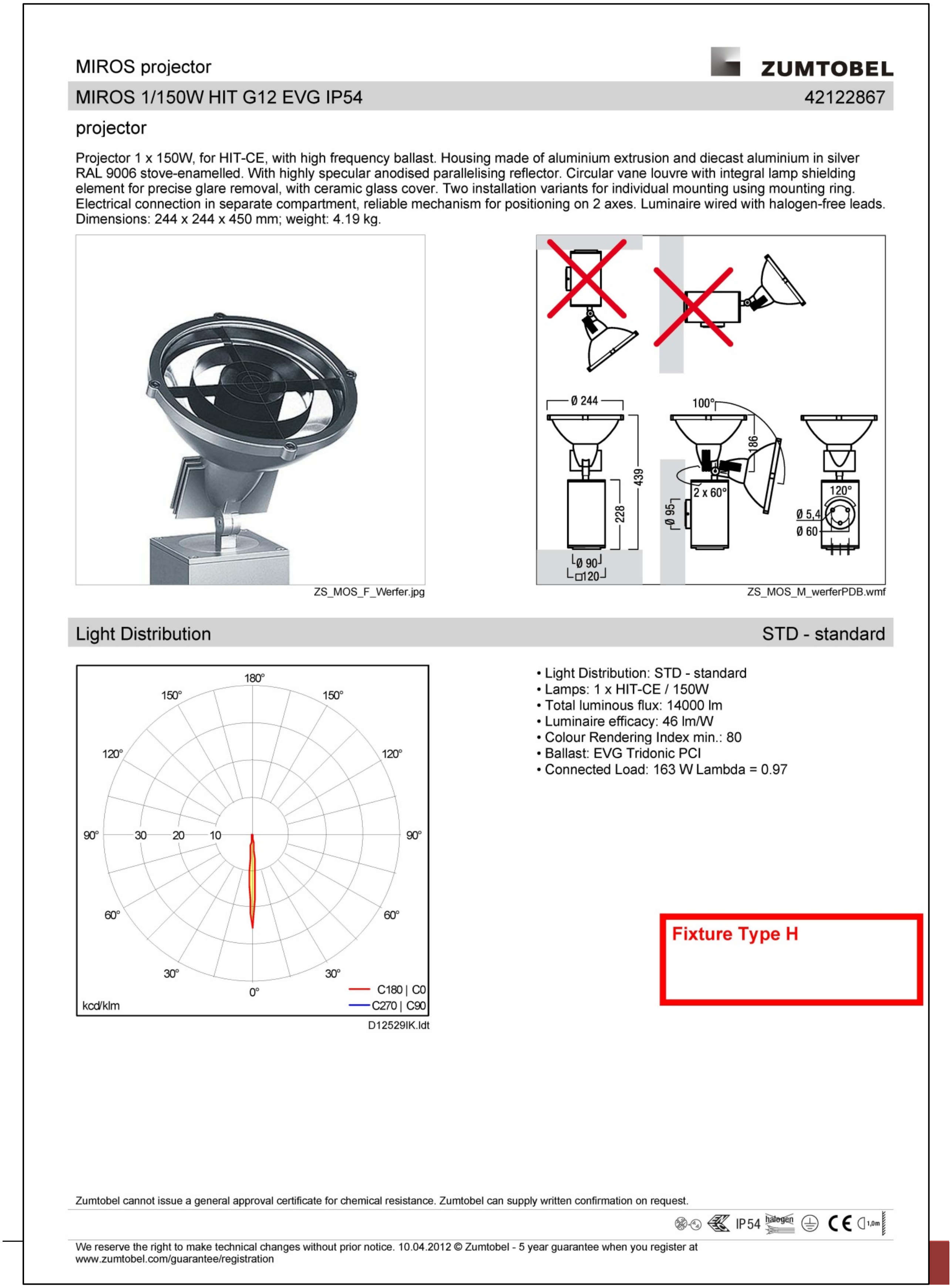
[4] Color Rendering Index within +/- 2%.

Philips Lightolier
e: lol.webmaster@philips.com
t: (508) 679-8131
w: www.lightolier.com

C4L10WW December 6, 2011

Specifications are subject to change without notice.

Job Information **Type:**



MIROS projector

ZUMTOBEL

MIROS 1/150W HIT G12 EVG IP54 42122867

projector

Projector 1 x 150W, for HIT-CE, with high frequency ballast. Housing made of aluminium extrusion and diecast aluminium in silver RAL 9006 stove-enamelled. With highly specular anodised parallelising reflector. Circular vane louvre with integral lamp shielding element for precise glare removal, with ceramic glass cover. Two installation variants for individual mounting using mounting ring. Electrical connection in separate compartment, reliable mechanism for positioning on 2 axes. Luminaire wired with halogen-free leads. Dimensions: 244 x 244 x 450 mm; weight: 4.19 kg.

ZS_MOS_F_Werfer.jpg

ZS_MOS_M_werferPDB.wmf

Light Distribution STD - standard

D12529IK.ldt

- Light Distribution: STD - standard
- Lamps: 1 x HIT-CE / 150W
- Total luminous flux: 14000 lm
- Luminaire efficacy: 46 lm/W
- Colour Rendering Index min.: 80
- Ballast: EVG Tridonic PCI
- Connected Load: 163 W Lambda = 0.97

Fixture Type H

Zumtobel cannot issue a general approval certificate for chemical resistance. Zumtobel can supply written confirmation on request.

We reserve the right to make technical changes without prior notice. 10.04.2012 © Zumtobel - 5 year guarantee when you register at www.zumtobel.com/guarantee/registration

Quality Lighting
1611 Clovis R. Barker Road
San Marcos, Texas 78666
Toll Free Phone (800) 545-1326
FAX (866) 713-6002
www.qualitylighting.com
e-mail: Quality.Info@Philips.com

UF2 LED

Security

Accent

Facade

Recreational Fields

Sign Lighting

Landscape Lighting

Specifications

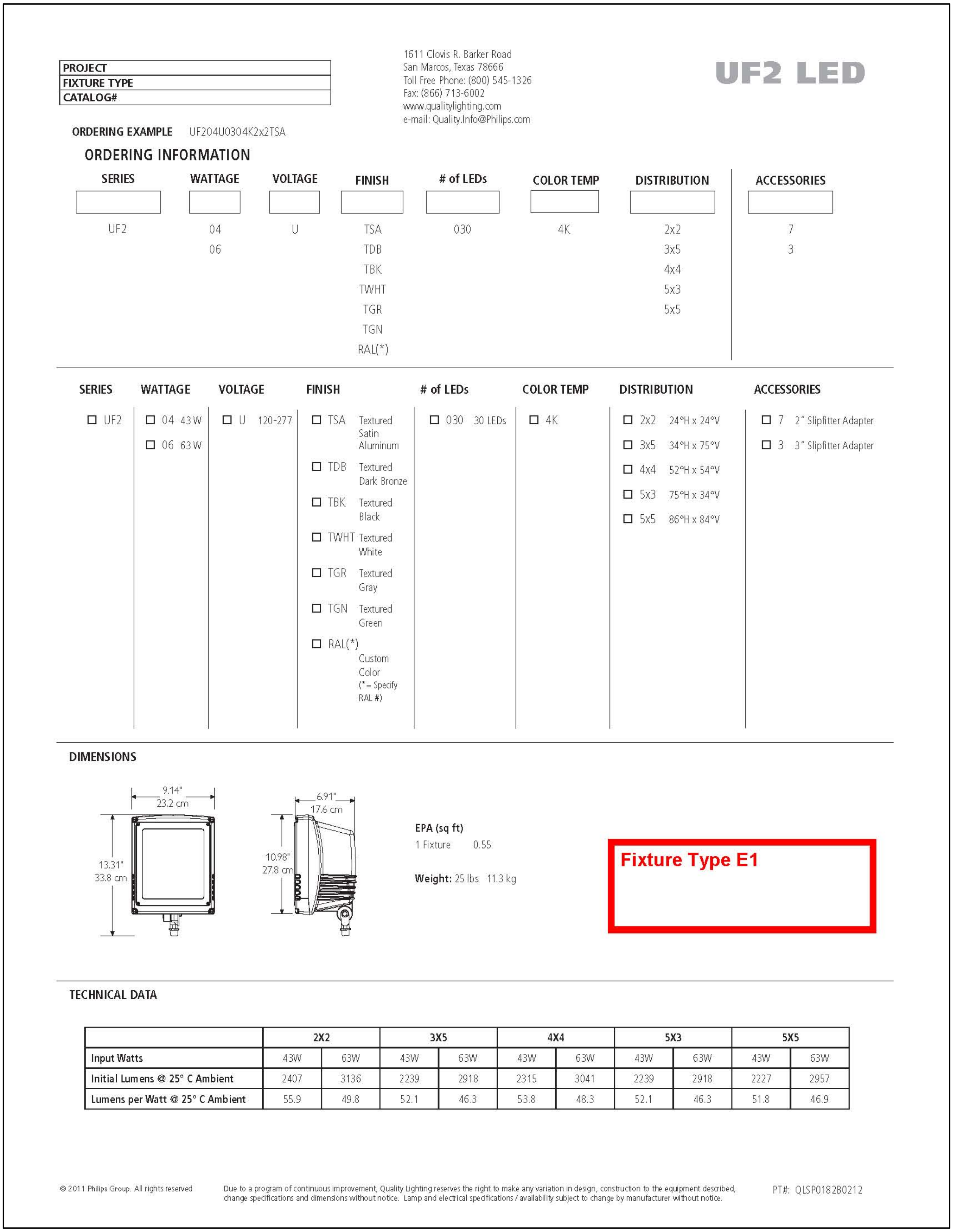
c UL us

CONSTRUCTION	Precision die-cast aluminum construction body. Cast aluminum lens frame with heat sink. Lens screws are specially designed captive stainless steel screws. Extruded silicone gasket.Available with vandal shield, wire guard and visor. Tempered glass lens.
OPTICS	30 high-output LEDS available in 4K color temperature. 30 individual precision optics collect and redirect light to optimize performance. Optical system individually controls the placement of light in the target area.
ELECTRICAL	Electronic LED driver accepts 120-277 V, 50/60 Hz input. Furnished with 10 kV surge protector standard.
MOUNTING	3/4" arm with serrated teeth lock arm mount unit into position. The UF Series can be angled for indirect/ accent lighting. Unit can be aimed above or below horizontal.
FINISH	Polyester powder coat, electrostatically applied, which is preceded by a five step pre-treatment process including an iron phosphate priming stage for superior coating adhesion. This process meets or exceeds all ASTM testing requirements, including those for 1,000 hour salt spray endurance testing.
LISTINGS	UL/cUL 1598 listed, suitable for wet locations.
WARRANTY	Mechanical, finish and electrical shall be covered by a limited 5-year warranty. See terms and conditions for details.

Fixture Type E1

Quality Lighting is a Philips group brand

PHILIPS



PROJECT	
FIXTURE TYPE	
CATALOG#	

1611 Clovis R. Barker Road
San Marcos, Texas 78666
Toll Free Phone: (800) 545-1326
Fax: (866) 713-6002
www.qualitylighting.com
e-mail: Quality.Info@Philips.com

UF2 LED

ORDERING EXAMPLE UF204U0304K2x2TSA

ORDERING INFORMATION

SERIES	WATTAGE	VOLTAGE	FINISH	# of LEDs	COLOR TEMP	DISTRIBUTION	ACCESSORIES
UF2	04	U	TSA	030	4K	2x2	7
	06		TDB			3x5	3
			TBK			4x4	
			TWHT			5x3	
			TGR			5x5	
			TGN				
			RAL(*)				

SERIES	WATTAGE	VOLTAGE	FINISH	# of LEDs	COLOR TEMP	DISTRIBUTION	ACCESSORIES
☐ UF2	☐ 04 43 W	☐ U 120-277	☐ TSA Textured Satin Aluminum	☐ 030 30 LEDs	☐ 4K	☐ 2x2 24°H x 24°V	☐ 7 2" Slipfitter Adapter
	☐ 06 63 W		☐ TDB Textured Dark Bronze			☐ 3x5 34°H x 75°V	☐ 3 3" Slipfitter Adapter
			☐ TBK Textured Black			☐ 4x4 52°H x 54°V	
			☐ TWHT Textured White			☐ 5x3 75°H x 34°V	
			☐ TGR Textured Gray			☐ 5x5 86°H x 84°V	
			☐ TGN Textured Green				
			☐ RAL(*) Custom Color (* = Specify RAL #)				

DIMENSIONS

9.14"
23.2 cm
13.31"
33.8 cm
6.91"
17.6 cm
10.98"
27.8 cm

EPA (sq ft)
1 Fixture 0.55

Weight: 25 lbs 11.3 kg

Fixture Type E1

TECHNICAL DATA

	2X2		3X5		4X4		5X3		5X5	
Input Watts	43W	63W	43W	63W	43W	63W	43W	63W	43W	63W
Initial Lumens @ 25° C Ambient	2407	3136	2239	2918	2315	3041	2239	2918	2227	2957
Lumens per Watt @ 25° C Ambient	55.9	49.8	52.1	46.3	53.8	48.3	52.1	46.3	51.8	46.9

Due to a program of continuous improvement, Quality Lighting reserves the right to make any variation in design, construction to the equipment described, change specifications and dimensions without notice. Lamp and electrical specifications / availability subject to change by manufacturer without notice.

PT#: QLSP0182B0212

PROJECT
FIXTURE TYPE
CATALOG#

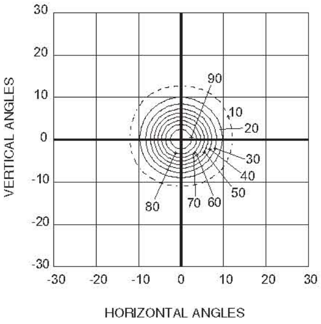
1611 Clovis R. Barker Road
San Marcos, Texas 78666
Toll Free Phone: (800) 545-1326
Fax: (866) 713-6002
www.qualitylighting.com
e-mail: Quality.Info@Philips.com

UF2 LED

PHOTOMETRIC DATA

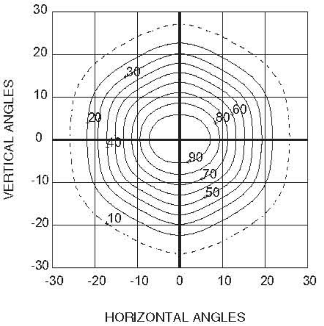
Luminaire: UF2 LED 2x2 Distribution
Lamp: 30 White LEDs with Clear Prismatic Plastic Optics

Beam Spread:	12.7 Deg Horiz
(at 50% Max CD)	12.2 Deg Vert
Field Spread:	24.1 Deg Horiz
(at 10% Max CD)	23.6 Deg Vert
Beam Lumens:	1028
Field Lumens:	1847
Total Lumens:	2407



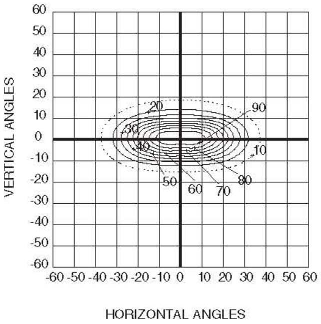
Luminaire: UF2 LED 4x4 Distribution
Lamp: 30 White LEDs with Clear Prismatic Plastic Optics

Beam Spread:	30.4 Deg Horiz
(at 50% Max CD)	31.0 Deg Vert
Field Spread:	51.7 Deg Horiz
(at 10% Max CD)	53.7 Deg Vert
Beam Lumens:	1213
Field Lumens:	1970
Total Lumens:	2315



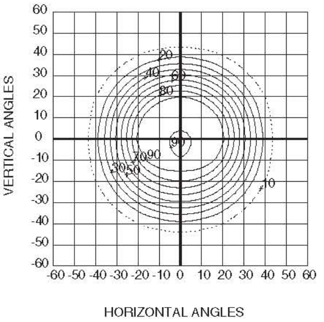
Luminaire: UF2 LED 5x3 Distribution
Lamp: 30 White LEDs with Clear Prismatic Plastic Optics

Beam Spread:	44.8 Deg Horiz
(at 50% Max CD)	16.5 Deg Vert
Field Spread:	74.7 Deg Horiz
(at 10% Max CD)	33.6 Deg Vert
Beam Lumens:	1080
Field Lumens:	1865
Total Lumens:	2239



Luminaire: UF2 LED 5x5 Distribution
Lamp: 30 White LEDs with Clear Prismatic Plastic Optics

Beam Spread:	59.9 Deg Horiz
(at 50% Max CD)	54.9 Deg Vert
Field Spread:	85.9 Deg Horiz
(at 10% Max CD)	84.0 Deg Vert
Beam Lumens:	1575
Field Lumens:	2079
Total Lumens:	2227



Fixture Type E1

PT#: QLSP0182B0212