PENNSTATE

*Innovation Park*
*at Penn State*

# 329 Innovation Boulevard

## State College, PA

# AE Senior Thesis Final Report


Preparded By:
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Structural Option


Spring 2008
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## General Building Data:

- **Building Occupants:** No occupants at the current time
- **Building Function:** Commercial Offices
- **Size:** 87,000 sq. ft.
- **Height:** 4 stories, 58 ft. tall
- **Dates of Construction:** August 2007 – late 2008
- **Project Cost:** Private
- **Project Delivery Method:** Design/Bid/Build

### Unique Building Aspect:

- Pre-engineering Pedestrian Bridge

## Electrical Aspects:

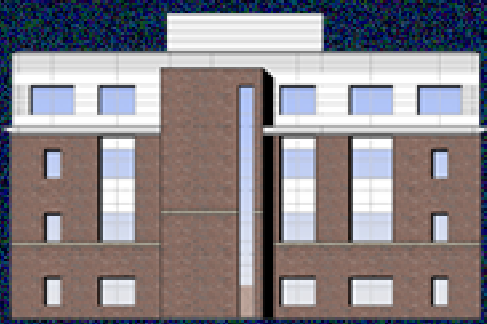
- 480Y/277V, 3Φ, 4W Service From (New) Transfomer
- 480V, 500 W, 3Φ, Emergency Generator
- (5) 30kVA Transformers For 208Y/120V, 3Φ, 4W Service Located on Each Floor
- See Lighting Aspects For Various Fixtures Used

## Lighting Aspects

- Various Types of Fixtures Used:
    - Vertical Open Reflector CFL Down lights, 4' Industrial w/ 25% Uplight, Wall Sconces, 4' Recessed Direct w/ Parabolic Baffle, Round Area Lights, etc.

## Project Team

- **Owner:** CB Richard Ellis
- **CM:** Leonard S. Fiore, Inc.
- **Architect:** L. Robert Kimball & Associates
- **Engineer:** L. Robert Kimball & Associates



## Structural Aspects:

- **Foundation:** 4" Normal Weight Concrete SOG w/ Interior & Exterior Footings/Piers
- **Superstructure:** Steel Columns/Beams/Girders
- **Floor System:** 3.25" Lightweight Concrete w/ One Layer WWF On 3" Galvanized Composite Steel Deck (6.25" Total Thickness)
- **Lateral System:** Full Moment Resisting Connec tions
- **Envelope:** Brick Veneer w/ Aluminum Curtain Wall System, and Prefinished Composited Metal Panel Systems

## Mechanical Aspects

- (1) 570 GPM 90.0 Ton Cooling Tower
- (4) 285 GPM Condenser Pumps
- (2) 150 GAL Electric Boilers
- (4) Rooftop Heat Pump Provided w/ Enthalpy Exchange Wheel
- (14) Indoor Heat Pumps Each W/ Micro processor Control Board

## BUILDING DESCRIPTION:

329 Innovation Boulevard is a completed design for multiple commercial tenants. It is located in the Innovation Park at Penn State, State College, PA. The building is four stories tall, with a mechanical penthouse located on the roof. The total height is 58', and the footprint is 21,000 SF. It is a steel framed structure with a concrete composite flooring system. The veneer includes brick, aluminum panels, and glass curtain walls. It typically follows the style of the current buildings of Innovation Park.

## PROJECT GOALS:

329 Innovation Boulevard has become a "business incubator" due to its close proximity to The Pennsylvania State University. Many start-up businesses may be interested in locating to the park, making space grudgingly unavailable. The current floor plan of 329 can most likely accommodate 2-3 tenants per floor. With large spaces already being provided with the existing framing system (consisting of moment frames), the only way to create more leasable space is to go up.

A theoretical two-story expansion of the pre-built building was proposed. This expansion would have numerous effects on the various systems of the building, but three were looked at: the structural system, the façade system, and the mechanical system. Knowing that any expansion will ultimately cost more money, the new systems would have to be reasonably economical.

## STRUCTURAL DEPTH:

The expansion of 329 Innovation Boulevard would entail the redesign of the framing members – gravity and lateral. The lateral system was changed from moment frames to braced frames. This interfered with the open space previously provided, but was ultimately more cost efficient. Generally, the beams slightly increased in size, and the previously designed columns were able to withstand the new loads created by increased wind pressure (higher elevation). The braced frames consisted of HSS shapes ranging from HSS6x6x3/8 to HSS9x9x3/8. The new connections were designed and consisted of ¼" welds with lengths of 6-8" on all four sides of the braces. This bracing system created an extremely rigid structure and yielded minimal deflections, but cost less than an expansion with moment connections.

## ARCHITECTURAL BREADTH:

An architectural breadth study was performed to analyze the façade of 329 Innovation Boulevard. A new façade was designed to maintain the mold established by the existing buildings in the park. A thermal and moisture analysis was performed on the new façade. Although the new façade achieved thermal comfort levels, it manufactured additive costs.

## MECHANICAL BREADTH:

Due to increased mechanical loads from the expansion of the building, a redesign of the mechanical system was performed. The existing system of heat pumps is set up to be "built-out" and is temporary. Research done showed office buildings leaning towards VAV mechanical systems, and after comparing the pro's and con's, it seemed to make sense to redesign the system as VAV. The appropriate equipment was sized after finding the loads through Trace 700. The loads were created by parameters and values set forth by ASHRAE. Although the VAV system may be more costly upfront, it will yield savings in maintenance and operational costs.

## FINAL RECOMMENDATION:

After exploring the redesigns of three systems of the building multiple conclusions can be deducted:

- A two-story expansion would require redesign no matter what, but a redesign of the lateral resisting system may be more cost efficient. The braced frames yielded cheaper costs for raw materials over moment frames. My lateral system is not the most efficient (due to so little deflections) and may be worth further investigation.

- The original gravity framing members were marginally affected and would involve little redesign work.

- The savings from the structural redesign may be absorbed in the costs of the proposed façade and mechanical system, but they both are efficient, and the mechanical system produces minimal costs in the long-term.

# PROJECT BACKGROUND

329 Innovation Boulevard is a completed design in terms of the design phase, and is currently undergoing the construction phase. The structure will house multiple commercial tenants. It is located in the Innovation Park at Penn State, State College, PA. It will face Innovation Blvd. directly across from 328 Innovation Boulevard, which hosts the buildings designers, L. Robert Kimball & Associates. Due to the fact that tenants have not currently leased the provided space, the building utilizes an open floor plan to help facilitate any possible tenants.

The building is four stories tall, with a mechanical penthouse located on the roof. The total height is 58', and the footprint is 21,000 SF. It is a steel framed structure with a concrete composite flooring system. The veneer includes brick, aluminum panels, and glass curtain walls. It typically follows the style of the current buildings of Innovation Park. 329 Inn. Blvd. provides a pre-engineered bridge for pedestrian usage, which leads to an entrance on the second floor.


## 329 Innovation Boulevard

**Building Information**

| | |
|---|---|
| **Owner:** | C. B. Richard Ellis |
| **Architect:** | L. Robert Kimball & Assoc. |
| **Construction:** | Leonard S. Fiore, Inc. |
| **Structural:** | L. Robert Kimball & Assoc. |
| **Mechanical:** | L. Robert Kimball & Assoc. |
| **Electrical:** | L. Robert Kimball & Assoc. |
| **Building Size:** | 87,000 SF |
| **Building Height:** | 4 Stories (58') |
| **Project Cost:** | Private |
| **Delivery Method:** | Design-Bid-Build |
| **Construction Start:** | August 2007 |
| **Construction Finish:** | Late 2008 |

# SITE LOCATION

329 Innovation Boulevard is located in Innovation Park. Innovation Park itself is located adjacent to the Pennsylvania State University, which is one of its major selling points. Due to the close proximity of the school, Innovation Park prides itself as a prime location for businesses due to easy access to the research and technology resources of the University and its well-trained and skilled workforce.

> ***"I can't think of a better place to operate a high-tech engineering business. Not only are we practically next door to Penn State's $26 million nanofabrication facility, we're within a five-hour drive of Philadelphia, Pittsburgh, Washington, D.C., Toronto, and New York"***
>
> *Bob Burlinson, President and CEO, NanoHorizons*

The image to the right is the master plan of Innovation Park. The orange buildings are the existing, the purple are the buildings under construction, and tan are the sites of future construction. The purple building located just below the orange building is the recently finished 330 Innovation Boulevard. The other purple building is the site of 329 Innovation Boulevard.

# CONSTRUCTION

The constrution of 329 Innovation Boulevard is underway, and will be completed later this year. By the looks of the master plan, a lot more of construction will be taking place, as Innovation Park looks to double its number of buildings. Here are a few pictures of the current construction of 329 Innovation Boulevard:

**Photographed By: Jeremy R. Powis, Spring 2008**

# GENERAL ARCHITECTURE

The architecture of 329 Innovation Boulevard is heavily influenced by the surrounding buildings. The first building built in Innovation Park was the Penn Stater which is a Conference Center/Hotel. Even though Innovation Park is located down the road of the actual campus of Penn State, the influence of the school's architecture has spilled over. Penn State has multiple architectural themes, and the themes enable people to easily group buildings together in terms of when they were built. The newer buildings located on campus display similar themes to those displayed in Innovation Park. However, Innovation Park's themes and architecture are more simplistic compared to the campus's. Here are some visual examples of the parallel's between campus and the park:

## Campus Buildings:

**Smeal School of Business**

**Leonhard Building**

## Innovation Park Buildings:

**The Lupurt Building**

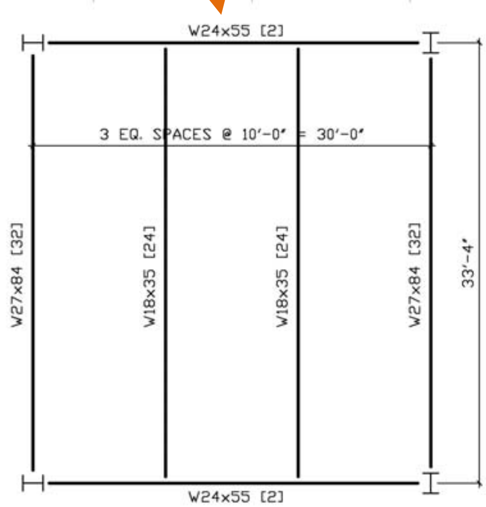
**328 Innovation Boulevard**

**Outreach Building**

## EXISTING SYSTEM

The four-story building of 329 Innovation Boulevard is supported by a steel superstructure. The floor framing system consists of a composite slab and metal deck on wide flange beams and girders. The concrete used is 3½" lightweight concrete with one layer of 6x6xW1.4xW1.4 WWF. The metal decking used is 3" galvanized wide rib type composite deck. The decking is to be continuous over a minimum of three spans. The total thickness of the flooring system comes to 6½" and therefore, the top of steel (beams and girders) is located at -6½" from the finished floor. The typical size of the beams is W18x35 and they span 33'-3" and the girders range from W18x35 to W21x44 and typically span 30'0". There are minimal interferences on each floor, making each of the three floor systems practically identical.


**Typical Framing Plan Figure 8.1**




**Enlarged Typical Bay Framing Plan Figure 8.2**

Lateral resistance is provided by several full moment connections of beams, girders, and columns. These connections can be found in the middle bay of the building on each end of the building. There are two columns on each end where the two beams and two girders are all connected by full moment connections. Majority of the moment connections occur in the interior of the building, and there are total of twelve moment connections on the exterior frame. The mechanical penthouse located on the roof utilizes flat strap bracing in plane with the stud wall. The following 3D model shows the location of the moment frames (blue members):

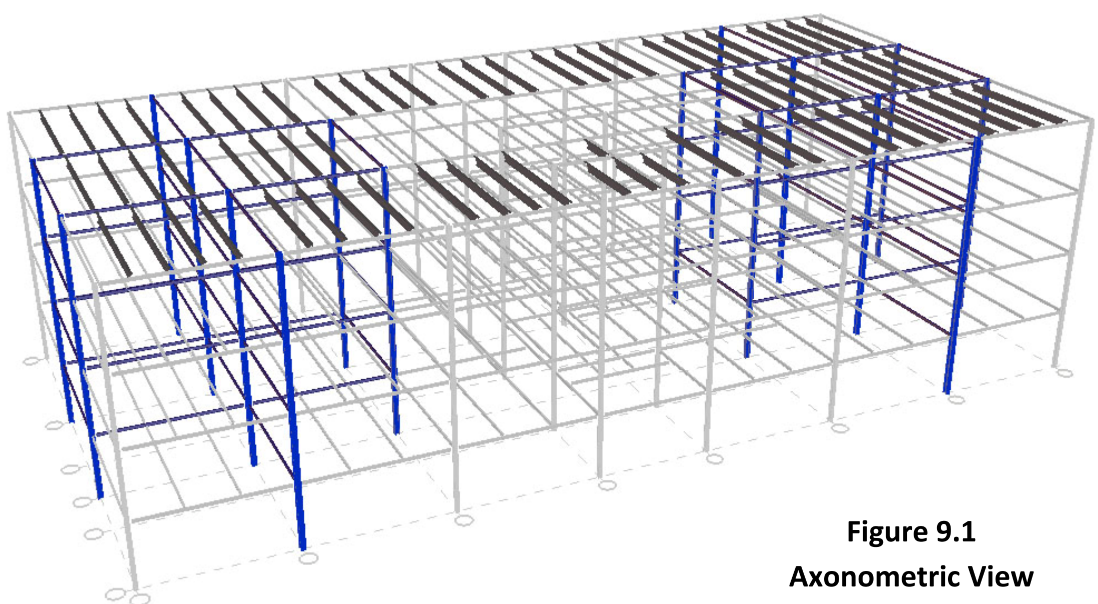


**Figure 9.1**
**Axonometric View**

## TWO-STORY EXPANSION

A theoretical two-story vertical expansion was proposed for 329 Innovation Boulevard. The two floors will affect the following:

- **Gravity Members**
- **Resistive System Members** (Due to changes in the wind and seismic loads)

This structural depth will go through the process of re-analyzing and re-sizing the gravity members. It will also explore an alternative resisting system, and size the members involved.

# DESIGN LOADS

| | |
|---|---|
| **Live Loads** | |
| Corridors | 100 PSF |
| Stairs | 100 PSF |
| Public Areas | 100 PSF |
| Mechanical/Electrical Rooms | 175 PSF |
| Open Plan Office (80 PSF + 20 PSF Partitions) | 100 PSF |
| Slabs-On-Grade (U.N.O.) | 100 PSF |
| Slabs-On-Grade (Dock/Receiving) | 200 PSF |
| **Roof Live Loads** | |
| Minimum Roof Live Load | 20 PSF |
| **Dead Loads** | |
| Partition Allowance | 20 PSF |
| Lightweight Concrete Slab | 115 PCF |
| MEP | 5 PSF |
| Metal Decking | 2-3 PSF (Deck Catalog) |
| Beam Weight | Specific To Each Member |
| **Snow Loads** | |
| Terrain Category | C |
| Ground Snow Load ($P_g$) | 40 PSF |
| Snow Exposure Factor ($C_e$) | 0.9 |
| Thermal Factor ($C_t$) | 1.0 |
| Snow Importance Factor ($I_s$) | 1.0 |
| **Wind Loads** | |
| Minimum Wind Load | 10 PSF |
| Uplift On Roof | 20 PSF |
| Basic Wind Velocity | 90 MPH |
| Wind Importance Factor | 1.0 |
| Wind Exposure Category | C |
| Internal Pressure Coefficient | ±0.18 |
| Components And Cladding | By Supplier |

# DESIGN LOADS CONT'D

**Seismic Loads**

| | |
|---|---|
| Seismic Importance Factor ($I_E$) | 1.0 |
| Seismic Response Acceleration ($S_s$) | 16.8% |
| Spectral Response Acceleration ($S_1$) | 5.9% |
| Spectral Response Coefficient ($S_{DS}$) | 13.4% |
| Spectral Response Coefficient ($S_{D1}$) | 6.7% |
| Seismic Design Category | A |
| Site Class | C |
| Long-Period Transition Period ($T_L$) | 6 Sec. |
| Seismic Force Resisting System | Undetailed |
| Response Modification Factor (R) | 3.0 |
| Seismic Response Coefficient ($C_S$) | 0.045 |
| Deflection Amplification Factor ($C_d$) | 3.0 |
| Design Base Shear | 60 Kips |
| Analysis Procedure | Eq. Lat. F. |

# WIND ANALYSIS

Due to the change in height of the building, the previous wind analysis done had to be revised. The new height will affect the wind pressures applied to the building, and thus increasing the overturning moment of the initial analysis. The members and foundation will have to be designed to withstand these new loads. The general information remained the same, and is given in the table below:

| Wind Loading According to ASCE7-05 | |
|---|---|
| Basic Wind Speed | 90 MPH |
| Exposure Category | C |
| Enclosure Classification | Enclosed |
| Building Category | II |
| Importance Factor | 1.0 |
| Internal Pressure Coefficient | 0.18 |

The following page contains tables that include the new pressures used to find the loads applied to each story level. ASCE7-05 was utilized to obtain the values.

| North/South Wind Pressure Values | | | | | | |
|---|---|---|---|---|---|---|
| z (ft) | Kz | $q_z$ | $P_{windwardl}$(PSF) | $P_{leeward}$(PSF) | $P_{sidewall}$(PSF) | $P_{total}$(PSF) |
| 0-15 | 0.85 | 14.98 | 12.84 | -8.43 | -14.83 | 21.27 |
| 20 | 0.90 | 15.86 | 13.59 | -8.43 | -14.83 | 22.02 |
| 25 | 0.95 | 16.74 | 14.35 | -8.43 | -14.83 | 22.78 |
| 30 | 0.98 | 17.27 | 14.80 | -8.43 | -14.83 | 23.23 |
| 40 | 1.04 | 18.33 | 15.71 | -8.43 | -14.83 | 24.14 |
| 50 | 1.09 | 19.21 | 16.46 | -8.43 | -14.83 | 24.89 |
| 60 | 1.14 | 20.09 | 17.22 | -8.43 | -14.83 | 25.65 |
| 70 | 1.17 | 20.62 | 17.67 | -8.43 | -14.83 | 26.10 |
| 80 | 1.21 | 21.33 | 18.28 | -8.43 | -14.83 | 26.71 |
| 90 | 1.24 | 21.86 | 18.73 | -8.43 | -14.83 | 27.16 |

| East/West Wind Pressure Values | | | | | | |
|---|---|---|---|---|---|---|
| z (ft) | Kz | $q_z$ | $P_{windwardl}$(PSF) | $P_{leeward}$(PSF) | $P_{sidewall}$(PSF) | $P_{total}$(PSF) |
| 0-15 | 0.85 | 14.98 | 11.34 | -4.31 | -14.83 | 15.65 |
| 20 | 0.90 | 15.86 | 12.01 | -4.31 | -14.83 | 16.32 |
| 25 | 0.95 | 16.74 | 12.67 | -4.31 | -14.83 | 16.98 |
| 30 | 0.98 | 17.27 | 13.07 | -4.31 | -14.83 | 17.38 |
| 40 | 1.04 | 18.33 | 13.87 | -4.31 | -14.83 | 18.18 |
| 50 | 1.09 | 19.21 | 14.54 | -4.31 | -14.83 | 18.85 |
| 60 | 1.14 | 20.09 | 15.21 | -4.31 | -14.83 | 19.52 |
| 70 | 1.17 | 20.62 | 15.61 | -4.31 | -14.83 | 19.92 |
| 80 | 1.21 | 21.33 | 16.14 | -4.31 | -14.83 | 20.45 |
| 90 | 1.24 | 21.86 | 16.54 | -4.31 | -14.83 | 20.85 |

The new story forces in the long direction (North/South) are as follows:

| | |
|---|---|
| **T/ Met. Panel (86’)** | **88.6 Kips** |
| **Level 6 (60’)** | **74.9 Kips** |
| **Level 5 (56’)** | **72.7 Kips** |
| **Level 4 (42’)** | **60.0 Kips** |
| **Level 3 (28’)** | **65.0 Kips** |
| **Level 2 (14’)** | **61.6 Kips** |

These values produce an overturning moment of **21,400 ‘K.** This value will be compared to the new overturning moment obtained through seismic analysis to establish the controlling load combination. The overturning moment in the East/West direction is **8,500 ‘K**.

# SEISMIC ANALYSIS

Like the wind analysis, the previous seismic analysis needed to be revised. New values needed to be obtained due to the change in height and the change in the building frame system. The framing system is changing from moment frames to braced, which changes the response modification coefficient. The coefficient was taken from ASCE7-05 Table 12.2.1 B-4, ordinary steel concentrically braced frames.

| Seismic Loading According to ASCE7-05 | | |
|---|---|---|
| Seismic Design Category | | A |
| Seismic Use Group | | II |
| Importance Factor ($I_E$) | | 1.0 |
| $S_S$ | | 0.168 |
| $S_1$ | | 0.059 |
| $S_{DS}$ | | 0.134 |
| $S_{D!}$ | | 0.067 |
| Site Class | | C |
| Response Coefficient | | |
| | N-S | 0.041 |
| | E-W | 0.041 |
| Response Mod. Factor | | |
| | N-S | 3.00 |
| | E-W | 3.00 |
| Period | | 0.555 |
| V (kips) | | 85 |
| K | | 1.03 |

The following table was used to obtain the story forces ($F_x$), the design base shear, and the overturning moment:

| Floor | Weight | Height (ft) | K | $h^K$ | $W*h^K$ | Cvx | V (K) | Fx |
|---|---|---|---|---|---|---|---|---|
| 2 | 330 | 14 | 1.03 | 15.254 | 5033.74 | 0.04 | 85 | 3.8 |
| 3 | 330 | 28 | 1.03 | 31.203 | 10296.86 | 0.09 | 85 | 7.8 |
| 4 | 330 | 42 | 1.03 | 47.425 | 15650.16 | 0.14 | 85 | 11.8 |
| 5 | 330 | 56 | 1.03 | 63.827 | 21062.90 | 0.19 | 85 | 15.9 |
| 6 | 330 | 70 | 1.03 | 80.364 | 26520.25 | 0.24 | 85 | 20.0 |
| Roof | 343.3 | 86 | 1.03 | 99.396 | 34122.71 | 0.30 | 85 | 25.7 |
| **Totals** | **1993.3** | | | | **112686.62** | **1.00** | | **85.0** |
| **Base Shear:** | | | 85.0 Kips | | | | | |
| **Overturning Moment:** | | | 5270 Ft.-Kips | | | | | |

## WIND VS. SEISMIC COMPARISON

The overturning moment caused by wind (21,400'$^{K}$) is much greater than the moment produced by seismic loads (5,270'$^{K}$). Multiple load combinations where considered, they included:

1.4D

1.2D + 1.6L

**1.2D + 0.5L +1.6W (Controlled)**

1.2D + 1.6W

0.9D + 1.6W

1.28D + 0.5L + 1.202E

1.28D + 1.202E

0.82D + 1.202E

This load combination controlled the previous design of 329 Innovation Boulevard. State College is located in a region of low seismic activity, so this combination is sensible. The two-story vertical expansion did affect the overturning moment greatly, however. The moment produced by wind (21,400'$^{K}$) is over twice the moment produced by the original design of the building (10,035'$^{K}$). This new moment inspired the idea of creating a new lateral resisting system. The existing lateral system of moment frames would have to be modified, anyway, to transfer the moments through the beams to the columns, and back down to the foundation. Braced frames will be able to transfer the moments through the structure.

## BRACED FRAME SYSTEM

Ordinary moment frames (OMF) are usually used in low seismic region (State College is one) or used as gravity frames in high seismic regions. OMFs are expected to withstand limited inelastic deformations in their members and connections when subjected to forces resulting from the motions of the design. With the increased loads, the connections will become more elaborate and more difficult to design.

Concentrically Braced Frames (CBF) are directed along work-lines that intersect at points and are initially developed to resist wind-induced actions in the linearly elastic range. They are characterized by their high elastic stiffness. The braces are designed to carry all of the lateral force shears. Concentrically braced frames have been selected to carry the new loads produced by the wind pressures. Of course there are advantages and disadvantages to both systems, including the large open areas produced by moment frames and the obstructions caused by braced frames. Braced frames also mean more costs in steel; however, the additional two floors of tenant space will more than likely compensate for these additional costs.

## LOCATION OF BRACED FRAMES

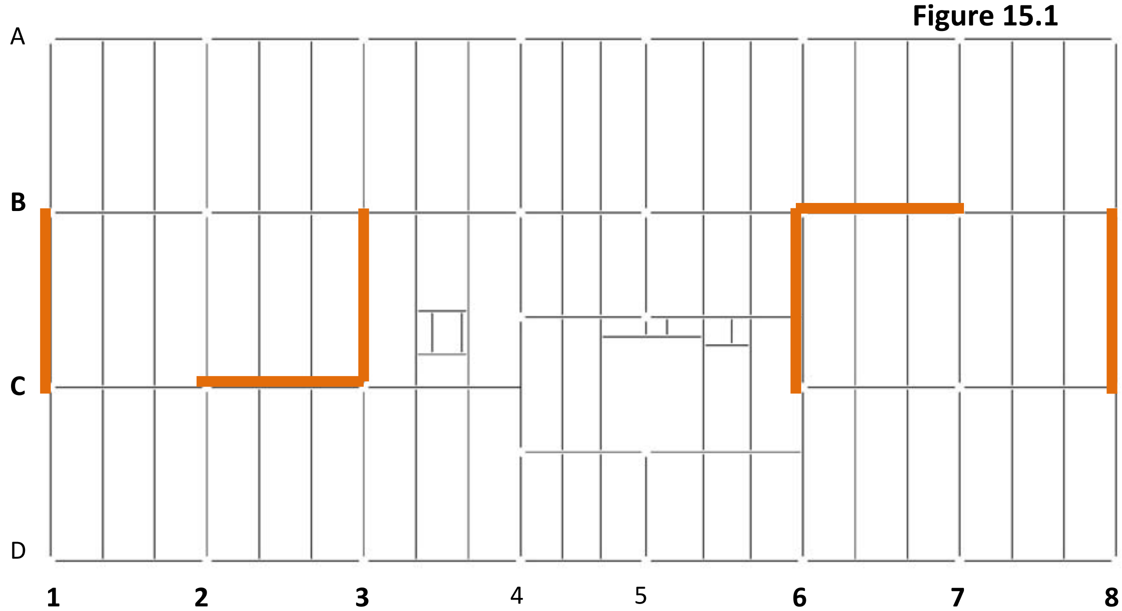
As mentioned previously, a disadvantage of braced frames are obstructions that the form in spaces. This is where good coordination between architect and engineer becomes a priority. These obstructions must be able to coincide with the architectural layout of the space, including window and door locations. Fortunately for 329 Innovation Boulevard, the architectural plans are created after the tenant leases the space. The open floor plan allows for easy placement of the frames.

The engineer is now able to dictate the architectural plans of the space with the position of the frames. There were multiple factors that I had taken into consideration when deciding where the optimal location of the frames would be, they included:

- **Center of Rigidity/Center of Mass**
- **Previous Architectural Aspects**
- **Possible Architectural Schemes w/ Braced Frames**

The center of rigidity and the center of mass was a priority, because by creating the same location for the two centers, I am able to eliminate any torsional effects on the building. For this reason and knowing that the center of mass will be located near the geometric center, I kept the frames symmetrical around the center of building, and located them along the central bays of the building. The following plan shows the preliminary location of the braced frames:

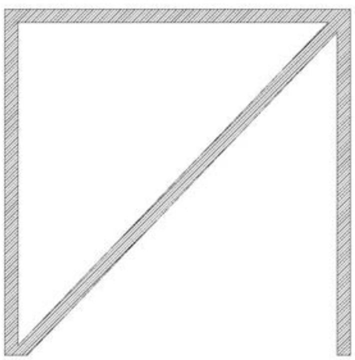
**Figure 15.1**



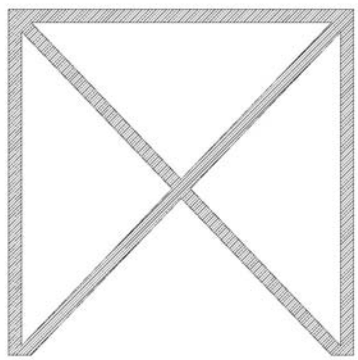
The idea of locating the braces through the central bays stemmed from not wanting to interfere with the façade and its fenestrations. The two braces on the ends are located along the stairways of the building. Entrances/exits to these stairways cannot be obstructed, so that helped with the selection of what type of braced frame to use.

## SELECTION OF BRACED FRAMES

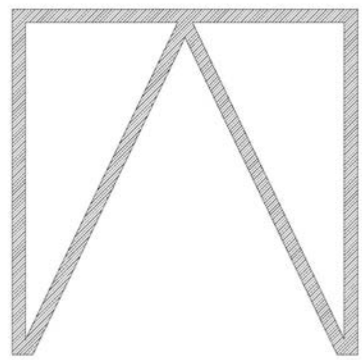
The following images are the three types of braced frames considered:



**Diagonal Bracing**



**X-Bracing**

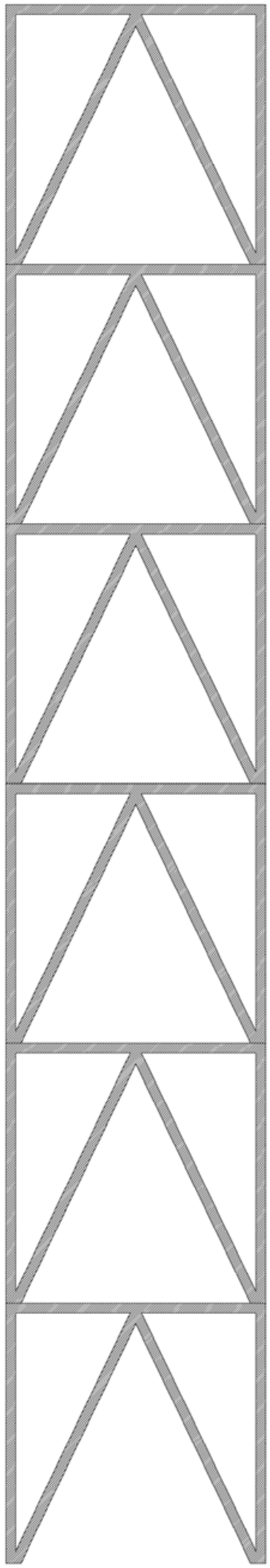


**Chevron Bracing**

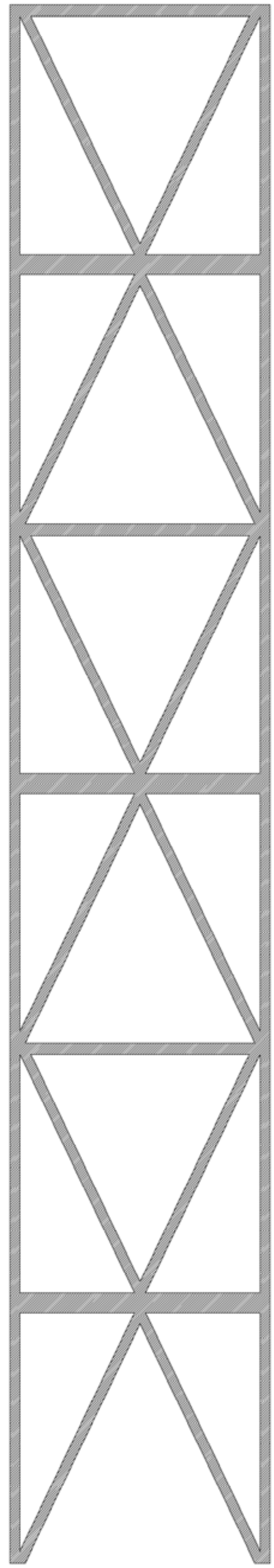
X-bracing clearly makes the most obstructions, and was no longer considered, but aspects of the design were considered. Alternating diagonal bracing, or K-bracing, was initially used for the design. The members for the bracing needed to be large for strength purposes. The large members made the system extremely rigid, and the deflections produced were minimal. Minimal deflections aren't bad, but it was clear that the system did not have to be that rigid. The deflections were much less than the industry standard of H/400, so in order to get a less rigid frame, and thus smaller members, chevron bracing was used. Chevron bracing provides adequate space for doorways, and other possible fenestrations. The inverted V chevron bracing was used on the two frames located on the ends of the buildings. This allowed the location of the planned doorways to the stairway to remain the same. Alternating V and inverted V chevron bracing was used for the four interior frames. This created a two-story "x-bracing" and was used to help create some flexibility in the possible floor plans.

The following page includes the initial elevations of the frames:

## CHEVRON BRACING SCHEMATICS



**Two Exterior Frames**



**Four Interior Frames**

## STRUCTURAL PLAN

Knowing that the cost of a shear stud includes about $10 in steel plus installation costs, I decided to maintain the composite decking; however, I opted not to maintain the composite beams. The new structural system will be composite deck on non-composite beams. I anticipate deeper beams, but I am assuming that it will ultimately create savings in the system.

The concrete used is 3½" lightweight concrete with one layer of 6x6xW1.4xW1.4 WWF. The metal decking used is 3" galvanized wide rib type composite deck. The decking is to be continuous over a minimum of three spans. The total thickness of the flooring system comes to 6½" and therefore, the top of steel (beams and girders) is located at -6½" from the finished floor. The typical size of the beams is W18x35 and they span 33'-3" and the girders range from W18x35 to W21x44 and typically span 30'0".

## RAM 3D MODEL

RAM Structural System was utilized to model the building, size the appropriate members, and find the reactions of the members. The following is the 3D RAM model; it shows the location of the braces (red and purple members), and framing of the two-story addition:

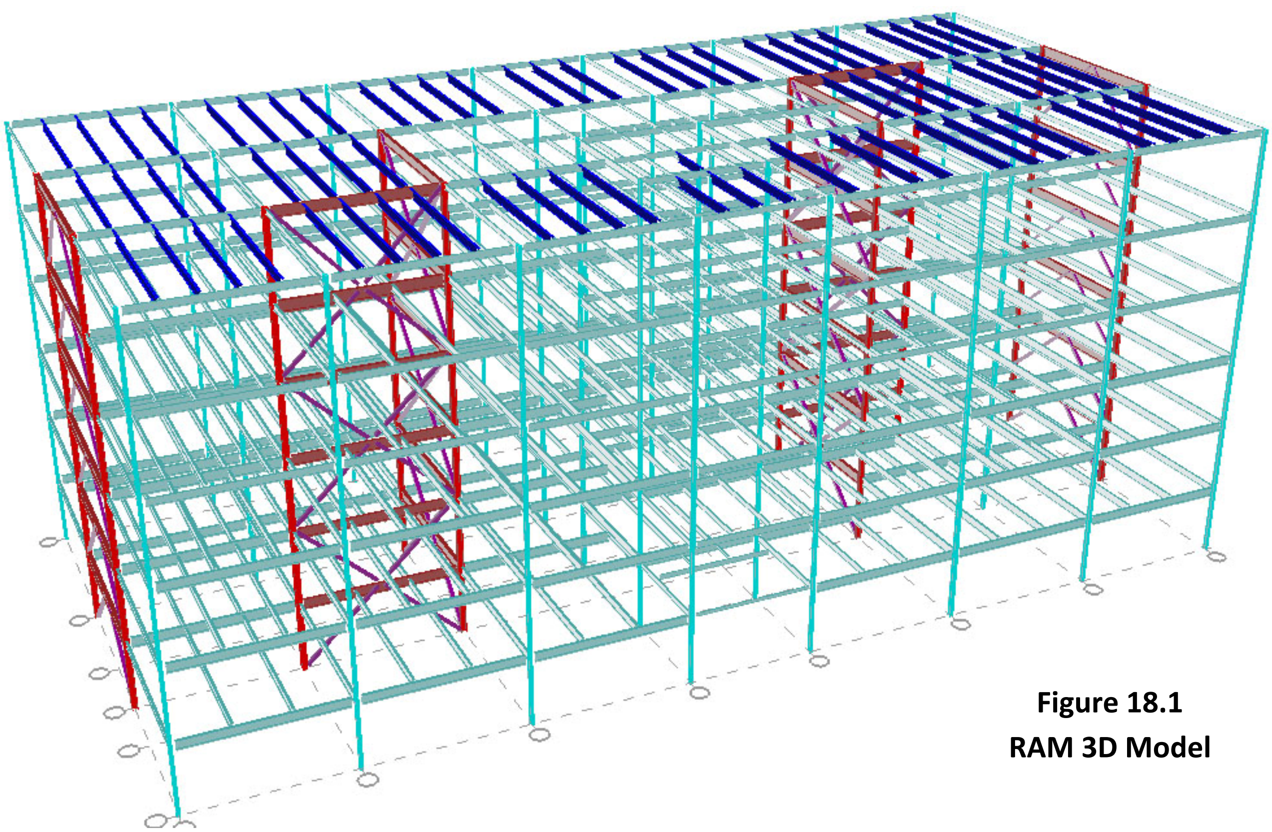


**Figure 18.1**
**RAM 3D Model**

## INITIAL SIZING OF MEMBERS

The beams utilized in the braced frames were taken from the existing plan. I did this because I found the beams used less than 50% of their capacity in previous technical assignments. I also knew that these beams would have to be large to resist the wind loads. So four W27x84s were used in the long direction and two W24x68s were used in the short direction. In an attempt to reduce the size of the columns, I tried to utilize W10s of different weights.

The bracing member sizes would depend on what shape the braces would be. I considered only two shapes – wide flange and rectangular or square HSS. There are advantages and disadvantages to both, and it comes down to a preference between the two. Due to advances in HSS connections, a new chapter (Chapter K) was added to the Steel Manual. It is titled "Design of HSS and Box Member Connections". *Modern Steel Construction* published an article about this addition of design techniques, and stated that "it ushered in a new era in the use of hollow structural connections." I decided to use these new techniques of design, and opted to use square HSS members for the bracing.

A quick hand check was done, and the initial size of the braces came out to be an HSS8x8x3/8. The overall thickness of these braces (8") is smaller than the width of the flange and web of the columns (12.2" and 9.125", respectively), which would allow the wall thickness to be lesser. These initial members were implemented into RAM Structural System, and check against the various codes and strength checks.

The roof was not redesigned, so the original members (wide flange beams and steel web joists) were used in the model. Their sizes would remain the same, due to the fact that no new loads were applied to them.

## STRENGTH CODE CHECK

A strength check was performed using the RAM Structural System model. The results were obtained by loading the model and analyzing it using numerous load combinations. The load combinations were generated by RAM through the load combinations drop-menu. RAM used IBC 2003 LRFD to obtain the combinations. Knowing that wind controls the resisting system - dead, live, and wind loads only were applied to the model. As previously mentioned, the controlling load combination was:

**1.2D + 0.5L +1.6W**

The strength check dictated the size of the bracing members. The initial size of HSS8x8x3/8 was not large enough for the first two floors for the interior frames, and was too large for top four floors for the exterior frames. The braces on the interior frames were increased from HSS8x8x3/8 to HSS9x9x3/8 for the first two floors. The braces on the exterior frames were decreased from HSS8x8x3/8 to HSS6x6x3/8.

The abovementioned load combination produced the greatest values compared to the other combinations. RAM used the combination to check the resisting members according to strength. It uses a scale so that anything less than 1.0 is an acceptable value. The diagram below shows the color-coded results of RAM's analysis. Note that all members use less than 94% of the maximum strength, with majority less than 70%, meaning that the frames are adequate in strength. The strength code check performed by RAM ultimately dictated the size of the columns. It will be seen later that the system is rigid and produces minimal drift affects, but the members were needed to be larger due to strength. The columns were still reduced in size from the existing plan and are discussed in the next section.

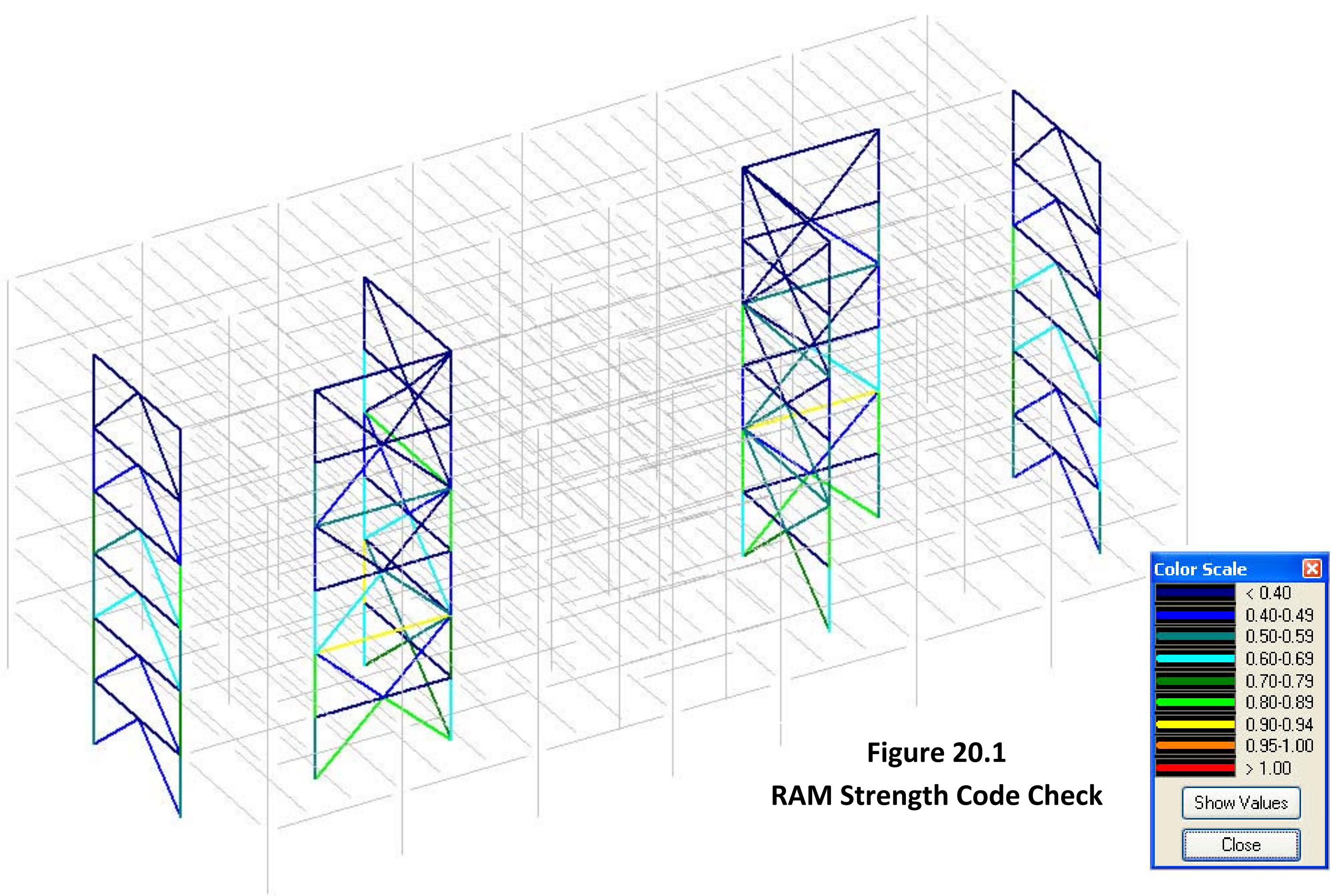



**Figure 20.1**
**RAM Strength Code Check**

## COLUMN CODE CHECK

RAM Structural System was used to size the gravity member columns. The output showed that the column sizes ranged from W10x33 to W10x49. These column sizes are smaller than the W12x53 and W12x65 columns used in the previous design of the structure. This may be because of the mechanical penthouse loads located on the roof. The columns may also be oversized for the possibility of additional equipment to roof. The mechanical breadth of this report explores the mechanical system, and verifies the assumption of additional equipment needed.

The columns were able to be reduced in size. The new lateral resisting columns consisted of a W10x77 spanning from the ground floor to the third floor and a W10x39 spanning the remaining floors on the east and west ends. The "L" shaped frames consisted of W10x100s spanning the first four floors and a W10x45 spanning the remaining two on the ends. Where the frames meet, the columns consist of a W12x79 that spans the first three floors and a W10x49 spanning the remaining. Clearly, these column sizes are smaller and are shown in a column schedule later in the report. The following is code check performed by RAM, and every column is designed below its max. capacity :

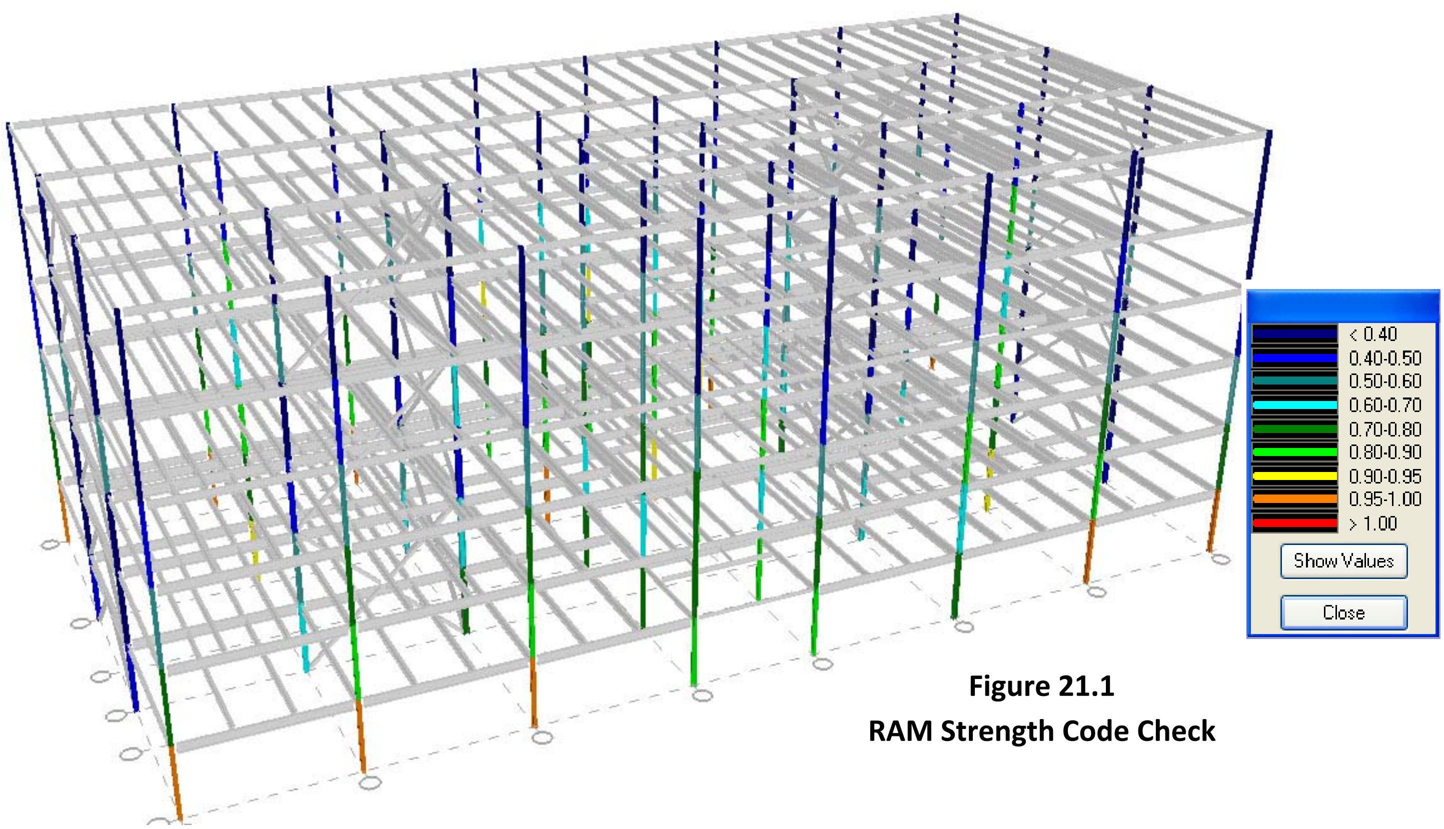



**Figure 21.1**
**RAM Strength Code Check**

# TORSION ANALYSIS

Along with resisting lateral loads, the braced frames must be able to withstand any torsional forces that may occur. Story shear is assumed to act through the center of mass of each level, and when the center of mass does not coincide with the center of rigidity a moment or torsion force is induced. RAM Frame was used to obtain the centers of rigidity and the centers of mass. The following table contains those values:

**Torsion Values**

| Floor | Centers of Rigidity | | Centers of Mass | |
|---|---|---|---|---|
| | X (Ft.) | Y (Ft.) | X (Ft.) | Y (Ft.) |
| 6th Floor | 102.35 | 49.78 | 101.96 | 49.88 |
| 5th Floor | 102.41 | 49.81 | 101.68 | 50.24 |
| 4th Floor | 102.50 | 49.84 | 101.68 | 50.25 |
| 3rd Floor | 102.30 | 49.88 | 101.68 | 50.26 |
| 2nd Floor | 101.92 | 49.92 | 101.68 | 50.26 |
| 1st Floor | 101.92 | 49.91 | 101.68 | 50.93 |

A straight comparison of the center of rigidity and center of mass shows that they do coincide almost exactly. The dimensions of 329 Innovation Boulevard are approximately 203'x100', which means the location of the center of mass/rigidity is almost at the geometric center of building. However, according to code, "where diaphragms are not flexible, the mass at each level shall be assumed to be displaced from the calculated center of mass in each direction a distance equal to 5% of the building dimension at that level perpendicular to the direction of the force under consideration. The effect of this displacement on the story shear distribution shall be considered." RAM Frame has accounted for the 5% eccentricity, and the values remain practically identical. The symmetry of 329 Innovation Boulevard in both layout and member sizes aspects have adequately resisted any possible torsional moment created by the lateral loads. No torsional forces have been prepared due to the fact that they will be very minimal.

## DRIFT ANALYSIS

The maximum displacement and story drift were calculated using RAM Frame. The maximum values were found under the wind loading, due to the fact that it was the only lateral force applied to the frame. These values were compared to H/400, which yields the acceptable total displacement and story drift. The 329 Innovation Boulevard Expansion is 86' tall, and therefore the acceptable amount of drift is 2.58". Below is a table containing the comparison of the RAM values and the acceptable drift values: Following the comparison table is the deflected shape produced by RAM frame. The values in the comparison table correspond to the red deflected shape of the frames.

**Critical Displacements**

| Floor | Height (ft.) | FF Height (ft.) | H/400 (in.) | RAM Disp. Values (in.) | RAM Drift Values (in.) | H/400 (in.) |
|---|---|---|---|---|---|---|
| Roof | 86 | 16 | 2.58 | 0.62 | 0.11 | 0.48 |
| 6th Floor | 70 | 14 | 2.58 | 0.52 | 0.11 | 0.42 |
| 5th Floor | 56 | 14 | 2.58 | 0.41 | 0.11 | 0.42 |
| 4th Floor | 42 | 14 | 2.58 | 0.30 | 0.11 | 0.42 |
| 3rd Floor | 28 | 14 | 2.58 | 0.18 | 0.10 | 0.42 |
| 2nd Floor | 14 | 14 | 2.58 | 0.08 | 0.08 | 0.42 |
| 1st Floor | 0 | N/A | N/A | N/A | N/A | N/A |

- The drift values do not apply to the 1st floor due to the fact that is considered the ground floor, and the ground prevents any displacement.

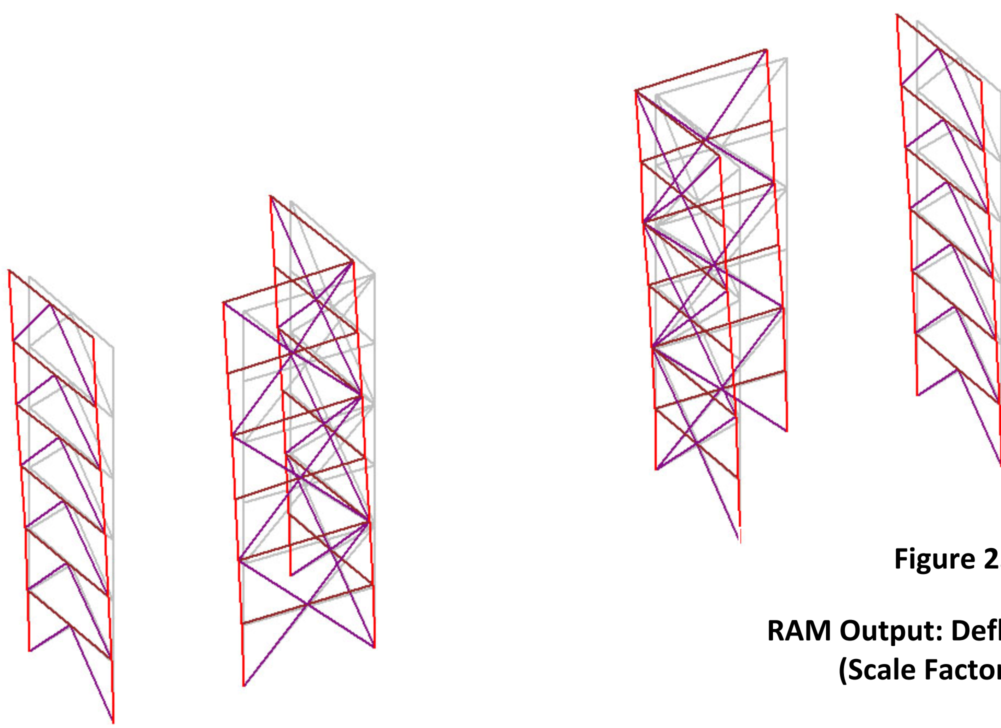


**Figure 23.1**

**RAM Output: Deflected Shape (Scale Factor = 100)**

## OVERTURNING ANALYSIS

The overall overturning moment was found to be 21,400'$^{K}$ due to the wind load acting in the North/South direction (Refer to Wind Loading under the Wind Analysis Section). Each braced frame will experience an overturning moment as well. This moment will be transferred to the foundation, and it is up to the foundation to resist these moments. Due to the symmetry of 329 Innovation Boulevard, the overturning moments of the frames located on the left side of the plan will be the same as those located on the right side. Refer back to Figure 15.1 for the location of the braced frames. The following table compares the overturning moments of each frame to the resisting moments. If the overturning moment exceeds that of the resisting moment, then additive tension reinforcing is required at the foundation.

**Moment Comparison**

| Frame | Grid Line Location | | Overturning Moment | Resisting Moment | Tension |
|---|---|---|---|---|---|
| | Left Side | Right Side | (Ft.-Kips) | (Ft.-Kips) | Req'd |
| B-C | Along #1 | Along #8 | 21,400 | 205,000 | No |
| B-C | Along #3 | Along #6 | 21,400 | 205,000 | No |
| B | N/A | 6-7 | 8,500 | 50,450 | No |
| C | 2-3 | N/A | 8,500 | 50,450 | No |

The comparison shows that no tension steel is required to resist the overturning moments. The dead loads alone are adequate. Foundations are discussed in the next section, and it is noted that micropiles are used as anchorage. Although they are not required because of the overturning moment, they may be used for other uplift forces not explored.

## FOUNDATIONS

The existing foundation system consists of grade beams and pile caps. The first floor is a slab-on-grade, which consists of 4" normal weight concrete reinforced with fibrous reinforcement. The pile caps are anchored by micropiles, which consist of 7" O.D. steel casing specified by the contractor. These micropiles span a certain length past the competent limestone, which is determined by the specialty contractor. The moments due to the lateral and gravity loads are transferred from the columns into the footings. The foundation should be adequate for the system, but if any redesign was required it would occur at the footings under the braced frames. The foundations would have to be redesigned if moment frames were used, which can ultimately be very expensive.

## CONNECTIONS

The connections between the HSS member and the wide flange beams and columns were designed to consist of gusset plates and welds. The gusset plates will be attached to the columns or beams prior to placement and the brace members can then be field welded to the plates. Fillet weld sizes are usually limited to less than 5/16", because that is the maximum size obtained with a single-pass weld. The braces saw a maximum 80 kips, which yielded a weld of 1/4" (< 5/16") with length of 8"on both sides of the HSS member. There actually four welds involved, two on each side of the gusset plate. The plate size is 1/2". The braces that saw lesser forces maintained the 1/4" weld and 1/2" plate size, but only a 6" length of weld was required. Obviously these welds could be smaller (due to the fact that the connection was designed for two welds, rather than four), but I left these lengths for safety purposes. The gusset plates were then sized by making sure that these connections would be possible geometrically. The typical connections included in this report were designed using the worst case loading, so the weld lengths may be even smaller with the braces that saw little force.

## COST ANALYSIS

Full-penetration welds for moment connections can cost up to $1,000 per connection and upwards to $2,000 if both flanges are engaged. The four-story framing system of 329 did not involve full-penetration welds, but are still very costly. Here's a breakdown:

| | |
|---|---|
| **Bolts:** | $10/bolt |
| **Fillet Welds:** | $35/lb of weld material<br>( x 10% for plates) |

These values will be used to find the price of a typical moment connection and judged against the pricing of the braced frame system. The braced frame system consists of the connections and the additional HSS members involved. Here's the values used for that system:

| | |
|---|---|
| **HSS:** | $700/ton |
| **Fillet Welds:** | $35/lb of weld material |
| **Plates (1/2" thk.):** | $24.50/S.F. |

The following page includes tables of rough estimates for the cost of moment frames vs. the cost of braced frames in the two-story expansion.

| Moment Connection Costs | | | | | |
|---|---|---|---|---|---|
| **Material** | **Cost/Unit** | **Unit/Connection** | **# of Connections Per Floor** | **# of Floors** | **Total Cost ($)** |
| Bolts | $10/bolt | 18 | 36 | 6 | 38880.00 |
| Welds | $35/lb | 4 | 36 | 6 | 30240.00 |
| Plates | | | | ( + 10%) | 6912.00 |
| **Total** | | | | | **76032.00** |

| Braced Connection Costs | | | | | |
|---|---|---|---|---|---|
| **Material** | **Cost/Unit** | **Size** | **Tons/Member** | **Quantity** | **Total Cost ($)** |
| | | HSS9x9x3/8 | 0.439 | 16 | 4916.8 |
| HSS | $700/ton | HSS8x8x3/8 | 0.386 | 40 | 10808 |
| | | HSS6x6x3/8 | 0.281 | 16 | 3147.2 |
| | | **Connection Type** | **SF of Plare/Connection** | | |
| | | A | 2.80 | 4 | 274.40 |
| | | B | 2.80 | 20 | 1372.00 |
| Plates | $24.50/SF | C | 4.70 | 12 | 1381.80 |
| | | D | 3.00 | 8 | 588.00 |
| | | E | 11.10 | 12 | 3263.40 |
| | | F | 6.10 | 24 | 3586.80 |
| | | **Connection Type** | **Pounds/Connection** | | |
| | | A | 0.334 | 4 | 50.77 |
| | | B | 0.334 | 20 | 253.84 |
| Welds | $35/lb | C | 0.668 | 12 | 304.61 |
| | | D | 0.444 | 8 | 134.98 |
| | | E | 1.777 | 12 | 810.31 |
| | | F | 0.889 | 24 | 810.77 |
| **Total** | | | | | **31703.67** |

These values are rough estimates, but they do show that it would be beneficial to switch to a braced frame system if the building was designed as six stories. Moment connections are extremely involved, more so than the braced frame connections, and would have more costs of design.

The next cost analysis contains general figures for the composite beam vs. non-composite beam system. A conservative value for total number of shear studs per floor is 1900. Each beam generally has 24 shear studs on it. Let's say that each shear stud is roughly $10 of steel alone (excluding cost of installation)

**Cost of Shear Studs** = $10(1900 Studs) **= $19,000**

The non-composite system yielded beams larger than the composite system. The typical plan of the composite system included a W18x35 @ 10' O.C.; whereas, the non-composite system used W21x44 @ 10' O.C. RSMeans prices W18x35s at $31/L.F. and W21x44s at $35.50/L.F., which is a difference of $4.50/L.F. There is about 60 W21x44s and W18x35s per floor and each span about 33.33'.

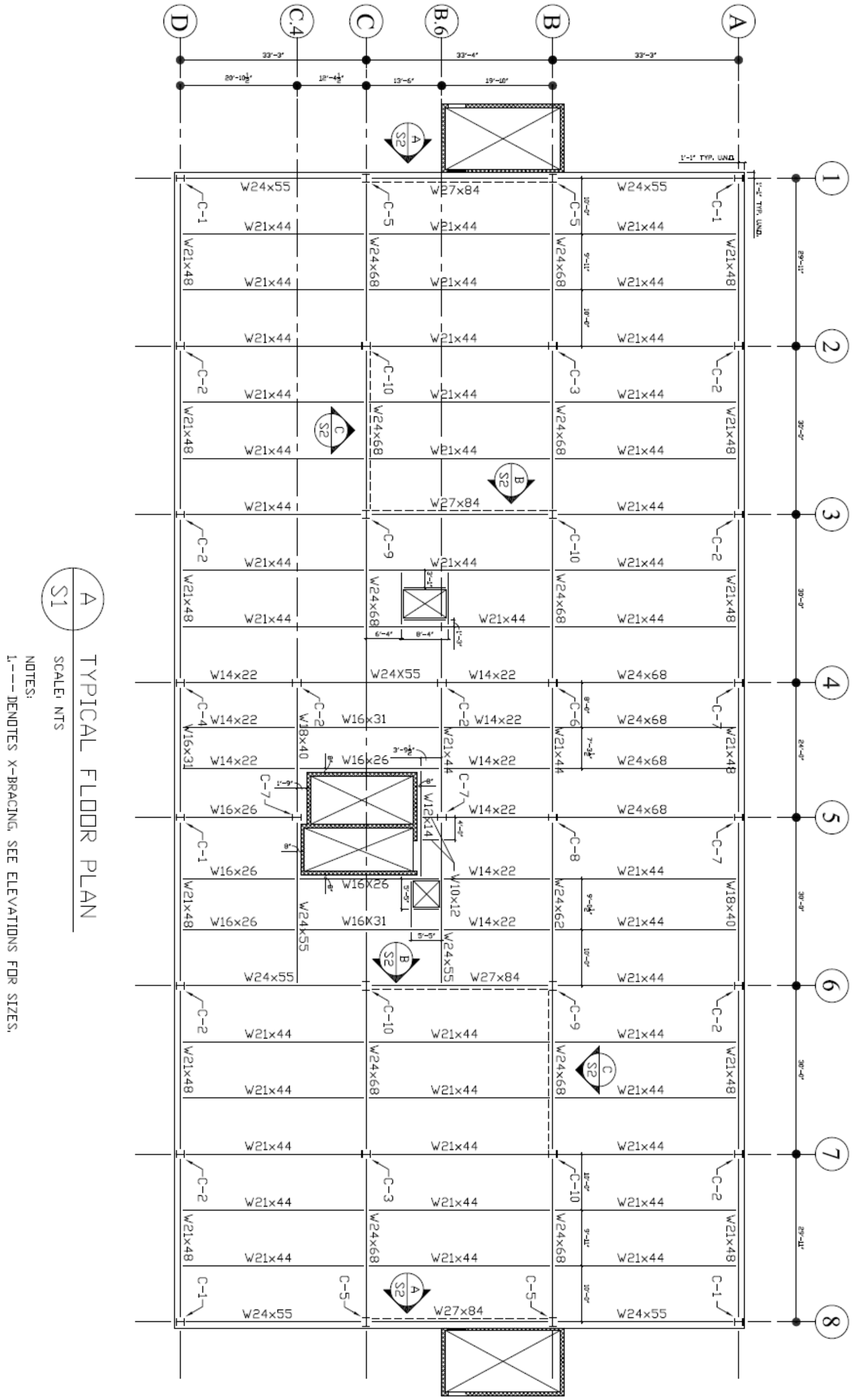
**Additive Cost of Beams** = $4.50/L.F.(60)(33.33') **= $9,000**

Once again, these are very rough numbers, but they yield about $10,000 in savings per floor. This means a possible total savings of $60,000. This not necessarily a jaw-dropper, but it does show that the non-composite system designed is slightly cheaper.

## STRUCTURAL DRAWINGS DESCRIPTION

The drawings included on the following pages are of the culmination of the design process. They include a typical floor plan, the braced frame elevations, and the typical connections used.

# STRUCTURAL DRAWINGS



# COLUMN SCHEDULE

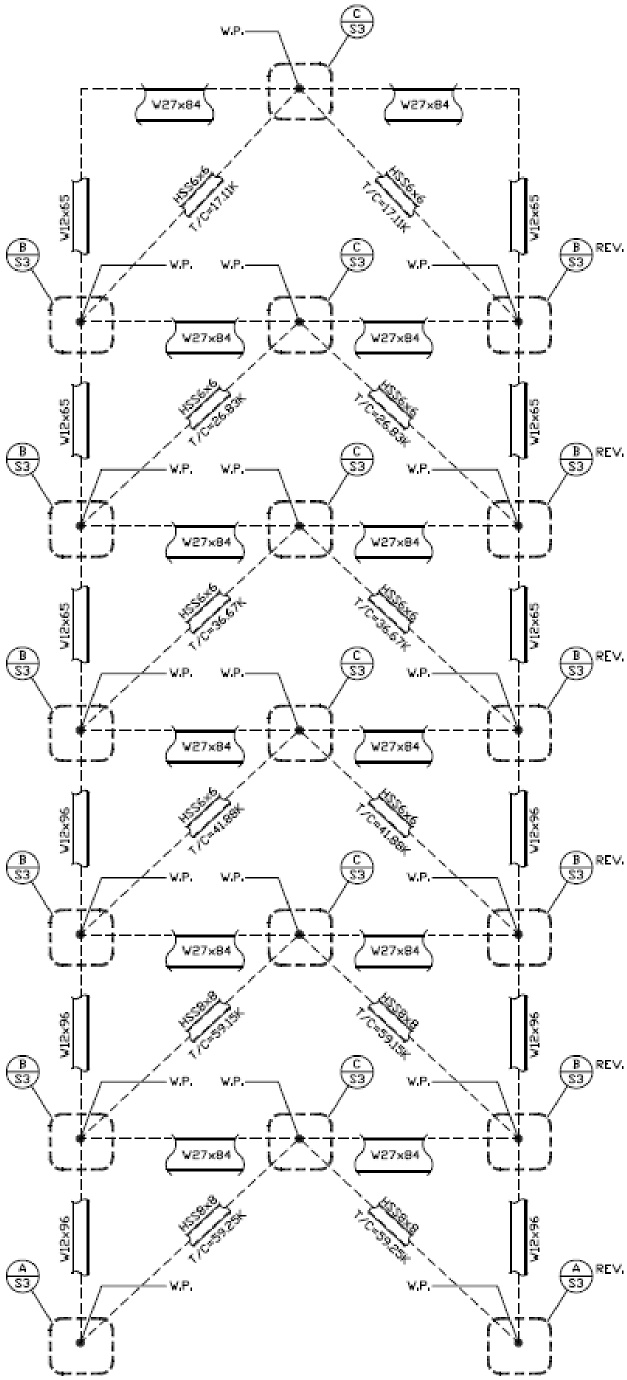
| COLUMN MARK | BOTT. OF BASE PLATE ELEVATION | FIRST FLOOR | SECOND FLOOR | THIRD FLOOR | FOURTH FLOOR | FIFTH FLOOR | SIXTH FLOOR | ROOF |
|---|---|---|---|---|---|---|---|---|
| C-1 | | W10x33 | W10x33 | W10x33 | W10x33 | W10x33 | W10x33 | |
| C-2 | | W10x45 | W10x45 | W10x39 | W10x39 | W10x33 | W10x33 | |
| C-3 | | W10x68 | W10x68 | W10x49 | W10x49 | W10x33 | W10x33 | |
| C-4 | | W10x39 | W10x39 | W10x33 | W10x33 | W10x33 | W10x33 | |
| C-5 | | W10x77 | W10x77 | W10x77 | W10x39 | W10x39 | W10x39 | |
| C-6 | | W10x54 | W10x54 | W10x49 | W10x49 | W10x33 | W10x33 | |
| C-7 | | W10x45 | W10x45 | W10x33 | W10x33 | W10x33 | W10x33 | |
| C-8 | | W10x49 | W10x49 | W10x45 | W10x45 | W10x33 | W10x33 | |
| C-9 | | W12x79 | W12x79 | W12x79 | W10x49 | W10x49 | W10x49 | |
| C-10 | | W10x100 | W10x100 | W10x100 | W10x100 | W10x45 | W10x45 | |

SPLICE TYP.

SPLICE TYP.

SPLICE TYP.

COLUMN SCHEDULE

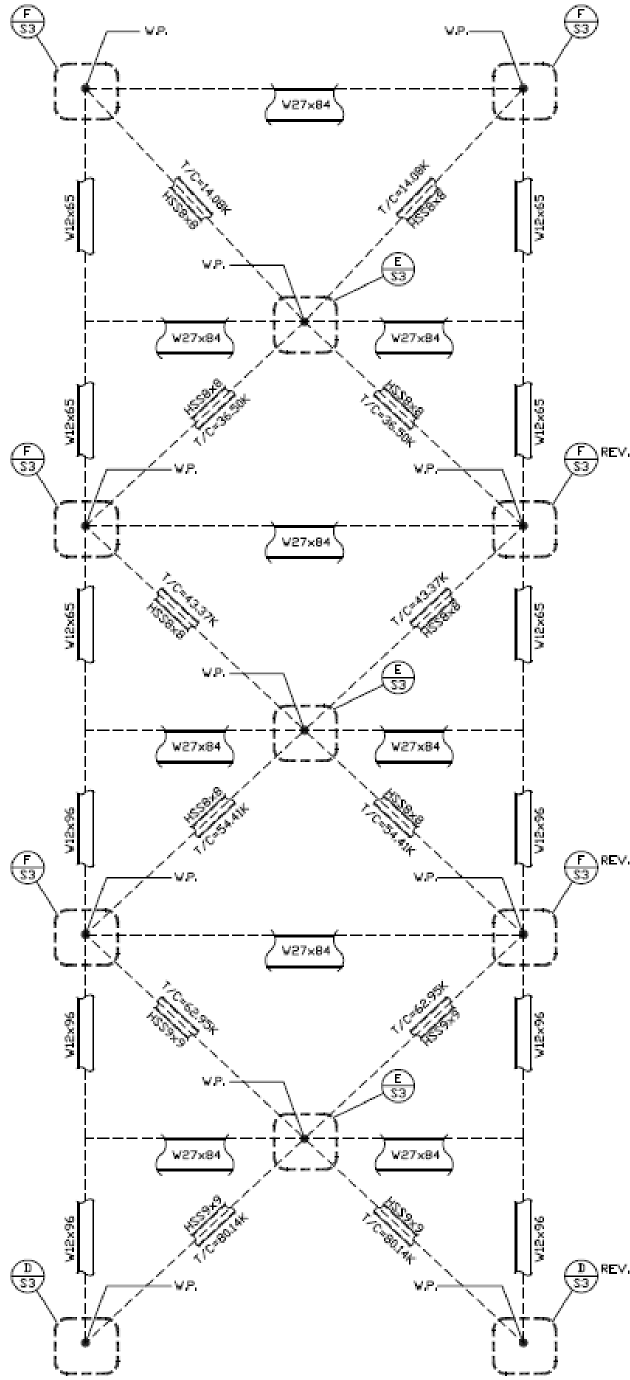


A/S2 ELEVATION

SCALE: NTS

NOTES:

1. REV. DENOTES THE MIRROR IMAGE OF CONNECTION.
2. ALL BRACES ARE 3/8" THICK

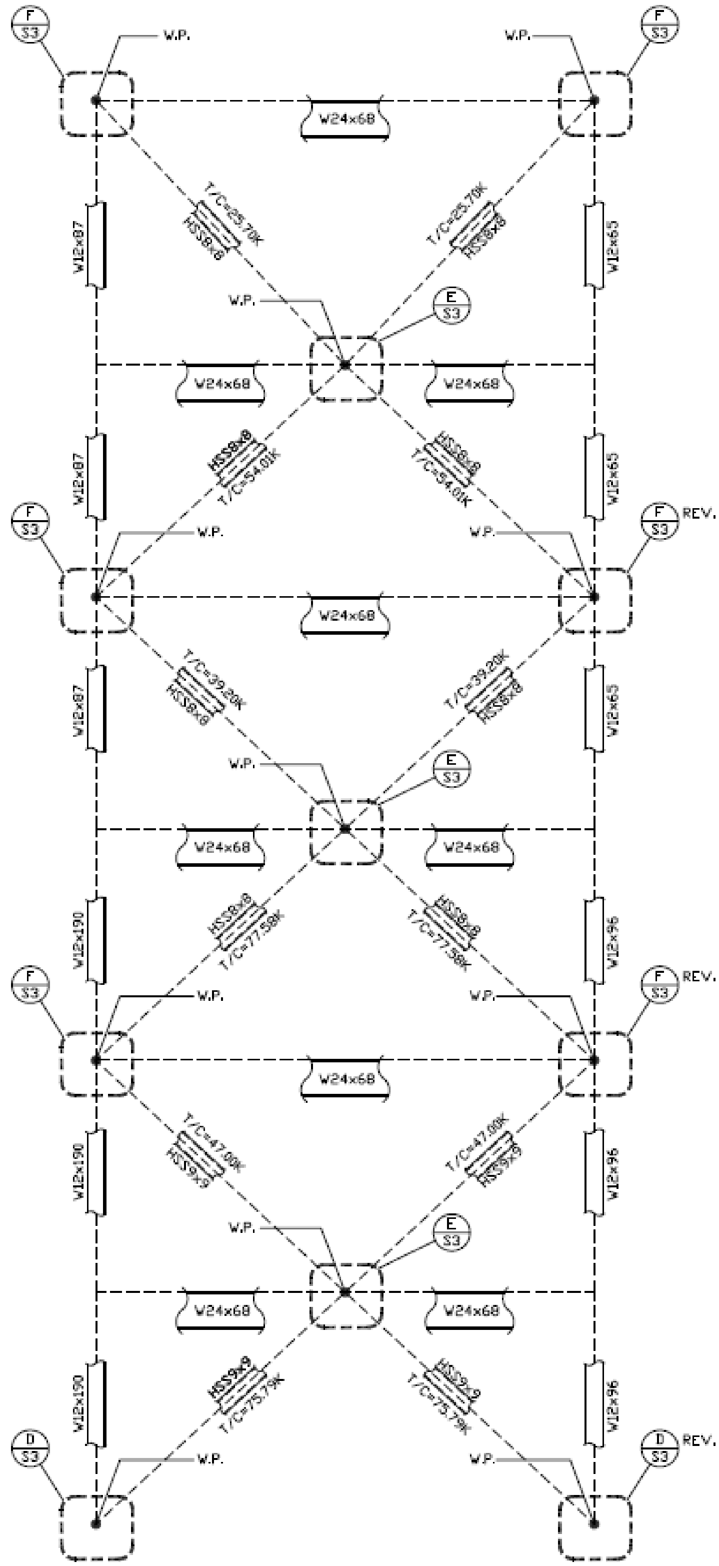


B/S2 ELEVATION

SCALE: NTS

NOTES:

1. REV. DENOTES THE MIRROR IMAGE OF CONNECTION.
2. ALL BRACES ARE 3/8" THICK



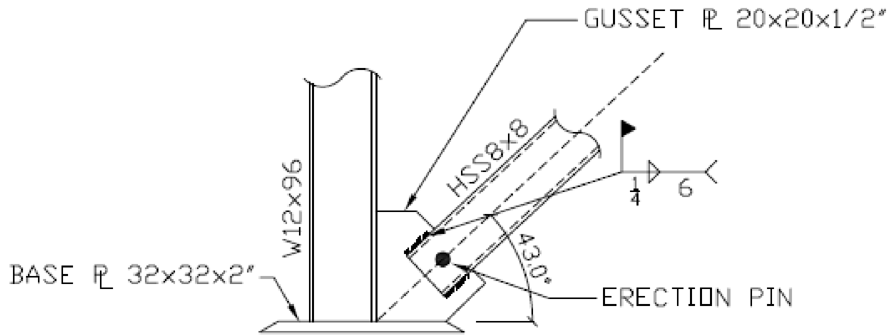

C
S2

# ELEVATION

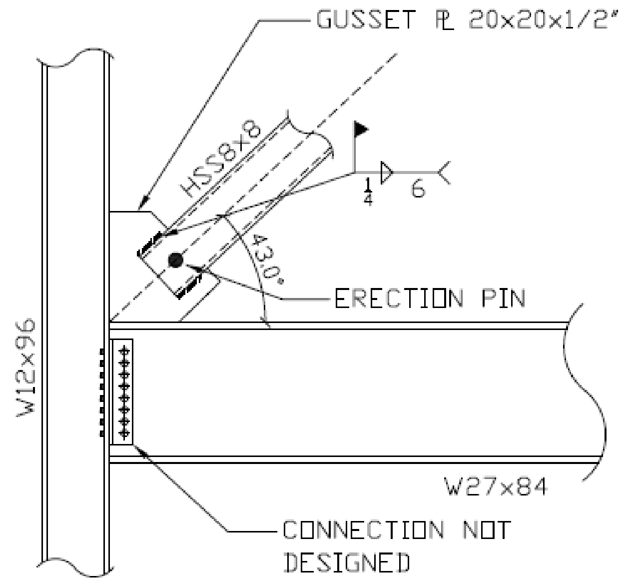
SCALE: NTS

NOTES:

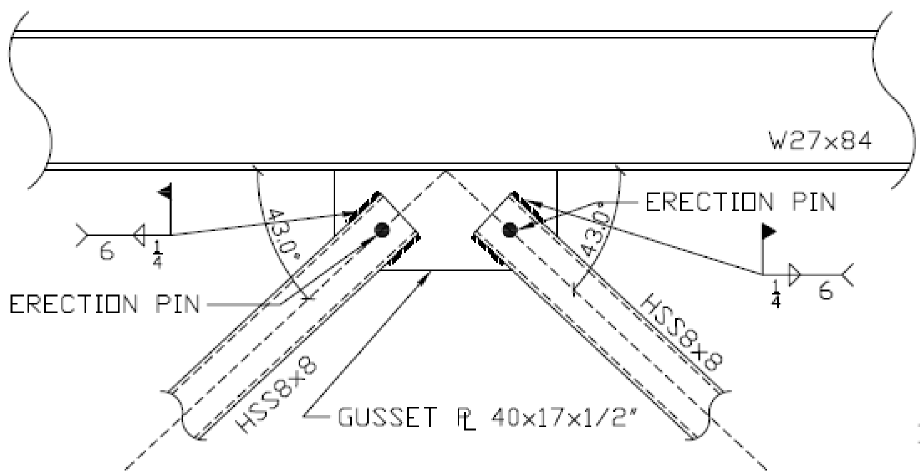
1. REV. DENOTES THE MIRROR IMAGE OF CONNECTION.
2. ALL BRACES ARE 3/8" THICK



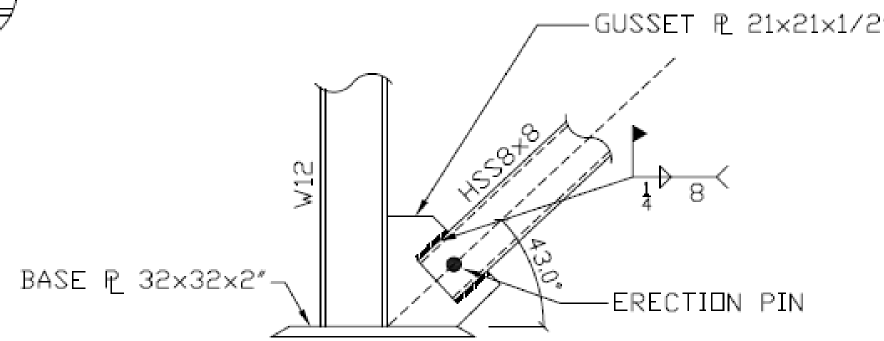

A CONNECTION
S3 SCALE: NTS



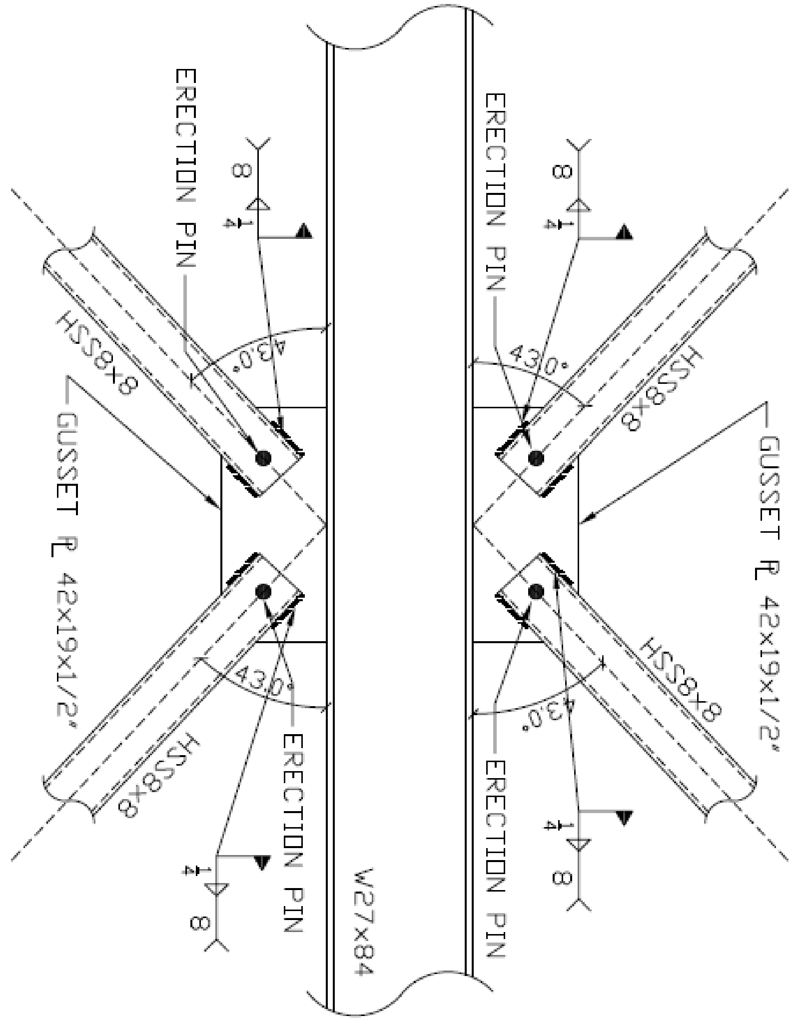

B CONNECTION
S3 SCALE: NTS



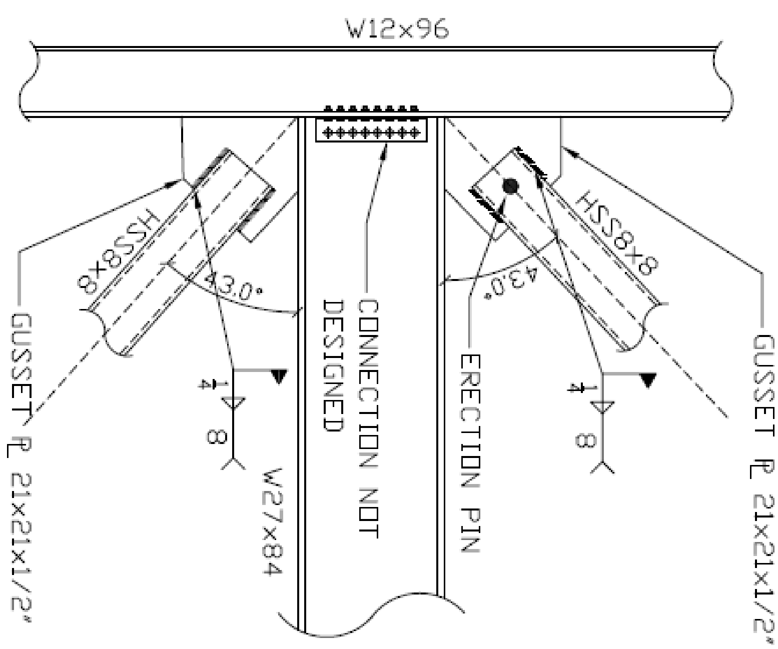

C CONNECTION
S3 SCALE: NTS




D CONNECTION
S3 SCALE: NTS




E CONNECTION
S3
SCALE: NTS




F CONNECTION
S3
SCALE: NTS

# CONCLUSIONS

The proposed two-story expansion of 329 Innovation Boulevard required a redesign of the structural members. The height increase proved to greatly affect the wind loads applied to the building. This brought on the alteration of the lateral resisting system. The previous system of moment frames would have to be redesigned to withstand these new loads, and would in most cases involve more elaborate moment connections. Since moment connections are costly and time consuming to design, an alternate resisting system was explored.

Chevron braced frames involving HSS shapes was implemented into the expansion of 329. Six frames were designed along the central bay of the building. The member sizes range from HSS6x6x3/8 to HSS9x9x3/8. Architectural aspects were taken into consideration, and the position of the frames was primarily dictated by not wanting to obstruct the façade. The lateral system yielded extremely small deflections, but the members were unable to be reduced in size due to the fact that the size was controlled by strength. This causes the building to be extremely rigid, which is not a bad thing, but it may not be the most efficient system.

Many changes occurred in the gravity system of the building. This was due to the changes in lateral system and floor system. The usage of a non-composite system caused the beams and girders to increase in size, while the columns were able to be reduced in size. The typical beam sizes increased from W18x35 beams and W24x55 girders to W21x44 beams and W24x68 girders. A price analysis was performed and it can be concluded that the additional cost due to an increase in member sizes does not surpass the cost of shear studs. The deeper beams and girders do mean that the finished floor to finished ceiling may be affected. However, I feel that since top of steel to top of steel is 14’, there is plenty of room for any possible mechanical equipment involved.

The columns decreased in size. They were typically W12x96s for the first two floors and spliced to W12x65s for the remaining two. The columns also got as large as W12x190s. This was due to the fact that they were utilized to resist large moments in the moment frame system. The new system of braced frame allowed for a reduction of size due to the interaction between brace and column. The gravity columns were all able to be W10s of numerous sizes ranging from W10x33 to W10x68. The columns in the braced frames were required to be larger than the gravity members, due to the additive moments. The largest columns were located at the corners of the “L” frames.

The consisted of a W12x79 spanning the first three floors, and a W10x49 spans the remaining.

Overall, if an expansion was proposed, this redesign is time and cost saving. It involved the redesign of the lateral resisting system and the gravity members. The time it would take to redesign the moment connections and the cost of them would be much greater than the time and money involved in this redesign. Perhaps the lateral system could be less rigid to make it even more efficient, but this redesign allows for a six-story office building to be designed without starting from square one, which would occur if moment connections and frames were continued.

## INNOVATION PARK

Innovation Park at Penn State is an engine of invention and a catalyst for job creation. Its mission is to provide space, access to Penn State facilities, and business support services that help companies transfer the knowledge within the University to the market place and to foster economic development. The participating companies have adopted the following motto:

> *"It's a mindset, a philosophy, a place for creating the future. We've taken the academic and research tradition of Penn State and fused it with scientific discovery and entrepreneurship to create a destination called Innovation Park."*

As a community with the same goals and objectives, Innovation Park is a unified collection of businesses. Not only do the companies involved agree on purpose, the buildings that house these companies are unified through appearance. Many different architects and engineers have been involved in Innovation Park, but each project has incorporated characteristics of previous projects to give the park a theme. Much of this has to do with the materials used, but subtle characteristics were used in the redesign of 329 Innovation Boulevard. The following sections look into multiple facades of Innovation Park, explain the materials used, the selection of materials, and present a possible façade design for 329 Innovation Boulevard.

## THE BUILDINGS OF INNOVATION PARK

The center of Innovation Park is occupied by the Penn Stater, which doubles as a conference center and a hotel. The Penn Stater is the biggest attraction of Innovation Park and one of the first builldings built in the park. It set the standard and produced the overall appearance of Innovation Park. The buildings below starting with the top left and going clockwise are as follows:

The Lupert Building, The Penn Stater, The Outreach Building, 328 Innovation Boulevard, and Technology Center

This collection of Innovation Park buildings is a good example of the various materials and schemes present in the park. The primary materials for the façade are red brick, large glass windows and at times ribbon windows, and a common composite material found on many Penn State buildings. Notice how the same materials have created such diverse facades. The materials and themes of these buildings greatly influenced the redesign of the façade of 329 Innovation Boulevard.

**Note: The Images on this Page Will Be Used a Reference for Following Pages**

# 329 INNOVATION BOULEVARD

The following section will discuss how I came up with the new façade of 329 Innovation Boulevard. First lets start with the original façade for the actual 329 Innovation Boulevard. The image below shows that it closely resembles 328 Innov. Blvd. and rightfully so, fore they have the same designers. Notice how the brick veneer gives the illusion of columns by seperating the windows. This scheme was also used on 328's façade.

The next image shows the existing façade with the two-story expansion. The brick veneer expresses the verticality of the building. The cornice also gives a nice accent to the horizontal.

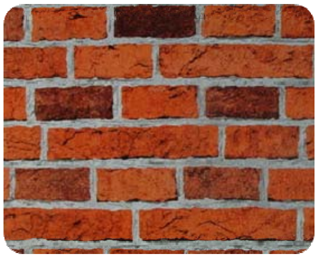
The re-design of the façade drew inspiration from the buildings of Innovation Park. The images of Innovation Park may be useful when describing the changes made to the façade. Here is an elevation of 329 with my redesign of the façade:

To contrast the verticality expressed in the previous elevation, I chose to express the horizontal. Ribbon windows were used to achieve this. The ribbon windows were inspired by the Outreach Building, which also utilizes ribbon windows. Breaks in the windows were needed so that there are areas to place partitions on the interior. The first and sixth floors used the first and fourth floors' façade of the actual building. I wanted to keep something constant, and I feel it gives a nice contrast to what is occuring in the middle four floors of the building. The stairwells on the sides of the building got a face-lift, and the brick was removed and replaced with metal cladding. The Lupert Building served as inspiration for this change. Windows were also added to the wells for natural daylight. The floor plan of 329 is not yet established, but I have used the brick veneer in an attempt to signify that the exterior reflects the appearance of the interior spaces. The brick veneer seperates the building in half, and I am assuming that two or more tenants will occupy the floor. I feel the brick veneer helps indicate multiple tenants per floor.

The following sections will use the new façade and its materials to analyze the moisture and thermal performance of the façade.

# THE MATERIALS

As mentioned before, the façade materials used in Innovation Park are brick, glass, and metal cladding.



Brick

Glass

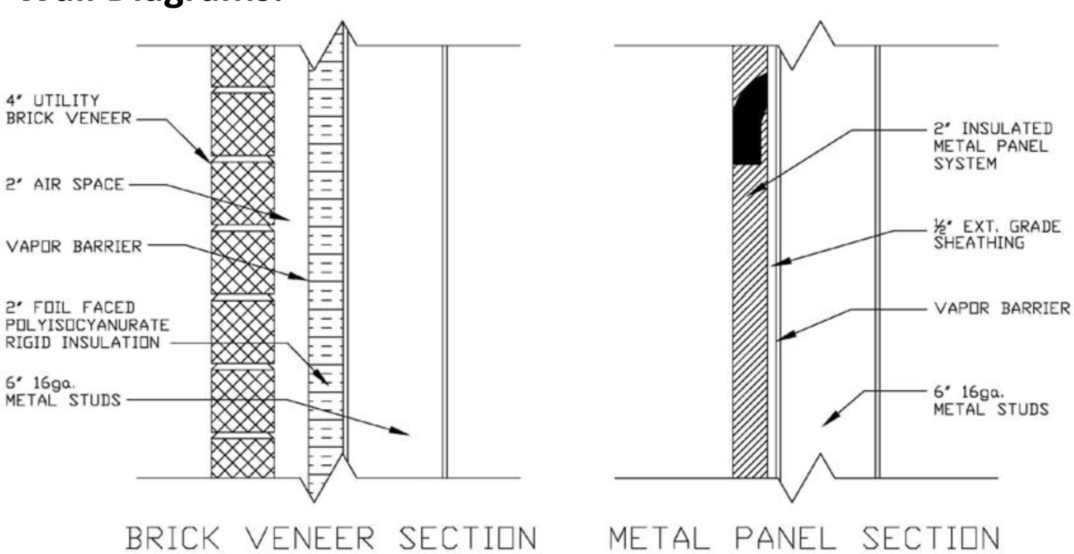
Metal Cladding

These materials directly affect the thermal comfort of the building. Many studies have shown that these materials alter the effects of the outside climate, and is nicely summed up by the following quote:

> *"The building envelope separating the indoor space from the outdoor environment has an important role in the passive control because it acts as a modifier of the direct effects of climate variables such as the outdoor temperature, humidity, wind, solar radiation and rain."*
>
> *Dr. Wong Nyuk Hien, 2006*

The materials' R-Value is a numerical representation of a material's insulation properties. A material will slow the transfer of heat through it, and the larger the R-Value, the more of an insulator it is. The following diagram and chart will be used to determine the overall R-Value of the façade:

## Wall Diagrams:



## R-Value Table (English):

| Material | R-Value Per Inch | R-Value Per Thickness | U-Value |
|---|---|---|---|
| Polyisocyanurate (Foil Faced) | 7.20 | 14.40 | 0.0694 |
| Brick 4" Common | | 0.80 | 1.2500 |
| 1/2" Fiberboard Shething | | 1.32 | 0.7576 |
| ABP Wall Panel | | 16.00 | 0.0625 |
| 5500 ISOWEB Window Type F | | 5.41 | 0.1850 |

*Note: Selection of materials was based on R-Values.  U-Value=1/R-Value*

# THERMAL ANALYSIS

A study in Hong Kong by the Commisoner of Building Control concluded with the following:

*ENVELOPE THERMAL TRANSFER VALUE (ETTV) FOR AIR-CONDITIONED BUILDINGS*

*THE ENVELOPE THERMAL TRANSFER VALUE (ETTV) OF THE BUILDING, AS DETERMINED IN ACCORDANCE WITH THE FORMULA SET OUT IN THE "GUIDELINES ON ENVELOPE THERMAL TRANSFER VALUE FOR BUILDINGS" ISSUED BY THE COMMISSIONER OF BUILDING CONTROL, SHALL NOT EXCEED 50 $W/M^2$.*

And according to the Building and Construction Authority:

$$ETTV = 12(1-WWR)U_W+3.4(WWR)U_F+211(WWR)(CF)(SC) \quad \text{(METRIC)}$$

Where:

- ETTV: envelope thermal transfer value ($W/m^2$)
- WWR: window-to-wall ratio (fenestration area/gross area)
- $U_w$: thermal transmittance of opaque wall ($W/m^2 {}^\circ K$)
- $U_f$: thermal transmittance of fenestration ($W/m^2 {}^\circ K$)
- CF: correction factor for solar heat gain through fen.
- SC: shading coefficients of fenestration

| North/ South Direction (English) | | | | |
|---|---|---|---|---|
| Material | Area ($ft^2$) | R-Value | U-Value | A*U |
| Opaque Wall | | | | |
| Polyisocyanurate | 9418 | 14.40 | | |
| Brick | 9418 | 0.80 | | |
| **Total** | | **15.20** | **0.0658** | **619.61** |
| Fiberboard | 3928 | 1.32 | | |
| Wall Panel | 3928 | 16.00 | | |
| **Total** | | **17.32** | **0.0577** | **226.79** |
| Fenestration | | | | |
| Window | 4414 | 5.41 | 0.1850 | 816.59 |
| **Total** | | | | **816.59** |

| North/ South Direction (Metric) | | | | |
|---|---|---|---|---|
| Material | Area ($m^2$) | R-Value | U-Value | A*U |
| Opaque Wall | | | | |
| Polyisocyanurate | 875 | 2.52 | | |
| Brick | 875 | 0.14 | | |
| **Total** | | **2.66** | **0.3757** | **328.70** |
| Fiberboard | 365 | 0.23 | | |
| Wall Panel | 365 | 2.80 | | |
| **Total** | | **3.03** | **0.3297** | **120.33** |
| Fenestration | | | | |
| Window | 410 | 0.95 | 1.0564 | 433.10 |
| **Total** | | | | **433.10** |

$$ETTV = 12((328.7 + 120.33)/1650) + 3.4(433.1/1650) + 211(433.1/1650)(0.80)(1.00)$$

$$ETTV = 48.5\ W/m^2 < 50\ W/m^2$$

The square area of windows and R-Value of them dictated the equation. The first two terms are relatively small, and the third term was used to find the right combination of square area and R-Value.

## MOISTURE ANALYSIS

Condensation may occure on either side of the windows; however, condensation is not necessarily a problem. It will form water on non-porous materials such as the glass itself, and the metal studs. It may also be absorbed by the porous such as drywall. A problem occurs when sufficient drying does not occur, the safe storage of the materials are exceeded, and when materials susceptible to moisture are used. The following calculations shows how the interior dewpoints were obtained, which would be used for mechanical purposes:

**Inside Surface Film C-Value From ASHRAE: C = 8.3**

**$R_{surface\ film} = 1/8.3 = 0.1205$**

**Surface Temperature Index, $TI_{surface}$** $= R_{surface\ film}/R_{total}$
$= 0.1205/(0.1205 + 0.95)$
$= 0.114$

**$T_{Dewpoint,\ Interior} < T_{Int} - Ti_{surface}(T_{int} - T_{Ext})$**

**Design Values:** **$T_{Int} = 70$ °F**

**Average Temperatures:** **Winter (Low):** **$T_{Ext} = 18$ °F**
**Summer (High):** **$T_{Ext} = 81$ °F**

**Winter:** **$T_{Dewpoint,\ Interior}$** $< 70 + 0.114(70 - 18)$
**< 76 °F**

**Summer:** **$T_{Dewpoint,\ Interior}$** $< 70 - 0.114(70 - 81)$
**< 68 °F**

The results show that the interior temperature should not climb above 76 °F in the winter and shouldn't fall below 68 °F in the summer. These temperatures should be taken into consideration for the climate control of the space.

## STRUCTURAL IMPACT

As is the case for most steel frame structures, the façade is known as a "hanging façade." The façade itself does not contribute to the structural system, but is connected by numerous means. This means that the structural system is designed to withstand any additive loads of the façade. These loads are very minimal due to the fact that this particular façade is self-load bearing. The majority of the façade's load is transferred through itself down to the ground and foundation. For these reasons, it was not necessary to perform a structural analysis of the façade.

## CONCLUSIONS

The redesign of 329 Innovation Boulevard was intended to re-create a façade that still fit the mold of Innovation Park. It used many influences from other buildings and expresses the horizontal rather than the vertical of the previous design. The materials used were the same of the previous system. Therefore, in terms of performance, the selection of manufacturer's would be the key element. A comfort standard from Hong Kong was used to evaluate the new façade. It dictated the selection of windows and the area the windows occupied. The square footage had to be decreased from a previous design and the best ribbon windows provided by Kawneer were needed. The windows may become a price issue because of this, but the square footage can be reduced until a desired window is achieved. A moisture analysis was performed using the R-Value of the façade. It was found that the interior temperature should climb above 76 °F in the winter and shouldn't fall below 68 °F in the summer. If the temperatures happen to decrease or increase past those values, condensation would form. However, condensation is not detramental as long is it is properly taken care of. It does become a problem when the following occurs: when there isn't sufficient drying, the safe storage of the materials are exceeded, and when materials susceptible to moisture are used. The calculations done show that the façade will not have a strenuous affect on the mechanical system, and is rather efficient. From the 48 $W/m^2$ found before, it can be determined that the North façade losses 5,720 KWhr each month. Allegheny Power prices a Kilowatt Hour at 2.5 cents, which yields a cost of $143. Assuming that the South façade is identical, and a reduction of windows on the East and West, the cost due to energy loss throught the façade should be in the $400 to $500 range.

## MECHANICAL REDESIGN INTRODUCTION

Due to the addition of two floors, the mechanical load will increase. The following sections will detail the process of redesigning the mechanical system of 329 Innovation Boulevard. An analysis of the new system will also be provided.

## CURRENT MECHANICAL SYSTEM

329 Innovation Boulevard utilizes 14 indoor heat pumps, each with micro-processor control boards, and four rooftop heat pumps, provided with enthalpy exhange wheels. Heat pumps include a reversing valve and optimized heat exchangers so that the direction of the heat flow may be reversed. The rooftop heat pumps draw the outside air and begin the process of supplying the spaces. Here are some advantages and disadvantages of a heat pump system:

| | Heat Pump Advantages |
|---|---|
| 1 | Even temperatures |
| 2 | Comfortable humidity levels in winter |
| 3 | Less noise and odor |
| 4 | No pilot light or vent |
| 5 | No seasonable change-over |
| 6 | Only one fuel bill |
| 7 | May supply hot water w/ excess heat |

| | Heat Pump Disadvantages |
|---|---|
| 1 | Unable to operate at low temperatures, which requires a back-up system |
| 2 | People find the air supplied to be "cold" during the winter |

The rooftop heat pumps provide 4700 CFMs each, whereas two indoor terminal heat pumps located in the lobby supply 900 CFMs, four pumps located at the core on each floor supply 600 CFMs, and the remaining eight pumps (two per floor) supply 1800 CFMs, for a total of 28,000 CFMs supplied. The following calculation shows what percentage of outdoor air is suppied:

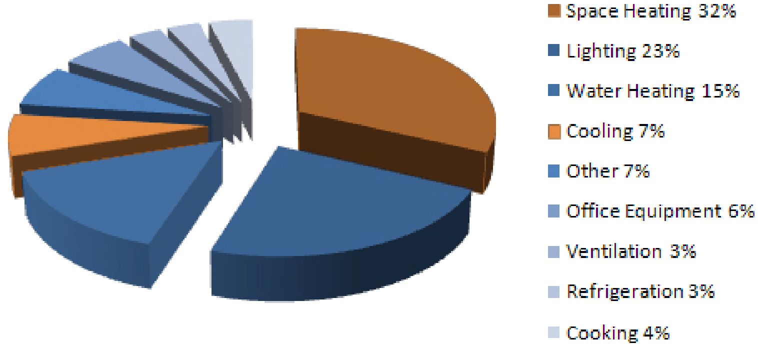
**% Outdoor Air Supplied** = (2)(4,700 CFM)/28,000 CFM
= **33.6 %**

**CFM/SF** = 28,000 CFM/(4)(21,000 SF)
= **0.33 CFM/SF**

Along with other factors, the redesign of the mechanical system will be judged against those values. With a greater total load, the new system will have to supply much more outdoor air to achieve that percentage.

# NEW MECHANICAL SYSTEM

In an effort to reduce system energy cost and usage, a variable air volume system was selected for the redesign of the mechanical system for 329 Innovation Boulevard. The pie chart below illustrates the breakdown of energy used in commericial buildings:




***Source: Commercial Buildings Energy Consumption Survey**

The chart shows that 39% of the energy used in the building goes to heating and cooling. Therefore, an efficient mechanical system will greatly affect the amount of energy used by the building. Since energy costs money, an efficient system will ultimately save the owner money. A VAV system allows each designated zone its own independent control. The system is designed to supply only the volume of conditional air to a space that is needed to satisfy the load.

Much like the heat pumps, VAV systems have multiple advantages and disadvantages.

| | VAV Advantages | | VAV Disadvantages |
|---|---|---|---|
| 1 | Produces minimal margin of error from the specified desired temperature | 1 | Latent heat may cause issues in auditoriums and conference rooms |
| 2 | Contributes significantly to the efficiency of the system | 2 | Minimum outside air requirements must be met |
| 3 | Individually controlled zones (as small as individual rooms) | 3 | Decreased air temperature may lead to poor dispersion of the tempered air |
| 4 | Little cost added to operational cost to run the system | 4 | Little control over pressurization |
| 5 | Requires minimal maintenance | 5 | Equipment located just above the ceiling can create noise |

The industry has seen a shift towards VAV systems in office buildings, and while heat pumps may work in the four-story building, it may be beneficial to use VAV with the expansion.

# TRACE® 700 PARAMETERS

The Trace 700 Parameters are largerly based on the programs defaults and values tabulated in the façade study sections.

**Internal Loads:**

I. People
   a. Type: General Office Space
   b. Density: 143 sq ft/person
   c. Schedule: Cooling Only (Design)
   d. Sensible: 250 Btu/hr
   e. Latent: 200 Btu/hr

II. Lightning
   a. Type: Recessed fluorescent, not vented, 80% load to space
   b. Heat Gain: 2 W/sq ft

III. Miscellaneous Loads
   a. Type: Std. Office Equipment
   b. Energy: 0.5 W/sq ft

**Airflow**

I. Ventilation:
   a. Type: General Office Space
   b. Cooling: 20 cfm/person
   c. Heating: 20 cfm/person

**Thermostat**

I. Thermostat Settings:
   a. Cooling Dry Bulb: 75 °F
   b. Heating Dry Bulb: 68 °F
   c. Relative Humidity: 50 %
   d. Cooling Driftpoint: 90 °F
   e. Heating Driftpoint: 55 °F

# TRACE® 700 OUTPUTS

## SYSTEM SUMMARY

### DESIGN AIRFLOW QUANTITIES

By PSUAE

| | | MAIN SYSTEM | | | | | Auxiliary System | Room |
|---|---|---|---|---|---|---|---|---|
| System Description | System Type | Outside Airflow cfm | Cooling Airflow cfm | Heating Airflow cfm | Return Airflow cfm | Exhaust Airflow cfm | Supply Airflow cfm | Exhaust Airflow cfm |
| System - 001 | Variable Volume Reheat | 17,622 | 145,609 | 43,891 | 145,609 | 17,622 | 0 | 0 |
| Totals | (30% Min Flow Default) | 17,622 | 145,609 | 43,891 | 145,609 | 17,622 | 0 | 0 |

**Note:** **Airflows on this report are not additive because they are each taken at the time of their respective peaks. To view the balanced system design airflows, see the appropriate Checksums report (Airflows section).**

Project Name: 329 Innovation Boulevard TRACE® 700 v4.1
Dataset Name: P:\Thesis\Research\Mechanical Breadth\329 Inn Boul System.trc Alternative - 1 Design Airflow Quantities report page 1

# VAV BOX SIZING

The VAV boxes are sized based upon the Cooling Airflow (145,609 cfm) found using Trace. They each should be in the range of 2,000-3,000 cfm for acoustical reasons. There are two zones per floor, and six floors; therefore, if each VAV box is sized for 3,000 cfm, the following is how many are requried per zone:

**# VAV Boxes** = 145,609 cfm/(2 Zones)(6 Floors)(3,000 cfm/box)
= **4.04**

Try 5 Boxes Per Zone:

**VAV Box Size (CFM)** = 145,609 cfm/(2 Zones)(6 Floors)(5 Boxes/Zone)
**= 2,430 CFM**

**Krueger KQFP Ultra-Quiet VAV units will be used (Total CFM = 2960 > 2430 CFM). The unit size is 7, and the inlet size is 16. The following is a table of the specifications and noise output:**

▼ KQFP, DISCHARGE SOUND DATA

| Unit Size | Inlet Size | Flow Rate | | Min Δ Ps | | Primary @ 0.5" Δ Ps Octave Band Sound Power, Lw | | | | | | Lp | Primary @ 1.0" Δ Ps Octave Band Sound Power, Lw | | | | | | Lp | Primary @ 2.0" Δ Ps Octave Band Sound Power, Lw | | | | | | Lp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CFM | (L/s) | "WG | (Pa) | 2 | 3 | 4 | 5 | 6 | 7 | NC | 2 | 3 | 4 | 5 | 6 | 7 | NC | 2 | 3 | 4 | 5 | 6 | 7 | NC |
| | | 740 | (349) | 0.014 | (3.5) | 47 | 43 | 43 | 38 | 31 | 23 | - | 52 | 47 | 47 | 42 | 35 | 28 | - | 56 | 51 | 51 | 45 | 38 | 32 | - |
| | | 1480 | (698) | 0.056 | (13.9) | 58 | 52 | 50 | 47 | 42 | 35 | - | 62 | 56 | 55 | 51 | 46 | 39 | - | 67 | 60 | 59 | 54 | 49 | 44 | - |
| 7 | 16 | 2220 | (1048) | 0.126 | (31.3) | 64 | 57 | 55 | 52 | 49 | 42 | - | 68 | 61 | 59 | 56 | 52 | 46 | - | 73 | 65 | 64 | 60 | 56 | 50 | 25 |
| | | 2960 | (1397) | 0.224 | (55.6) | 68 | 61 | 58 | 56 | 53 | 46 | - | 73 | 65 | 63 | 60 | 57 | 51 | 25 | 77 | 69 | 67 | 63 | 60 | 55 | 31 |
| | | 3700 | (1746) | 0.349 | (86.9) | 71 | 64 | 61 | 59 | 57 | 50 | 23 | 76 | 68 | 65 | 63 | 60 | 55 | 29 | 80 | 72 | 70 | 66 | 64 | 59 | 35 |

## VAV DUCT SIZING

**Equation Method:**
Friction loss can be expressed by the following equation:

$\Delta p = (0.109136\ q^{1.9}) / d_e^{5.02}$

Where:
$\Delta p$ = friction (head or pressure ) (inches water gauge/100 ft of duct)
$d_e$ = equivalent duct diameter (inches)
q = air volume flow - (cfm - cubic feet per minute)


And:

$d_e = 1.30 \times ((a \times b)^{0.625}) / (a + b)^{0.25})$

*ACCORDING TO ENERGY DESIGN RESOURCES "ADVANCED VAV SYSTEM DESIGN BRIEF": FOR VAV SYSTEM SUPPLY AIR DUCT MAINS, USE A STARTING FRICTION RATE OF 0.25 TO 0.30 IN. PER 100 FT. AT THE AIR HANDLER.*

To achieve a friction value of 0.25, $d_e$ must equal 16.2"
Assume square ducts to start:

16.2 $= 1.30 \times (a^{2(0.625)}) / (2a)^{0.25}$
a = 14.8" ≈ 15.0"

Try 18"x12": $d_e$ $= 1.30 \times ((18 \times 12)^{0.625}) / (18 + 12)^{0.25})$
= 16.0" ≈ 16.2" **OK**

**Ductulator Method:**

Air Volume: 2,430 CFM
Friction Per 100 Feet of Duct: 0.25

Ductulator Checks:

Rectangular Duct Possabilities: 15"x15" 18"x12" 16"x14 — *Equation Method Checks Ductulator Values*

Other Ductulator Value: Velocity = 1700 FPM

## OUTDOOR SUPPLIED AIR AND VENTILATION RATE ANALYSIS

The following analysis utilizes ASHRAE Standard 62.1-2007. The standard focuses on ventilation for acceptable air quality. The existing mechanical system was designed for 33% outdoor, whereas the VAV system will be designed for 20%, which is typical of VAV systems. Therefore, each Air Handler Unit outside air flow will be about 10% of the total supply air. The following table utilizes ASHRAE values and equations to find the minimum required primary outdoor airflow for the summation of the different areas in the building:

| Occupancy Category | Area SF | Occupant Density | Zone Population | People Outdoor Air Rate | Area Outdoor Air Rate | Breathing Zone Outdoor Airflow | Primary Outdoor Air Fraction | Min. Req'd Primary Outdoor Airflow |
|---|---|---|---|---|---|---|---|---|
| Office Building | $A_z$ | #/1000 $ft^2$ | $P_z$ | $R_p$ | $R_a$ | $V_{bz}$ | $Z_p$ | $V_{pz}$ |
| Office Space | 115920 | 5 | 580 | 5 | 0.06 | 9855.2 | ≤0.15 | 65701.33 |
| Reception Area | 7200 | 30 | 216 | 5 | 0.06 | 1512 | ≤0.15 | 10080.00 |
| Telephone/Data Entry | 480 | 60 | 29 | 5 | 0.06 | 173.8 | ≤0.15 | 1158.67 |
| Main Entry Lobbies | 2400 | 10 | 24 | 5 | 0.06 | 264 | ≤0.15 | 1760.00 |
| Totals | 126000 | | 849 | | | 11805 | | |

Those values are then used to find the total outdoor air intake values for summation of the different areas in the building and are found in the following table:

| Occupancy Category | Zone Population | Occupant Diversity | Uncorrected Outdoor Air Intake | System Ventilation Efficiency | Outdoor Air Intake |
|---|---|---|---|---|---|
| Office Building | Pz | D | Vou | Ev | Vot |
| Office Space | 580 | 0.683 | 8936.35 | 1.0 | 8936.35 |
| Reception Area | 216 | 0.254 | 706.77 | 1.0 | 706.77 |
| Telephone/Data Entry | 29 | 0.034 | 33.75 | 1.0 | 33.75 |
| Main Entry Lobbies | 24 | 0.028 | 147.39 | 1.0 | 147.39 |

The total outdoor air intake is 9,524.26 CFM, which is less than the 17,622 CFM provided. (This value was taken from Trace 700 Output table.) The percentage of outdoor suppy can be found by the following:

**% Outdoor Air Supplied** = (17,622 CFM)/145,609 CFM
= **12.1 %**

**CFM/SF** = 145,609 CFM/(6)(21,000 SF)
= **1.16 CFM/SF**

If one AHU (Air Handler Unit) is used to supply the air, it must be custom made. Trane designs custom AHUs that are able to supply from 1500 – 200,000 CFM, which is a large enough range to create one AHU for the building. Obviously, more AHUs could be used to lessen to the load, but that would involve the design of connections and coordination of supply ductwork. One AHU may help simplify the design.

## CONCLUSIONS

The heat pump system (existing) provides 0.33 CFM/SF, where a typical system supplies around 1.0 CFM/SF. This is because it is a temporary system due to the fact that the tenants are unknown. The heat pumps placed on each floor are labeled as temporary air conditioning units, and are most likely provided for the workers. The ductwork indicate locations for temporary grilles to be removed after tenant fit out. After researching heat pump systems and other possible systems, it was concluded that a VAV system may be more efficient and cost effective. Assuming that the spaces would be used as general offices, Trace was utilized to formulate the design loads. The findings were compared to the values tabulataed using ASHRAE's Standard 62.1-2007 and substantially met the requirements.

The cooling design load was found to be 145,609 CFM, and the main system capacity was 327 tons. The spaces were designed as two different zones (assuming two tenants per floor), and each zone is equipped with 5 VAV boxes in an effort to easily regulate the temperature. Krueger KQFP Ultra-Quiet VAV Unit Size 7 were found to be able to handle the required load. 15"x15" ductwork is able to transfer the air, but 18"x12" and 16"x14" also work, and may be used for architectural finishing purposes. One AHU unit was selected and must be custom made by Trane. Only one was selected to help alleviate coordination problems between AHUs, but multiple AHUs are always possible.

Overall, the VAV system may cost more money upfront (due to installation, custom units, etc.). However, VAV systems have very minimal operational costs and low maintenance is required. So if the owner has the money upfront it may be the way to go. The industry has seen a switch to VAV systems in office buildings over the past five years, as well.

The proposal of an expansion of 329 Innovation Boulevard was explored in three areas: structural, architectural, and mechanical.  Obviously, an additional two stories will affect the structure, the façade, and the mechanical system of the building.

Structurally, a new resisting system was explored to withstand the new wind pressures applied to the building.  This affected the gravity members, as well. A new flooring system was impleted and consisted of non-composite beams with a composite slab rather than the orifinal composite beams with a composite slab.  The typical beam sizes increased from W18x35 beams and W24x55 girders to W21x44 beams and W24x68 girders.  A price analysis was performed and it can be concluded that the additional cost due to an increase in member sizes does not surpass the cost of shear studs.  The deeper beams and girders do mean that the finished floor to finished ceiling may be affected.  However, I feel that since top of steel to top of steel is 14', there is plenty of room for any possible mechanical equipment involved.

The columns decreased in size.  They were typically W12x96s for the first two floors and spliced to W12x65s for the remaining two.  The columns also got as large as W12x190s.  This was due to the fact that they were utilized to resist large moments in the moment frame system.  The new system of braced frame allowed for a reduction of size due to the interaction between brace and column.  The gravity columns were all able to be W10s of numerous sizes ranging from W10x33 to W10x68.  The columns in the braced frames were required to be larger than the gravity members, due to the additive moments. The largest columns were located at the corners of the "L" frames.  The consisted of a W12x79 spanning the first three floors, and a W10x49 spans the remaining.

The existing moment frames allow the interior space to have minimal obstructions, but may become too costly with the expansion.  The lateral resisnting system was switched to a braced frame system for the entire building.  The braces would consist of HSS shapes and be in the form of chevron braces.  Architectural and structural aspects were considered when placing the braces, and they were located concentrically around the geometric center of the building and in the central bay of the building.  The braces were dictated by the strength code, and altimately formed an extremely rigid structure, yielding minimal deflections.  RAM Structural System was utilized to size the appropriate members and find the forces applied to the members.  The members ranged from HSS6x6x3/8 to HSS9x9x3/8, and they saw a maximum of 85 kips of tensile and compressive forces.  These forces were used to design the connections of the frames.  Field welds were used, and were ¼” in size, and ranged from 6-8” in length on all four sides of the HSS shapes. A cost analysis between raw materials in a six-story 329 Innovation Boulevard building with moment connections (from initial design) was compared to the cost of the six-story building with the new braced frame system. The braced frame system was clearly cheaper, and may justify taking the time to redesign if a two-story expansion was proposed.

Architecturally, the façade of the building would have to be altered for the expansion. A façade study was done to maintain an appearance that would fit the mold of the buildings surroundings – Innovation Park. Numerous characteristics of other buildings in the park were implanted in the redesign of 329’s façade. These characteristics included: ribbon windows and metal cladding among others. A thermal and moisture analysis was performed and helped dictate the selection of materials for the façade. Ultimately a comfortable thermal level was achieved, but required “top-shelf” materials. The additive costs may be absorbed by the savings of the structure system, but overall it may be concluded that the existing façade is more than adequate to be continued for the two-story expansion.

Mechanically, the two-story expansion would increase the mechanical laod of the building. The initial design, which consists of heat pumps, is temporary, and able to be adjusted for when tenants lease the space. Research done showed a shift to VAV systems in office buildings, so the redesign of the mechanical system was chosen to be VAV. Trace 700 was utilized to create the design loads (based on ASHRAE standards) and to model the VAV mechanical system. The output obtained was used to size appropriate equipment such as: VAV boxes, ductwork, and air handler units. A single AHU was used, which meant that it would have to custom, but would help alleviate coordination problems with syncing multiple units through shaftwork and connections. Once again, the redesign of the mechanical system may be more costly, but it does have multiple benefits. Compared to the heat pumps, it will have less maintenance costs and very little operational costs. The benefits may justify the switch in systems and the overall shift seen in office buildings.

Overall, an expansion of 329 Innovation Boulevard would ultimately equate to more work no matter what. An exploration of different systems allowed me to get a better understanding of the whole design process, and may have uncovered some unique findings. The new structure is extremely rigid, and may have been better off with less braced frames, but it still would be less costly than a moment framed structure. The new façade may be thermally efficient and moisture controlled, but can be deemed costly. The new mechanical system may be costly up front, but has long-term benefits, and is based on realistic loads. I feel that each of the newly designed systems have multiple benefits, and are effective solutions to an expansion of 329 Innovation Boulevard.

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**The Rest of My Family,** for pretending to understand what I'm talking about. That read, I'll be proud if you get this far!

**Janitor Rich, Master of the Custodial Arts,** for keeping things ex-siiiiiiiting, and the lab clean, we know you're not slaves.

**"Batty the Bat",** for paying an early morning visit one day in the lab and returning later. Hope Tom didn't hurt you with his bat shield and leprechaun flute.

**And last, but not least,**

**My Fellow AE's,** for making the past four years the most enjoyable experience of my life. Thanks for all the friendships, the laughs, the help, the parties, and putting up with me. May the future hold nothing but good things for all of you!

***THANK YOU!***

# A. STRUCTURAL APPENDIX

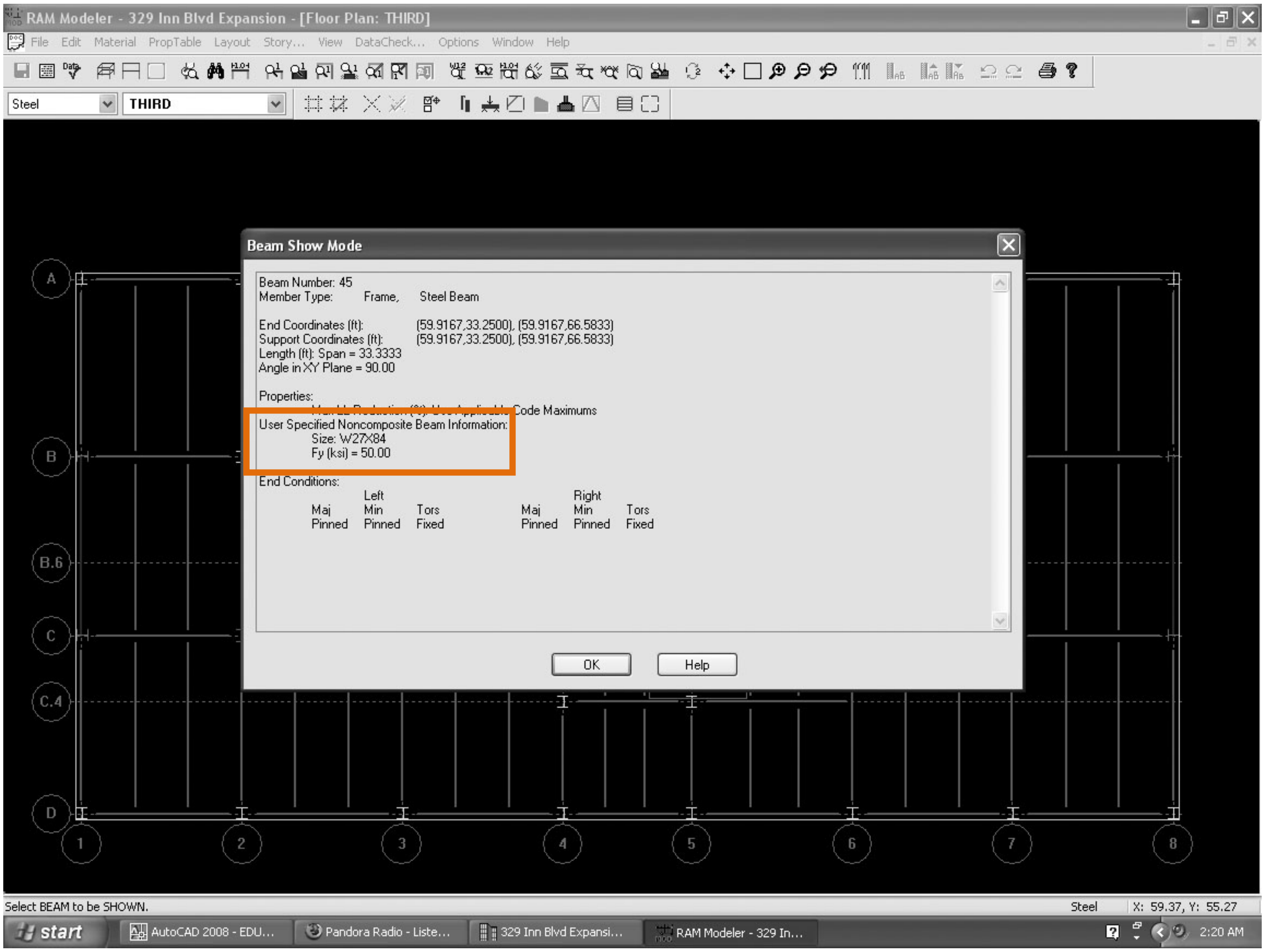
## CALCULATIONS

***Numerous calculations are available upon request, they include:***

- Lateral Loads
  - Story Forces
  - Story Shears
- RAM Structural System Output
- RAM Structural System Models
- RAM Structural System Hand Calcs (Spot-Checks)
- Connection Hand Calculations
- Trace 700 Output

***This Appendix includes RAM Output utilized in the report.***

# RAM DESIGN PARAMETERS




***THE BEAMS WERE DESIGNED AS <u>NONCOMPOSITE</u>.***

# ASCE SEISMIC VALUES

**TABLE 12.2-1 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE–RESISTING SYSTEMS (continued)**

| Seismic Force-Resisting System | ASCE 7 Section where Detailing Requirements are Specified | Response Modification Coefficient, $R^a$ | System Overstrength Factor, $\Omega_0{}^g$ | Deflection Amplification Factor, $C_d{}^b$ | Structural System Limitations and Building Height (ft) Limit[c] — Seismic Design Category: B | C | D[d] | E[d] | F[e] |
|---|---|---|---|---|---|---|---|---|---|
| **E. DUAL SYSTEMS WITH INTERMEDIATE MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES** | 12.2.5.1 | | | | | | | | |
| 1. Special steel concentrically braced frames[f] | 14.1 | 6 | 2½ | 5 | NL | NL | 35 | NP | NP[h,k] |
| 2. Special reinforced concrete shear walls | 14.2 | 6½ | 2½ | 5 | NL | NL | 160 | 100 | 100 |
| 3. Ordinary reinforced masonry shear walls | 14.4 | 3 | 3 | 2½ | NL | 160 | NP | NP | NP |
| 4. Intermediate reinforced masonry shear walls | 14.4 | 3½ | 3 | 3 | NL | NL | NP | NP | NP |
| 5. Composite steel and concrete concentrically braced frames | 14.3 | 5½ | 2½ | 4½ | NL | NL | 160 | 100 | NP |
| 6. Ordinary composite braced frames | 14.3 | 3½ | 2½ | 3 | NL | NL | NP | NP | NP |
| 7. Ordinary composite reinforced concrete shear walls with steel elements | 14.3 | 5 | 3 | 4½ | NL | NL | NP | NP | NP |
| 8. Ordinary reinforced concrete shear walls | 14.2 | 5½ | 2½ | 4½ | NL | NL | NP | NP | NP |
| **F. SHEAR WALL-FRAME INTERACTIVE SYSTEM WITH ORDINARY REINFORCED CONCRETE MOMENT FRAMES AND ORDINARY REINFORCED CONCRETE SHEAR WALLS** | 12.2.5.10 and 14.2 | 4½ | 2½ | 4 | NL | NP | NP | NP | NP |
| **G. CANTILEVERED COLUMN SYSTEMS DETAILED TO CONFORM TO THE REQUIREMENTS FOR:** | 12.2.5.2 | | | | | | | | |
| 1. Special steel moment frames | 12.2.5.5 and 14.1 | 2½ | 1¼ | 2½ | 35 | 35 | 35 | 35 | 35 |
| 2. Intermediate steel moment frames | 14.1 | 1½ | 1¼ | 1½ | 35 | 35 | 35[h] | NP[h,i] | NP[h,i] |
| 3. Ordinary steel moment frames | 14.1 | 1¼ | 1¼ | 1¼ | 35 | 35 | NP | NP[h,i] | NP[h,i] |
| 4. Special reinforced concrete moment frames | 12.2.5.5 and 14.2 | 2½ | 1¼ | 2½ | 35 | 35 | 35 | 35 | 35 |
| 5. Intermediate concrete moment frames | 14.2 | 1½ | 1¼ | 1½ | 35 | 35 | NP | NP | NP |
| 6. Ordinary concrete moment frames | 14.2 | 1 | 1¼ | 1 | 35 | NP | NP | NP | NP |
| 7. Timber frames | 14.5 | 1½ | 1½ | 1½ | 35 | 35 | 35 | NP | NP |
| **H. STEEL SYSTEMS NOT SPECIFICALLY DETAILED FOR SEISMIC RESISTANCE, EXCLUDING CANTILEVER COLUMN SYSTEMS** | 14.1 | 3 | 3 | 3 | NL | NL | NP | NP | NP |

[a] Response modification coefficient, $R$, for use throughout the standard. Note $R$ reduces forces to a strength level, not an allowable stress level.
[b] Reflection amplification factor, $C_d$, for use in Sections 12.8.6, 12.8.7, and 12.9.2
[c] NL = Not Limited and NP = Not Permitted. For metric units use 30.5 m for 100 ft and use 48.8 m for 160 ft. Heights are measured from the base of the structure as defined in Section 11.2.
[d] See Section 12.2.5.4 for a description of building systems limited to buildings with a height of 240 ft (73.2 m) or less.
[e] See Section 12.2.5.4 for building systems limited to buildings with a height of 160 ft (48.8 m) or less.
[f] Ordinary moment frame is permitted to be used in lieu of intermediate moment frame for Seismic Design Categories B or C.
[g] The tabulated value of the overstrength factor, $\Omega_0$, is permitted to be reduced by subtracting one-half for structures with flexible diaphragms, but shall not be taken as less than 2.0 for any structure.
[h] See Sections 12.2.5.6 and 12.2.5.7 for limitations for steel OMFs and IMFs in structures assigned to Seismic Design Category D or E.
[i] See Sections 12.2.5.8 and 12.2.5.9 for limitations for steel OMFs and IMFs in structures assigned to Seismic Design Category F.
[j] Steel ordinary concentrically braced frames are permitted in single-story buildings up to a height of 60 ft (18.3 m) where the dead load of the roof does not exceed 20 psf (0.96 kN/m²) and in penthouse structures.
[k] Increase in height to 45 ft (13.7 m) is permitted for single story storage warehouse facilities.

dual systems, the more stringent system limitation contained in Table 12.2-1 shall apply and the design shall comply with the requirements of this section.

**12.2.3.1 $R$, $C_d$, and $\Omega_0$ Values for Vertical Combinations.** The value of the response modification coefficient, $R$, used for design at any story shall not exceed the lowest value of $R$ that is used in the same direction at any story above that story. Likewise, the deflection amplification factor, $C_d$, and the system over strength factor, $\Omega_0$, used for the design at any story shall not be less than the largest value of this factor that is used in the same direction at any story above that story.

**EXCEPTIONS:**

1. Rooftop structures not exceeding two stories in height and 10 percent of the total structure weight.

**12.7.4 Interaction Effects.** Moment-resisting frames that are enclosed or adjoined by elements that are more rigid and not considered to be part of the seismic force–resisting system shall be designed so that the action or failure of those elements will not impair the vertical load and seismic force–resisting capability of the frame. The design shall provide for the effect of these rigid elements on the structural system at structural deformations corresponding to the design story drift ($\Delta$) as determined in Section 12.8.6. In addition, the effects of these elements shall be considered where determining whether a structure has one or more of the irregularities defined in Section 12.3.2.

## 12.8 EQUIVALENT LATERAL FORCE PROCEDURE

**12.8.1 Seismic Base Shear.** The seismic base shear, $V$, in a given direction shall be determined in accordance with the following equation:

$$V = C_s W \qquad (12.8\text{-}1)$$

where

$C_s$ = the seismic response coefficient determined in accordance with Section 12.8.1.1

$W$ = the effective seismic weight per Section 12.7.2.

**12.8.1.1 Calculation of Seismic Response Coefficient.** The seismic response coefficient, $C_s$, shall be determined in accordance with Eq. 12.8-2.

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I}\right)} \qquad (12.8\text{-}2)$$

where

$S_{DS}$ = the design spectral response acceleration parameter in the short period range as determined from Section 11.4.4

$R$ = the response modification factor in Table 12.2-1

$I$ = the occupancy importance factor determined in accordance with Section 11.5.1

The value of $C_s$ computed in accordance with Eq. 12.8-2 need not exceed the following:

$$C_s = \frac{S_{D1}}{T\left(\frac{R}{I}\right)} \quad \text{for } T \leq T_L \qquad (12.8\text{-}3)$$

$$C_s = \frac{S_{D1}T_L}{T^2\left(\frac{R}{I}\right)} \quad \text{for } T > T_L \qquad (12.8\text{-}4)$$

$C_s$ shall not be less than

$$C_s = 0.01 \qquad (12.8\text{-}5)$$

In addition, for structures located where $S_1$ is equal to or greater than $0.6g$, $C_s$ shall not be less than

$$C_s = \frac{0.5S_1}{\left(\frac{R}{I}\right)} \qquad (12.8\text{-}6)$$

**TABLE 12.8-1 COEFFICIENT FOR UPPER LIMIT ON CALCULATED PERIOD**

| Design Spectral Response Acceleration Parameter at 1 s, $S_{D1}$ | Coefficient $C_u$ |
|---|---|
| $\geq 0.4$ | 1.4 |
| 0.3 | 1.4 |
| 0.2 | 1.5 |
| 0.15 | 1.6 |
| $\leq 0.1$ | 1.7 |

where $I$ and $R$ are as defined in Section 12.8.1.1 and

$S_{D1}$ = the design spectral response acceleration parameter at a period of 1.0 s, as determined from Section 11.4.4

$T$ = the fundamental period of the structure (s) determined in Section 12.8.2

$T_L$ = long-period transition period (s) determined in Section 11.4.5

$S_1$ = the mapped maximum considered earthquake spectral response acceleration parameter determined in accordance with Section 11.4.1

**12.8.1.2 Soil Structure Interaction Reduction.** A soil structure interaction reduction is permitted where determined using Chapter 19 or other generally accepted procedures approved by the authority having jurisdiction.

**12.8.1.3 Maximum $S_s$ Value in Determination of $C_s$.** For regular structures five stories or less in height and having a period, $T$, of 0.5 s or less, $C_s$ is permitted to be calculated using a value of 1.5 for $S_S$.

**12.8.2 Period Determination.** The fundamental period of the structure, $T$, in the direction under consideration shall be established using the structural properties and deformational characteristics of the resisting elements in a properly substantiated analysis. The fundamental period, $T$, shall not exceed the product of the coefficient for upper limit on calculated period ($C_u$) from Table 12.8-1 and the approximate fundamental period, $T_a$, determined from Eq. 12.8-7. As an alternative to performing an analysis to determine the fundamental period, $T$, it is permitted to use the approximate building period, $T_a$, calculated in accordance with Section 12.8.2.1, directly.

**12.8.2.1 Approximate Fundamental Period.** The approximate fundamental period ($T_a$), in s, shall be determined from the following equation:

$$T_a = C_t h_n^x \qquad (12.8\text{-}7)$$

where $h_n$ is the height in ft above the base to the highest level of the structure and the coefficients $C_t$ and $x$ are determined from Table 12.8-2.

**TABLE 12.8-2 VALUES OF APPROXIMATE PERIOD PARAMETERS $C_t$ AND $x$**

| Structure Type | $C_t$ | $x$ |
|---|---|---|
| Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces: | | |
| Steel moment-resisting frames | 0.028 (0.0724)[a] | 0.8 |
| Concrete moment-resisting frames | 0.016 (0.0466)[a] | 0.9 |
| Eccentrically braced steel frames | 0.03 (0.0731)[a] | 0.75 |
| All other structural systems | 0.02 (0.0488)[a] | 0.75 |

[a] Metric equivalents are shown in parentheses.

# Drift

RAM Frame v11.2
DataBase: 329 Inn Blvd Expansion
Building Code: IBC

Steel Code: IBC

**CRITERIA:**

| | | | |
|---|---|---|---|
| Rigid End Zones: | Ignore Effects | | |
| Member Force Output: | At Face of Joint | | |
| P-Delta: | Yes | Scale Factor: | 1.00 |
| Diaphragm: | Rigid | | |
| Ground Level: | Base | | |

**LOAD CASE DEFINITIONS:**

| | | |
|---|---|---|
| D | DeadLoad | RAMUSER |
| Lp | PosLiveLoad | RAMUSER |
| W1 | Wind | W_User |
| E1 | Siesmic | EQ_User |
| W2 | COMP WIND | Wind_IBC06_1_X |
| W3 | COMP WIND | Wind_IBC06_1_Y |
| W4 | COMP WIND | Wind_IBC06_2_X+E |
| W5 | COMP WIND | Wind_IBC06_2_X-E |
| W6 | COMP WIND | Wind_IBC06_2_Y+E |
| W7 | COMP WIND | Wind_IBC06_2_Y-E |
| W8 | COMP WIND | Wind_IBC06_3_X+Y |
| W9 | COMP WIND | Wind_IBC06_3_X-Y |
| W10 | COMP WIND | Wind_IBC06_4_X+Y_CW |
| W11 | COMP WIND | Wind_IBC06_4_X+Y_CCW |
| W12 | COMP WIND | Wind_IBC06_4_X-Y_CW |
| W13 | COMP WIND | Wind_IBC06_4_X-Y_CCW |

**RESULTS:**

**Location (ft): (60.001, 61.184)**

| Story | LdC | Displacement | | Story Drift | | Drift Ratio | |
|---|---|---|---|---|---|---|---|
| | | X | Y | X | Y | X | Y |
| | | in | in | in | in | | |
| SIXTH | D | -0.0019 | -0.0023 | -0.0002 | -0.0002 | 0.0000 | 0.0000 |
| | Lp | -0.0079 | -0.0038 | -0.0017 | -0.0003 | 0.0000 | 0.0000 |
| | W1 | -0.2144 | 0.6243 | -0.0587 | 0.1066 | 0.0003 | 0.0006 |
| | E1 | -0.0553 | 0.1556 | -0.0154 | 0.0286 | 0.0001 | 0.0001 |
| | W2 | 0.3132 | -0.0505 | 0.0470 | -0.0135 | 0.0002 | 0.0001 |
| | W3 | -0.1121 | 0.3371 | -0.0295 | 0.0490 | 0.0002 | 0.0003 |
| | W4 | 0.2381 | -0.0259 | 0.0357 | -0.0084 | 0.0002 | 0.0000 |
| | W5 | 0.2317 | -0.0499 | 0.0348 | -0.0118 | 0.0002 | 0.0001 |
| | W6 | -0.0995 | 0.1956 | -0.0244 | 0.0287 | 0.0001 | 0.0001 |
| | W7 | -0.0687 | 0.3102 | -0.0199 | 0.0449 | 0.0001 | 0.0002 |
| | W8 | 0.1508 | 0.2150 | 0.0131 | 0.0267 | 0.0001 | 0.0001 |
| | W9 | 0.3190 | -0.2908 | 0.0574 | -0.0469 | 0.0003 | 0.0002 |

# Drift

RAM Frame v11.2
DataBase: 329 Inn Blvd Expansion
Building Code: IBC

Steel Code: IBC

| Story | LdC | Displacement | | Story Drift | | Drift Ratio | |
|---|---|---|---|---|---|---|---|
| | W10 | 0.1271 | 0.2132 | 0.0118 | 0.0274 | 0.0001 | 0.0001 |
| | W11 | 0.0991 | 0.1093 | 0.0078 | 0.0126 | 0.0000 | 0.0001 |
| | W12 | 0.2533 | -0.1661 | 0.0450 | -0.0278 | 0.0002 | 0.0001 |
| | W13 | 0.2253 | -0.2700 | 0.0410 | -0.0425 | 0.0002 | 0.0002 |
| FIFTH | D | -0.0017 | -0.0021 | -0.0006 | -0.0010 | 0.0000 | 0.0000 |
| | Lp | -0.0061 | -0.0035 | -0.0021 | -0.0020 | 0.0000 | 0.0000 |
| | W1 | -0.1556 | 0.5178 | -0.0471 | 0.1061 | 0.0003 | 0.0006 |
| | E1 | -0.0399 | 0.1270 | -0.0122 | 0.0283 | 0.0001 | 0.0002 |
| | W2 | 0.2662 | -0.0371 | 0.0505 | -0.0115 | 0.0003 | 0.0001 |
| | W3 | -0.0826 | 0.2881 | -0.0246 | 0.0546 | 0.0001 | 0.0003 |
| | W4 | 0.2024 | -0.0175 | 0.0384 | -0.0067 | 0.0002 | 0.0000 |
| | W5 | 0.1969 | -0.0381 | 0.0374 | -0.0105 | 0.0002 | 0.0001 |
| | W6 | -0.0752 | 0.1669 | -0.0209 | 0.0317 | 0.0001 | 0.0002 |
| | W7 | -0.0488 | 0.2653 | -0.0160 | 0.0501 | 0.0001 | 0.0003 |
| | W8 | 0.1377 | 0.1883 | 0.0194 | 0.0323 | 0.0001 | 0.0002 |
| | W9 | 0.2617 | -0.2439 | 0.0563 | -0.0495 | 0.0003 | 0.0003 |
| | W10 | 0.1153 | 0.1858 | 0.0168 | 0.0326 | 0.0001 | 0.0002 |
| | W11 | 0.0913 | 0.0966 | 0.0123 | 0.0159 | 0.0001 | 0.0001 |
| | W12 | 0.2082 | -0.1383 | 0.0445 | -0.0288 | 0.0003 | 0.0002 |
| | W13 | 0.1843 | -0.2275 | 0.0400 | -0.0455 | 0.0002 | 0.0003 |
| FOURTH | D | -0.0011 | -0.0011 | -0.0006 | -0.0009 | 0.0000 | 0.0000 |
| | Lp | -0.0041 | -0.0015 | -0.0019 | -0.0017 | 0.0000 | 0.0000 |
| | W1 | -0.1085 | 0.4116 | -0.0466 | 0.1142 | 0.0003 | 0.0007 |
| | E1 | -0.0276 | 0.0986 | -0.0121 | 0.0298 | 0.0001 | 0.0002 |
| | W2 | 0.2157 | -0.0256 | 0.0553 | -0.0108 | 0.0003 | 0.0001 |
| | W3 | -0.0580 | 0.2335 | -0.0243 | 0.0606 | 0.0001 | 0.0004 |
| | W4 | 0.1640 | -0.0108 | 0.0420 | -0.0059 | 0.0003 | 0.0000 |
| | W5 | 0.1596 | -0.0275 | 0.0409 | -0.0103 | 0.0002 | 0.0001 |
| | W6 | -0.0542 | 0.1352 | -0.0211 | 0.0350 | 0.0001 | 0.0002 |
| | W7 | -0.0328 | 0.2151 | -0.0155 | 0.0559 | 0.0001 | 0.0003 |
| | W8 | 0.1183 | 0.1560 | 0.0232 | 0.0374 | 0.0001 | 0.0002 |
| | W9 | 0.2053 | -0.1943 | 0.0597 | -0.0536 | 0.0004 | 0.0003 |
| | W10 | 0.0984 | 0.1532 | 0.0199 | 0.0375 | 0.0001 | 0.0002 |
| | W11 | 0.0790 | 0.0807 | 0.0149 | 0.0185 | 0.0001 | 0.0001 |
| | W12 | 0.1637 | -0.1095 | 0.0473 | -0.0307 | 0.0003 | 0.0002 |
| | W13 | 0.1443 | -0.1820 | 0.0422 | -0.0496 | 0.0003 | 0.0003 |
| THIRD | D | -0.0006 | -0.0001 | -0.0003 | -0.0002 | 0.0000 | 0.0000 |
| | Lp | -0.0022 | 0.0002 | -0.0012 | -0.0002 | 0.0000 | 0.0000 |
| | W1 | -0.0619 | 0.2975 | -0.0310 | 0.1126 | 0.0002 | 0.0007 |
| | E1 | -0.0155 | 0.0689 | -0.0078 | 0.0281 | 0.0000 | 0.0002 |
| | W2 | 0.1605 | -0.0148 | 0.0567 | -0.0080 | 0.0003 | 0.0000 |
| | W3 | -0.0337 | 0.1729 | -0.0169 | 0.0641 | 0.0001 | 0.0004 |

# Drift

RAM Frame v11.2
DataBase: 329 Inn Blvd Expansion
Building Code: IBC

Steel Code: IBC

| Story | LdC | Displacement | | Story Drift | | Drift Ratio | |
|---|---|---|---|---|---|---|---|
| | W4 | 0.1220 | -0.0049 | 0.0432 | -0.0036 | 0.0003 | 0.0000 |
| | W5 | 0.1187 | -0.0173 | 0.0419 | -0.0084 | 0.0002 | 0.0000 |
| | W6 | -0.0332 | 0.1001 | -0.0157 | 0.0366 | 0.0001 | 0.0002 |
| | W7 | -0.0173 | 0.1592 | -0.0096 | 0.0595 | 0.0001 | 0.0004 |
| | W8 | 0.0951 | 0.1186 | 0.0299 | 0.0421 | 0.0002 | 0.0003 |
| | W9 | 0.1456 | -0.1408 | 0.0552 | -0.0540 | 0.0003 | 0.0003 |
| | W10 | 0.0785 | 0.1157 | 0.0251 | 0.0419 | 0.0001 | 0.0002 |
| | W11 | 0.0641 | 0.0622 | 0.0196 | 0.0212 | 0.0001 | 0.0001 |
| | W12 | 0.1164 | -0.0788 | 0.0441 | -0.0302 | 0.0003 | 0.0002 |
| | W13 | 0.1020 | -0.1324 | 0.0386 | -0.0509 | 0.0002 | 0.0003 |
| SECOND | D | -0.0002 | 0.0001 | -0.0002 | 0.0001 | 0.0000 | 0.0000 |
| | Lp | -0.0010 | 0.0004 | -0.0009 | 0.0004 | 0.0000 | 0.0000 |
| | W1 | -0.0308 | 0.1849 | -0.0297 | 0.1041 | 0.0002 | 0.0006 |
| | E1 | -0.0077 | 0.0408 | -0.0075 | 0.0246 | 0.0000 | 0.0001 |
| | W2 | 0.1038 | -0.0068 | 0.0606 | -0.0064 | 0.0004 | 0.0000 |
| | W3 | -0.0168 | 0.1088 | -0.0162 | 0.0602 | 0.0001 | 0.0004 |
| | W4 | 0.0789 | -0.0014 | 0.0460 | -0.0028 | 0.0003 | 0.0000 |
| | W5 | 0.0768 | -0.0089 | 0.0449 | -0.0069 | 0.0003 | 0.0000 |
| | W6 | -0.0175 | 0.0635 | -0.0148 | 0.0354 | 0.0001 | 0.0002 |
| | W7 | -0.0077 | 0.0997 | -0.0095 | 0.0549 | 0.0001 | 0.0003 |
| | W8 | 0.0652 | 0.0765 | 0.0333 | 0.0403 | 0.0002 | 0.0002 |
| | W9 | 0.0904 | -0.0868 | 0.0576 | -0.0499 | 0.0003 | 0.0003 |
| | W10 | 0.0534 | 0.0738 | 0.0274 | 0.0391 | 0.0002 | 0.0002 |
| | W11 | 0.0445 | 0.0410 | 0.0226 | 0.0214 | 0.0001 | 0.0001 |
| | W12 | 0.0723 | -0.0487 | 0.0456 | -0.0286 | 0.0003 | 0.0002 |
| | W13 | 0.0634 | -0.0815 | 0.0408 | -0.0463 | 0.0002 | 0.0003 |
| FIRST | D | -0.0000 | 0.0000 | -0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | Lp | -0.0000 | 0.0000 | -0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | W1 | -0.0011 | 0.0808 | -0.0011 | 0.0808 | 0.0000 | 0.0005 |
| | E1 | -0.0003 | 0.0162 | -0.0003 | 0.0162 | 0.0000 | 0.0001 |
| | W2 | 0.0431 | -0.0004 | 0.0431 | -0.0004 | 0.0003 | 0.0000 |
| | W3 | -0.0006 | 0.0487 | -0.0006 | 0.0487 | 0.0000 | 0.0003 |
| | W4 | 0.0328 | 0.0014 | 0.0328 | 0.0014 | 0.0002 | 0.0000 |
| | W5 | 0.0319 | -0.0020 | 0.0319 | -0.0020 | 0.0002 | 0.0000 |
| | W6 | -0.0027 | 0.0282 | -0.0027 | 0.0282 | 0.0000 | 0.0002 |
| | W7 | 0.0018 | 0.0449 | 0.0018 | 0.0449 | 0.0000 | 0.0003 |
| | W8 | 0.0319 | 0.0362 | 0.0319 | 0.0362 | 0.0002 | 0.0002 |
| | W9 | 0.0328 | -0.0368 | 0.0328 | -0.0368 | 0.0002 | 0.0002 |
| | W10 | 0.0260 | 0.0347 | 0.0260 | 0.0347 | 0.0002 | 0.0002 |
| | W11 | 0.0219 | 0.0196 | 0.0219 | 0.0196 | 0.0001 | 0.0001 |
| | W12 | 0.0266 | -0.0201 | 0.0266 | -0.0201 | 0.0002 | 0.0001 |
| | W13 | 0.0226 | -0.0352 | 0.0226 | -0.0352 | 0.0001 | 0.0002 |

# Criteria, Mass and Exposure Data

RAM Frame v11.2
DataBase: 329 Inn Blvd Expansion

**CRITERIA:**

Rigid End Zones: Ignore Effects
Member Force Output: At Face of Joint
P-Delta: Yes Scale Factor: 1.00
Ground Level: Base
Wall Mesh Criteria :
Wall Element Type : Shell Element with No Out-of-Plane Stiffness
Max. Allowed Distance between Nodes (ft) : 8.00

**DIAPHRAGM DATA:**

| Story | Diaph # | Diaph Type |
|---|---|---|
| SIXTH | 1 | Rigid |
| FIFTH | 1 | Rigid |
| FOURTH | 1 | Rigid |
| THIRD | 1 | Rigid |
| SECOND | 1 | Rigid |
| FIRST | 1 | Rigid |

Disconnect Internal Nodes of Beams: Yes
Disconnect Nodes outside Slab Boundary: Yes

**STORY MASS DATA:**

**Includes Self Mass of:**

Beams
Columns (Half mass of columns above and below)
Walls (Half mass of walls above and below)
Slabs/Deck

**Calculated Values:**

| Story | Diaph # | Weight kips | Mass k-s2/ft | MMI ft-k-s2 | Xm ft | Ym ft | EccX ft | EccY ft |
|---|---|---|---|---|---|---|---|---|
| SIXTH | 1 | 1070.0 | 33.23 | 145572 | 101.96 | 49.88 | 10.25 | 5.05 |
| FIFTH | 1 | 1114.1 | 34.60 | 156587 | 101.68 | 50.24 | 10.30 | 5.10 |
| FOURTH | 1 | 1113.5 | 34.58 | 156433 | 101.67 | 50.25 | 10.30 | 5.10 |
| THIRD | 1 | 1168.5 | 36.29 | 164603 | 101.68 | 50.26 | 10.30 | 5.10 |
| SECOND | 1 | 1172.9 | 36.43 | 165325 | 101.68 | 50.26 | 10.30 | 5.10 |
| FIRST | 1 | 1158.6 | 35.98 | 164444 | 101.68 | 50.93 | 10.30 | 5.10 |

| Story | Diaph # | Combine |
|---|---|---|
| SIXTH | 1 | None |
| FIFTH | 1 | None |
| FOURTH | 1 | None |
| THIRD | 1 | None |
| SECOND | 1 | None |
| FIRST | 1 | None |

# Center of Rigidity

RAM Frame v11.2
DataBase: 329 Inn Blvd Expansion

**CRITERIA:**

| | | | |
|---|---|---|---|
| Rigid End Zones: | | Ignore Effects | |
| Member Force Output: | | At Face of Joint | |
| P-Delta: | Yes | Scale Factor: | 1.00 |
| Ground Level: | Base | | |

Wall Mesh Criteria :

Wall Element Type : Shell Element with No Out-of-Plane Stiffness

Max. Allowed Distance between Nodes (ft) : 8.00

| | | Centers of Rigidity | | Centers of Mass | |
|---|---|---|---|---|---|
| **Level** | **Diaph. #** | **Xr** | **Yr** | **Xm** | **Ym** |
| | | **ft** | **ft** | **ft** | **ft** |
| SIXTH | 1 | 102.35 | 49.78 | 101.96 | 49.88 |
| FIFTH | 1 | 102.41 | 49.81 | 101.68 | 50.24 |
| FOURTH | 1 | 102.50 | 49.84 | 101.67 | 50.25 |
| THIRD | 1 | 102.30 | 49.88 | 101.68 | 50.26 |
| SECOND | 1 | 101.92 | 49.92 | 101.68 | 50.26 |
| FIRST | 1 | 101.92 | 49.91 | 101.68 | 50.93 |

# ABP Wall Panel Specifications

Thermal Properties - Test Data

Description: The ABP Wall Panel is similar in appearance to the IPP panel. The exterior profile is asymmetrical with expanded flat areas to reduce shadow lines. As with all IPS panels, the interior skin is fabricated in the Mesa profile.

Dimensions: The product is available in 2", 2-1/2", or 3", thick and can achieve R-Values to 23.9. The manufactured net width can be 36" or 42". Typical embossed exterior skins are provided in 24 or 22 gauge steel. The maximum recommended length for the ABP Panel is 30'0". Contact IPS for panel length options. Panel connections are made into structural members with concealed clips and fasteners.

Material:

Exterior - 24 ga. steel (std). 22 ga. also available.

Interior - 26 ga. steel (std). 24 and 22 ga. also available.

Finish Options:

Exterior - Signature® 200 (silicone polyester)
Signature® 300 (Kynar 500®/Hylar 5000®)

Interior - USDA White (standard)
Signature® 200 (silicone polyester)

Colors: IPS Panel Color and Finish Guide

Texture: The exterior and interior skins are embossed only.

Length: The maximum recommended length is 30' 0". Contact IPS for panel length options. IPS offers standard details for stack joint applications for walls over 30' 0" high.

Fasteners: Concealed, 14 ga. steel clip.

Thermal Properties

| ABP Wall Panel | | | |
|---|---|---|---|
| Product Code | Thickness | "U" Factor | "R" Factor |
| ABP 200 | 2" | .063 | 16.0 |
| ABP 250 | 2 1/2" | .050 | 19.9 |
| ABP 300 | 3" | .042 | 23.9 |

*Note: Insulation values determined by tests conducted in accordance with ASTM C236 at a mean temperature of 75 degrees F., winter condition corrected to 15 mph outside and still inside.*

# 5500 ISOWEB® WINDOW

NOVEMBER, 2007

## THERMAL TRANSMITTANCE

E.C. 97902-08

**For some regions and projects there may be minimum energy efficiency requirements for the building envelope, and its components, including windows. The shading coefficient (SC) and the thermal transmittance (U - value) of the window is then required to determine whether the building design complies with the specified energy requirements. Shading coefficient depends on the glass selected and should be obtained from the glass supplier. The U - value of the window varies with the type of glass and sealed unit edge construction, the window frame, and the relative areas of these components.**

**The window thermal transmittance values (U - values) shown in the chart below are based on CSA - A440.2 "Energy Performance Evaluation of Windows and Sliding Glass Doors." U - values of the centre of glass, edge of glass, and frame areas were computed using the VISION and FRAME thermal simulation programs. Overall window U - values were calculated using the following relationship:**

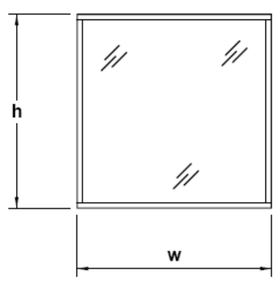
$$U_w = (U_c A_c + U_e A_e + U_f A_f)/A_w$$

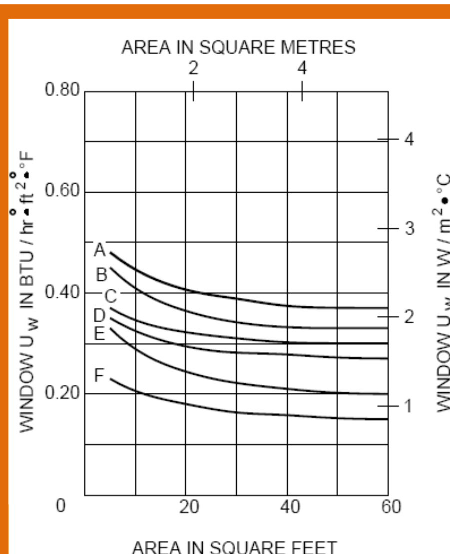
where

$U_w$ = U-value of complete window product
$U_c$ = calculated centre of glass U-value
$U_e$ = calculated edge of glass U-value
$U_f$ = calculated frame U-value
$A_c$ = centre of glass area
$A_e$ = edge of glass area
$A_f$ = frame area
$A_w$ = total window area

### OVERALL WINDOW U-VALUE ($U_w$)

**For fixed and operating window configurations as shown with height (h) equal to width (w).**




**SEALED UNIT GLAZING TYPE**

A = 6mm clear / ½" air / 6mm low-e[1] / metal spacer
B = 6mm clear / ½" argon / 6mm low-e[1] / metal spacer
C = 6mm clear / ½" argon / 6mm low-e[1] / warm edge spacer[3]
D = 6mm clear / ½" argon / 6mm low-e[2] / warm edge spacer[3]
E = [illegible]
F = 6mm clear / ½" argon / 6mm low-e[2] / ½"argon / 6mm low-e[2] / warm edge spacer[3]

1 - low-e coating emittance = 0.1
2 - low-e coating emittance = 0.03
3 - Edgetech Super "U" Spacer ®

**NOTES:** THE ABOVE SEALED UNIT GLAZING OPTIONS ARE PRESENTED FOR THE PURPOSES OF ILLUSTRATING THERMAL PERFORMANCE CAPABILITIES.

FOR WINDOWS WITH HEIGHT NOT EQUAL TO WIDTH, WHEN ADDING INTERMEDIATE VERTICALS OR HORIZONTALS, OR DIFFERENT GLASS INFILL, THE OVERALL WINDOW U - VALUE MAY VARY.

THE SPECIFIER SHOULD SELECT GLASS TO MEET THE PERFORMANCE REQUIREMENTS OF THE PROJECT.

## HVAC Equipment Sizing Calcs

*"Genius is the infinite capacity for taking pains."*
- Jane Ellis Hopkins

*"Problems are messages."*
Shakti Gawain

Sam Dardano, a Boulder-based code official who chairs the committee of statewide mechanical and plumbing inspectors, reports that by early next year roughly 75 percent of the building jurisdictions in Colorado will be operating under the International Codes. If that's true, here's a key item from the code that can help, not just hurt.

The International Energy Conservation Code (IECC) requires that load calculations be used to size heating and cooling equipment. 11' properly implemented, this could reduce the widespread tendency to oversize equipment. Yet both builders and code officials are uncertain how to evaluate such calculations to assure the results are accurate.

This article presents 10 top items to look for when evaluating HVAC sizing calcs.

### *Background*

An article titled "Bigger is Not Better," Published in the May-June 1995 Home Energy magazine, was one of the first to draw attention to the widespread problem of residential equipment oversizing. A study of design. construction and performance issues in northern Colorado hones built in the mid- to late1990S ( fcgov.com/utilities/es-performancestudy.php ) was the most recent to confirm that heating and cooling equipment tends to be oversized by substantial margins in this part of the country. The Colorado study showed heating systems were moderately oversized while air conditioning systems were nearly twice as large as needed - averaging 158 percent and 208 percent of design loads, respectively.

Furnace sizing ratios ranged from 106 percent to 234 percent of design heating requirements. Greater oversizing factors were typically observed in homes with insulated basements versus homes with uninsulated basements, suggesting that furnace-sizing practice had not yet reflected the reduction in heating loads due to basement insulation.

Cooling systems ranged from about 143 percent to 322 percent of design cooling requirements.

Note that for every hour of the year when heating and cooling requirements are less demanding than design conditions, the equipment is even further oversized.

Over-sized equipment requires more air flow and larger ductwork; without this, equipment will not operate within manufacturer specifications. Even if ductwork sizing is increased, the oversized equipment will short-cycle. These problems decrease efficiency and equipment life while compromising homeowner comfort. Utilities may be burdened with higher summer peak loads and more blown transformers. Builders and homeowners pay more for oversized systems.

Over-sizing typically occurs when contractors use "rules of thumb," such as "I toil of AC needed per 600 square feet" or other simple sizing approach based on their own experience. In 2000, Hank Rutkowski. author of ACCA Manual J: Residential Load Calculation, estimated that only 5 to 10 percent of' HVAC systems had calculations performed to help size systems. Furthermore, even when load calculations were performed, contractors were inclined to include fudge factors based on past customer complaints about comfort. "I've never been sued for installing too large a system," contractors have stated repeatedly.

In the 8th edition, published in April 2002, Rutkowski wrote, "Manual J calculations should be aggressive, which means the design should take full advantage of legitimate opportunities to minimize the size of estimated loads. In this regard, the practice of manipulating the outdoor design temperature, not taking full credit for efficient construction features, ignoring internal and external window shading devices, and then applying an arbitrary 'safety factor' is indefensible."

It should be noted that oversizing does not address many other related problems that cause homeowners to complain. As noted in the Colorado study. these include problems with excessive solar gain, insulation and air sealing flaws, lack of' ductwork design and many compromises in duct installation (constrictions. leakage, pressure imbalances, no way to balance air flow among branch ducts).

Does the above sound a little academic" It doesn't have to be. Aspen Homes now installs 40,000 Btu to 60,000 Btu furnaces in all their high-performance homes, replacing 100,000 and 120,000 Btu units, respectively, saving $40 to $50 a pop: their air conditioners are similarly downsized, saving at $250-$500.

## *Ten key sizing factors*

**1. Use acceptable sizing calculation tool:** Most jurisdictions allow calculations based on Manual J (Air Conditioning Contractors of America - an industry trade group). Manual J methods are based on the ASHRAE Handbook of Fundamentals. The 8th Edition of Manual J is the most current; it has been modified to reduce Manual Fs past tendency to enable over-sizing.

**2. Outdoor design temperatures:** There is considerable room for error here; check to assure the proper winter/summer outdoor design temperatures are used. The IECC specifies using `°97.5 percent values for winter and 2.5 percent values for summer, from tables in the ASHRAE Handbook of Fundamentals." (97.5 percent means during the average winter, the temperature will remain above that temperature 97.5 percent of the time.) Unfortunately, 97.5 percent and 2.5 percent values aren't available in the ASHRAE Handbook any longer. Contact E '-Star (see contact info below) for the comparable list of design temperatures.

In most Denver areas. the winter design temperature should be within a few degrees of 0 (leg. F, and the summer design temperature should he about 92 degrees.

**3. Indoor design temperatures:** Check to assure that proper indoor design temperatures are used (70 deg. F winter and 75 deg. F summer).

**4. Window orientation:** While heating equipment sizing is unaffected by window orientation. the impact of orientation on cooling loads can be substantial. In fact, in a new home built to the TECC standard, solar gains through windows are typically the home's largest contributor to peak cooling load up to 50 percent. For production builders, orientation should he considered when calculating cooling equipment size for the same model home placed on lots with different orientations. It should he noted that some homes with predominantly west-facing glass will not be comfortable. during some climate conditions. regardless of system size, without very smart window choices.

**5. Reasonable air infiltration assumptions.** A few jurisdictions insist that high air-leakage rates be assumed. Many contractors assume high leakage rates. Often, projected house leakage is overestimated, again contributing to over-sizing. House tightness testing results for geographic locations and specific builders should he factored in. A reasonable air leakage assumption: between 0.35 to 0.50 natural air-changes per hour, Unless a builder has data specific to their construction practices indicating they build tighter (or looser). (Engle Homes averages 0.12 air changes - four times tighter than the average home.)

**6. Proper energy features.** The R-values. U-values and window Solar Heat Gain Coefficients (SHGC) specified on the plans should match those used in the calculations. Foundation insulation and window values are prone to incorrect entry.

**7. Duct losses.** One figure is entered in the calculation to represent conductive losses from ducts in unconditioned spaces. It is otherwise specified and assumed that ductwork will be "substantially leak free," per code. (The IECC specifics this as being, "5 percent or less of the air handler's rated air-flow when the return grilles and supply registers are sealed off' and the entire distribution system-including the air handler cabinet is pressurized to 0.1-inch w.g. 125 pascals. Unfortunately, random testing in the northern Colorado showed that ductwork leakage averaged 130 percent of the average air-handler's rated air flow). Today, a small but growing number of Colorado HVAC contractors are developing the expertise to design and build tight ductwork. then buying equipment to perform pressure measurements that confirm their results. Duct losses are highly dependent on duct location. The number of ducts in exterior walls, garage ceilings, vented crawl spaces and attics is a critical factor, with respect to losses from both duct leakage and air infiltration. Ducts in the exterior of the envelope must be effectively insulated to a minimum of R8. (IECC 2003)

**8. Climatic moisture load factor.** The difference between the moisture content of the outdoor air and desired interior humidity is referred to as "design grains." Calculations should use "design grains" applicable to a particular jurisdiction (see Manual J). Latent loads are typically a tiny part of the design cooling load in this climate. In the metro area. designs grains are approximately -40. Latent loads for summer cooling typically in the 1.000 to 2.000 Btu/hr range (varying with house size).

**9. Assume shading devices.** Even for new homes. the presence of reasonable internal shading devices should be assumed. People can he expected to close their window cover day. Built-in external shading (overhangs, adjacent buildings, etc.) should also be factored in.

**10. Capacity margin of selected equipment.** This maximum sizing guideline should be followed: "The total capacity (sensible plus latent) of the cooling equipment should not exceed the total load (sensible plus latent) by more than 15 percent for cooling-only applications and warm-climate heat pump applications: or by more than 25 percent for cold-climate applications." (Manual J. 8th Edition)

# Air Handlers for Every Need

## Blower Coils
## Packaged Climate Changer™ AHU
## M-Series and T-Series Climate Changer™ AHU
## Custom Climate Changer™ Air Handlers


| Features | Blower Coil Units | Packaged Climate Changer | M-Series & T-Series AHU | Custom AHU |
|---|---|---|---|---|
| CFM Range | 400 - 3,000 | 1,500 - 15,000 | 1,500 - 60,000 | 1500 - 200,000 + |
| Application | Comfort | Comfort | Comfort | Comfort or Process |
| Aspect Ratio | Fixed | Fixed | Fixed | Variable |
| Fan Type | FC | FC | FC/BC/AF/Plenum/Q | All |
| Coil Location | Draw-Thru | Draw-Thru | Draw or Blow-Thru | Draw or Blow-Thru |
| Construction Matl | Galvanized | Galvanized | Galvanized | Flexible |
| Wall Construction | Single Wall | Single/Double | Optional Double | Flexible |
| Filtration | 1″ or 2″ | 2″ or 4″ | Flexible | Full Flexibility |
| Coil Flexibility | Row | Limited Fin/Row | Flexible | Full Flexibility |
| S.P. Capability | <2.5 in. wg | <4.0 in. wg | -4.0 to +6.0 in. wg | -12.0 to +12.0 in. wg |
| Thermal Break | None | None | Gasket | Yes |
| Unit Flexibility | Low | Medium | Medium - High | High |
| ICS Controls | ZN010, 510, 520 | AH540 | AH540/MP580 | MP580 |

## Application Comparison

| Space Type | Blower Coil Units | Packaged Climate Changer | M-Series & T-Series AHU | Custom AHU |
|---|---|---|---|---|
| Offices | ■ | ■ | ■ | ■ |
| Hospitals/Labs | O | O | ■ | ★ |
| Manufacturing | ■ | ■ | ★ | ■ |
| Industrial Processes | O | O | ★ | ★ |
| Schools | ★ | ★ | ★ | ★ |
| Hotels/Motels | ■ | ★ | ★ | O |
| Retails | ★ | ★ | ■ | O |

★ Targeted Applications ■ Common Applications O Occasional Applications

TRANE®

## KQFP DISCHARGE SOUND PERFORMANCE DATA

### ▼ KQFP, DISCHARGE SOUND DATA

| Unit Size | Inlet Size | Flow Rate | | Min Δ Ps | | Primary @ 0.5" Δ Ps Octave Band Sound Power, Lw | | | | | | Lp | Primary @ 1.0" Δ Ps Octave Band Sound Power, Lw | | | | | | Lp | Primary @ 2.0" Δ Ps Octave Band Sound Power, Lw | | | | | | Lp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CFM | (L/s) | "WG | (Pa) | 2 | 3 | 4 | 5 | 6 | 7 | NC | 2 | 3 | 4 | 5 | 6 | 7 | NC | 2 | 3 | 4 | 5 | 6 | 7 | NC |
| 2 | 6 | 100 | (47) | 0.013 | (3.1) | 32 | 31 | 27 | 23 | 23 | 24 | - | 35 | 31 | 28 | 24 | 26 | 29 | - | 37 | 32 | 28 | 25 | 29 | 34 | - |
| | | 200 | (94) | 0.050 | (12.4) | 44 | 43 | 39 | 33 | 30 | 28 | - | 47 | 44 | 39 | 34 | 33 | 32 | - | 49 | 45 | 40 | 36 | 36 | 37 | - |
| | | 300 | (142) | 0.113 | (28.0) | 51 | 51 | 45 | 39 | 34 | 30 | - | 54 | 51 | 46 | 40 | 37 | 35 | - | 56 | 52 | 47 | 41 | 40 | 39 | - |
| | | 400 | (189) | 0.200 | (49.8) | 57 | 56 | 50 | 43 | 36 | 31 | - | 59 | 57 | 51 | 44 | 40 | 36 | - | 61 | 57 | 51 | 46 | 43 | 41 | - |
| | | 500 | (236) | 0.313 | (77.8) | 60 | 60 | 54 | 46 | 39 | 33 | - | 63 | 61 | 54 | 47 | 42 | 37 | - | 65 | 61 | 55 | 49 | 45 | 42 | - |
| 3 | 8 | 180 | (85) | 0.013 | (3.3) | 35 | 41 | 40 | 31 | 26 | 23 | - | 39 | 43 | 42 | 33 | 29 | 28 | - | 43 | 46 | 45 | 36 | 33 | 33 | - |
| | | 360 | (170) | 0.053 | (13.2) | 47 | 49 | 45 | 38 | 32 | 28 | - | 51 | 52 | 47 | 40 | 36 | 33 | - | 55 | 55 | 50 | 43 | 39 | 37 | - |
| | | 540 | (255) | 0.119 | (29.6) | 54 | 54 | 48 | 42 | 36 | 31 | - | 58 | 57 | 50 | 45 | 39 | 35 | - | 62 | 60 | 53 | 47 | 43 | 40 | - |
| | | 720 | (340) | 0.212 | (52.7) | 59 | 58 | 50 | 45 | 39 | 33 | - | 63 | 60 | 53 | 48 | 42 | 37 | - | 67 | 63 | 55 | 50 | 46 | 42 | - |
| | | 900 | (425) | 0.331 | (82.3) | 63 | 60 | 52 | 47 | 41 | 34 | - | 67 | 63 | 54 | 50 | 44 | 39 | - | 71 | 66 | 57 | 52 | 48 | 44 | **23** |
| 4 | 10 | 290 | (137) | 0.014 | (3.5) | 40 | 41 | 40 | 33 | 26 | 20 | - | 43 | 43 | 42 | 36 | 29 | 23 | - | 45 | 46 | 45 | 38 | 32 | 27 | - |
| | | 580 | (274) | 0.056 | (13.8) | 53 | 51 | 47 | 43 | 37 | 30 | - | 56 | 53 | 49 | 45 | 40 | 34 | - | 58 | 56 | 52 | 48 | 43 | 37 | - |
| | | 870 | (411) | 0.125 | (31.1) | 61 | 57 | 51 | 48 | 43 | 36 | - | 63 | 59 | 54 | 51 | 46 | 40 | - | 66 | 62 | 56 | 53 | 49 | 43 | - |
| | | 1160 | (547) | 0.222 | (55.3) | 66 | 61 | 54 | 52 | 48 | 41 | - | 69 | 64 | 57 | 55 | 51 | 44 | **20** | 71 | 66 | 59 | 57 | 54 | 48 | **23** |
| | | 1450 | (684) | 0.348 | (86.5) | 70 | 64 | 57 | 55 | 51 | 44 | **22** | 73 | 67 | 59 | 58 | 54 | 48 | **25** | 75 | 69 | 61 | 60 | 57 | 51 | **28** |
| 5 | 12 | 420 | (198) | 0.014 | (3.4) | 38 | 41 | 42 | 33 | 25 | 20 | - | 43 | 45 | 45 | 37 | 29 | 26 | - | 48 | 49 | 49 | 40 | 33 | 31 | - |
| | | 840 | (396) | 0.055 | (13.7) | 48 | 47 | 47 | 42 | 35 | 28 | - | 53 | 51 | 51 | 45 | 39 | 34 | - | 58 | 55 | 54 | 48 | 43 | 39 | - |
| | | 1260 | (595) | 0.124 | (30.9) | 54 | 51 | 50 | 46 | 41 | 33 | - | 59 | 55 | 54 | 49 | 45 | 38 | - | 64 | 59 | 57 | 53 | 49 | 44 | - |
| | | 1680 | (793) | 0.221 | (54.9) | 58 | 53 | 53 | 50 | 45 | 36 | - | 63 | 57 | 56 | 53 | 49 | 42 | - | 68 | 61 | 59 | 56 | 53 | 47 | - |
| | | 2100 | (991) | 0.345 | (85.7) | 61 | 55 | 54 | 52 | 48 | 39 | - | 66 | 59 | 57 | 55 | 52 | 44 | - | 71 | 63 | 61 | 59 | 56 | 50 | **23** |
| 6 | 14 | 570 | (269) | 0.015 | (3.7) | 45 | 41 | 39 | 34 | 27 | 21 | - | 49 | 46 | 44 | 38 | 31 | 26 | - | 54 | 50 | 48 | 42 | 35 | 32 | - |
| | | 1140 | (538) | 0.059 | (14.7) | 54 | 48 | 46 | 43 | 37 | 31 | - | 59 | 53 | 51 | 47 | 42 | 36 | - | 63 | 58 | 56 | 51 | 46 | 41 | - |
| | | 1710 | (807) | 0.133 | (33.0) | 59 | 53 | 51 | 48 | 44 | 36 | - | 64 | 58 | 56 | 52 | 48 | 41 | - | 68 | 62 | 60 | 56 | 52 | 47 | - |
| | | 2280 | (1076) | 0.236 | (58.7) | 63 | 56 | 54 | 52 | 48 | 40 | - | 68 | 61 | 59 | 56 | 52 | 45 | - | 72 | 66 | 63 | 60 | 56 | 50 | **24** |
| | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | 16 | 740 | (349) | 0.014 | (3.5) | 47 | 43 | 43 | 38 | 31 | 23 | - | 52 | 47 | 47 | 42 | 35 | 28 | - | 56 | 51 | 51 | 45 | 38 | 32 | - |
| | | 1480 | (698) | 0.056 | (13.9) | 58 | 52 | 50 | 47 | 42 | 35 | - | 62 | 56 | 55 | 51 | 46 | 39 | - | 67 | 60 | 59 | 54 | 49 | 44 | - |
| | | 2220 | (1048) | 0.126 | (31.3) | 64 | 57 | 55 | 52 | 49 | 42 | - | 68 | 61 | 59 | 56 | 52 | 46 | - | 73 | 65 | 64 | 60 | 56 | 50 | **25** |
| | | 2960 | (1397) | 0.224 | (55.6) | 68 | 61 | 58 | 56 | 53 | 46 | - | 73 | 65 | 63 | 60 | 57 | 51 | **25** | 77 | 69 | 67 | 63 | 60 | 55 | **31** |
| | | 3700 | (1746) | 0.349 | (86.9) | 71 | 64 | 61 | 59 | 57 | 50 | **23** | 76 | 68 | 65 | 63 | 60 | 55 | **29** | 80 | 72 | 70 | 66 | 64 | 59 | **35** |

► *All sound data is based on tests conducted in accordance with ARI 880-98. ΔPs is the difference in static pressure from inlet to discharge. Sound power levels are in dB, re $10^{-12}$ watts. Discharge sound power is the sound emitted from the unit discharge. NC application data is from ARI Standard 885-98 Appendix E, as a function of flow rate shown. Dash (-) indicates a NC is less than 20. See K-Select for specific sound data for optional liners; 1/2" dual density liner shown. See Engineering section for reductions and definitions. ARI rating points based on 0.25" WG external pressure.*

### ▼ ARI CERTIFICATION RATING POINTS

| Unit Size | Inlet Size | Primary CFM | Min. Δ Ps | Sound Power @ 1.5" Δ Ps | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 2 | 3 | 4 | 5 | 6 | 7 |
| 2 | 6 | 400 | 0.200 | 61 | 57 | 51 | 45 | 41 | 38 |
| 3 | 8 | 700 | 0.200 | 64 | 62 | 53 | 49 | 44 | 39 |
| 4 | 10 | 1100 | 0.200 | 69 | 65 | 57 | 55 | 50 | 44 |
| 5 | 12 | 1600 | 0.200 | 68 | 61 | 57 | 55 | 52 | 45 |
| 6 | 14 | 2100 | 0.200 | 69 | 62 | 60 | 57 | 53 | 46 |
| 7 | 16 | 2800 | 0.200 | 75 | 67 | 65 | 61 | 58 | 52 |

ARI Standard 880

## KQFP RADIATED SOUND PERFORMANCE DATA

### ▼ KQFP, RADIATED SOUND DATA

| Unit Size | Inlet Size | Flow Rate CFM | Flow Rate (L/s) | Min Δ Ps "WG | Min Δ Ps (Pa) | Primary @ 0.5" Δ Ps Octave Band Sound Power, Lw 2 | 3 | 4 | 5 | 6 | 7 | Lp NC | Primary @ 1.0" Δ Ps Octave Band Sound Power, Lw 2 | 3 | 4 | 5 | 6 | 7 | Lp NC | Primary @ 2.0" Δ Ps Octave Band Sound Power, Lw 2 | 3 | 4 | 5 | 6 | 7 | Lp NC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 6 | 100 | (47) | 0.013 | (3.1) | 35 | 29 | 26 | 23 | 23 | 23 | - | 37 | 31 | 29 | 26 | 27 | 28 | - | 39 | 33 | 31 | 29 | 31 | 33 | - |
| | | 200 | (94) | 0.050 | (12.4) | 43 | 37 | 34 | 29 | 27 | 25 | - | 45 | 39 | 37 | 32 | 31 | 30 | - | 47 | 41 | 39 | 35 | 35 | 35 | - |
| | | 300 | (142) | 0.113 | (28.0) | 48 | 42 | 39 | 33 | 30 | 27 | - | 50 | 44 | 41 | 36 | 34 | 32 | - | 52 | 46 | 44 | 39 | 38 | 37 | - |
| | | 400 | (189) | 0.200 | (49.8) | 51 | 46 | 42 | 36 | 31 | 28 | - | 54 | 47 | 44 | 39 | 36 | 33 | - | 56 | 49 | 47 | 42 | 40 | 38 | **21** |
| | | 500 | (236) | 0.313 | (77.8) | 54 | 48 | 44 | 38 | 33 | 28 | - | 56 | 50 | 47 | 41 | 37 | 33 | **21** | 58 | 52 | 49 | 44 | 41 | 38 | **24** |
| 3 | 8 | 180 | (85) | 0.013 | (3.3) | 35 | 33 | 32 | 26 | 22 | 21 | - | 39 | 37 | 36 | 30 | 26 | 28 | - | 42 | 40 | 40 | 33 | 30 | 34 | - |
| | | 360 | (170) | 0.053 | (13.2) | 44 | 40 | 38 | 33 | 29 | 26 | - | 47 | 44 | 42 | 36 | 33 | 33 | - | 51 | 47 | 46 | 40 | 38 | 39 | - |
| | | 540 | (255) | 0.119 | (29.6) | 49 | 44 | 41 | 37 | 33 | 29 | - | 52 | 48 | 45 | 40 | 38 | 36 | - | 56 | 51 | 49 | 44 | 42 | 42 | **23** |
| | | 720 | (340) | 0.212 | (52.7) | 52 | 47 | 44 | 39 | 36 | 31 | - | 56 | 51 | 48 | 43 | 41 | 38 | **21** | 59 | 54 | 51 | 47 | 45 | 44 | **26** |
| | | 900 | (425) | 0.331 | (82.3) | 55 | 50 | 45 | 42 | 39 | 33 | - | 59 | 53 | 49 | 45 | 43 | 39 | **24** | 62 | 56 | 53 | 49 | 48 | 46 | **28** |
| 4 | 10 | 290 | (137) | 0.014 | (3.5) | 39 | 34 | 32 | 25 | 19 | 16 | - | 43 | 37 | 35 | 29 | 22 | 21 | - | 47 | 40 | 38 | 32 | 26 | 26 | - |
| | | 580 | (274) | 0.056 | (13.8) | 47 | 42 | 40 | 33 | 28 | 24 | - | 51 | 46 | 43 | 37 | 31 | 29 | - | 56 | 49 | 46 | 40 | 35 | 34 | - |
| | | 870 | (411) | 0.125 | (31.1) | 52 | 47 | 44 | 38 | 33 | 29 | - | 57 | 51 | 47 | 42 | 37 | 34 | **21** | 61 | 54 | 50 | 45 | 40 | 39 | **25** |
| | | 1160 | (547) | 0.222 | (55.3) | 56 | 51 | 47 | 42 | 37 | 32 | **21** | 60 | 54 | 51 | 45 | 41 | 37 | **25** | 64 | 58 | 54 | 48 | 44 | 42 | **28** |
| | | 1450 | (684) | 0.348 | (86.5) | 59 | 54 | 50 | 44 | 40 | 34 | **24** | 63 | 57 | 53 | 48 | 43 | 39 | **27** | 67 | 61 | 56 | 51 | 47 | 44 | **31** |
| 5 | 12 | 420 | (198) | 0.014 | (3.4) | 38 | 37 | 34 | 32 | 26 | 20 | - | 41 | 40 | 38 | 35 | 30 | 25 | - | 44 | 43 | 42 | 38 | 33 | 30 | - |
| | | 840 | (396) | 0.055 | (13.7) | 49 | 45 | 41 | 38 | 33 | 28 | - | 52 | 48 | 45 | 41 | 37 | 33 | - | 55 | 51 | 49 | 44 | 40 | 38 | **23** |
| | | 1260 | (595) | 0.124 | (30.9) | 55 | 49 | 45 | 42 | 37 | 32 | - | 58 | 53 | 49 | 45 | 40 | 37 | **23** | 61 | 56 | 52 | 48 | 44 | 42 | **27** |
| | | 1680 | (793) | 0.221 | (54.9) | 59 | 53 | 47 | 44 | 40 | 35 | **21** | 62 | 56 | 51 | 47 | 43 | 40 | **26** | 66 | 59 | 55 | 51 | 47 | 46 | **30** |
| | | 2100 | (991) | 0.345 | (85.7) | 63 | 55 | 49 | 46 | 42 | 38 | **26** | 66 | 58 | 53 | 49 | 45 | 43 | **30** | 69 | 61 | 57 | 52 | 49 | 48 | **34** |
| 6 | 14 | 570 | (269) | 0.015 | (3.7) | 44 | 39 | 37 | 32 | 26 | 22 | - | 48 | 44 | 41 | 35 | 30 | 28 | - | 53 | 48 | 46 | 39 | 34 | 34 | - |
| | | 1140 | (538) | 0.059 | (14.7) | 53 | 47 | 44 | 39 | 34 | 28 | - | 57 | 51 | 48 | 42 | 38 | 34 | **22** | 62 | 56 | 53 | 46 | 42 | 40 | **27** |
| | | 1710 | (807) | 0.133 | (33.0) | 58 | 51 | 48 | 43 | 39 | 32 | **22** | 63 | 55 | 52 | 47 | 43 | 38 | **27** | 67 | 60 | 57 | 50 | 47 | 44 | **32** |
| | | 2280 | (1076) | 0.236 | (58.7) | 62 | 54 | 51 | 46 | 42 | 35 | **25** | 67 | 58 | 55 | 50 | 46 | 41 | **30** | 71 | 63 | 60 | 53 | 50 | 47 | **36** |
| | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | 16 | 740 | (349) | 0.014 | (3.5) | 49 | 43 | 40 | 36 | 31 | 27 | - | 54 | 49 | 46 | 43 | 39 | 37 | - | 60 | 55 | 52 | 50 | 46 | 47 | **27** |
| | | 1480 | (698) | 0.056 | (13.9) | 57 | 50 | 48 | 44 | 39 | 34 | **22** | 63 | 56 | 54 | 51 | 47 | 44 | **28** | 68 | 62 | 60 | 58 | 55 | 54 | **35** |
| | | 2220 | (1048) | 0.126 | (31.3) | 62 | 55 | 52 | 48 | 44 | 38 | **26** | 68 | 60 | 58 | 55 | 52 | 48 | **33** | 73 | 66 | 64 | 62 | 60 | 58 | **40** |
| | | 2960 | (1397) | 0.224 | (55.6) | 66 | 58 | 55 | 51 | 48 | 41 | **30** | 71 | 63 | 61 | 58 | 56 | 51 | **37** | 77 | 69 | 68 | 65 | 63 | 61 | **44** |
| | | 3700 | (1746) | 0.349 | (86.9) | 68 | 60 | 58 | 54 | 51 | 44 | **33** | 74 | 66 | 64 | 61 | 58 | 54 | **40** | 80 | 72 | 70 | 68 | 66 | 64 | **47** |

► *All sound data is based on tests conducted in accordance with ARI 880-98. ΔPs is the difference in static pressure from inlet to discharge. Sound power levels are in dB, re $10^{-12}$ watts. Radiated sound power is the sound transmitted through the casing walls. NC application data is from ARI Standard 885-98 Appendix E, as a function of flow rate shown. Dash (-) indicates a NC is less than 20. See K-Select for specific sound data for optional liners; 1/2" dual density liner shown. See Engineering section for reductions and definitions. ARI rating points based on 0.25" WG external pressure.*

### ▼ ARI CERTIFICATION RATING POINTS

| Unit Size | Inlet Size | Primary CFM | Min Δ Ps | Sound Power @ 1.5" Δ Ps 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 6 | 400 | 0.200 | 54 | 48 | 45 | 39 | 37 | 35 |
| 3 | 8 | 700 | 0.200 | 62 | 55 | 50 | 44 | 40 | 32 |
| 4 | 10 | 1100 | 0.200 | 63 | 57 | 51 | 45 | 42 | 40 |
| 5 | 12 | 1600 | 0.200 | 65 | 58 | 53 | 48 | 44 | 41 |
| 6 | 14 | 2100 | 0.200 | 70 | 60 | 56 | 50 | 47 | 42 |
| 7 | 16 | 2800 | 0.200 | 74 | 67 | 65 | 62 | 61 | 59 |

ARI PERFORMANCE CERTIFIED™
ARI Standard 880

## Figure 1: Overview of Design Brief Contents

This Design Brief is organized around key design considerations and components that affect the performance of VAV systems.