Architecture Engineering Developments

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*Copyright: 2014-2016 Paul Drake*
By: Bren Rasmussen, Libby Hungerford, Nick Delach, Paul Drake
ARE 4600 Fall 2013, Senior Design Project, Original design by: Christopher Hall
ARCHITECTURE

REFLECTION

We first chose this design because we wanted to expand upon it in a way that both improved the aesthetics and performance of the building. The most immediate change was combining the towers so that they became flush while absorbing the core within the tower. This posed many structural challenges due to the decreased core size as well as the slenderness of the taller tower. Another significant design change was the facade. We wanted to create a sleek and modern system that complemented both the lean of the towers as well as their slender appearances. The glass panels each are 5' wide by 14' tall and are shaped similar to the faces of the North and South elevations. We have designed the glass panels to be highly reflective, to add to the overall motif of the building. Each panel is connected to the slab edges by spider connections to eliminate harsh lines created by exterior mullions. The plaza echoes the towers in both form and style. The plaza has pronounced sharp angles and edges; since our tower looks unique from any and every angle, we wanted to design a plaza that also created countless views to admire from.

HOTEL GROSS SQFT: 300,000  OFFICE GROSS SQFT: 600,000

FLOOR PLAN

SITE PLAN

As the building ascends the hotel and office floor plates will shift right and left respectively. The office includes one large and small leasable office space available. The hotel includes 10,375 sqft rooms, and 3,750 sqft rooms. The 750 sqft rooms will be deluxe suites for exclusive guests attending events at the Pepsi Center. There are 5 elevators for both the office and hotel sections. Each section will also have one express elevator and one service elevator. The core provides the much needed space for both mechanical, electrical and plumbing chases.

The site was designed to reflect the crossing of the two towers. It will be a closed plaza with commercial space for vendors. As the tower meets the ground, the crossing of the tower is accentuated by the plaza’s reflection of the tower itself.
The lateral system for the Kross Tower consists of a 2' thick concrete core and outrigger trusses on the four mechanical floors. The core will resist the lateral loads on the building, and the outriggers will transfer portions of the load to the perimeter columns by acting as a lever arm and transferring the moment from the core to the columns. Under a lateral loading, the outriggers transfer the load to the columns on the windward side of the tower causing tension, while the columns on the leeward side will be in compression.

The Kross tower leans at 4° and 8°. Leaning columns are used on the leaning edges of the building, while vertical columns are used in the interior of the building. The P-Delta effects created by the tower’s lean cause shear and overturning moment on the building’s lateral system. To help counteract the overturning moment on the leaning columns, tensioning cables are used on all the mechanical floors that run horizontal between the downward leaning columns and the center vertical part of the building. The cables will reduce the overturning moment in the columns.

Examples of existing leaning towers are: the Capital Gate building, Abu Dhabi, and the Veer Towers in Las Vegas. Each leaning high rise uses a different approach to combat the structural challenges created by the building’s lean. Capital Gate uses a concrete core and exterior diagrid system to achieve the 18° lean. The core was precambered and designed to straighten during construction as the upper floors were added. The Veer Towers use a core with shear walls extending off of it for the lateral system. The gravity loads are carried to the ground by vertical interior columns and leaning exterior columns on the two leaning edges of the buildings. The leaning columns are constructed of W-shape steel members embedded in 5’ of concrete.

**Sources:**
10 Introduction to Outrigger Systems
The Learning Towers of Vegas
Case Study: Capital Gate, Abu Dhabi
Mechanical shafts in the core will house ducts, pipes, and electrical systems. The intermediate air handling units will be housed in the core also. These units will supply the variable air volume boxes. The VAV boxes supply separate zones on each floor. The supply plenum will be under the raised floor, and supply conditioned air to the spaces through the swirl diffusers on the floor. The return air will be collected at the ceiling and returned to the exterior through the façade cavity.

The multi-use space needed flexibility and lots of natural light. Usually, a façade composed of entirely glass leads to overheating, even in the winter. This concept led our team to adopting a double-skin, ventilated façade for our tower. Having a "buffer zone" between the exterior and interior climates lessens the heat gains in the tower from exterior conditions. The heat from the sun can be captured in the cavity and exhausted out of the tower before the heat gains are felt by the interior spaces. This allows for a passive system to keep heat gains from the sun down, while still giving the benefits of natural light for the interior spaces.

A double-skin, ventilated façade consists of 2 layers of glass. The inner layer is the “window” for the users of the building. The outer layer is the exterior of the building. The two layers are separated by an air cavity used to exhaust the hot air from the building and act as a "buffer zone." The Titus® swirl diffuser in the floor is controllable by the occupant. These diffusers would be spaced approximately every 4 square feet. A linear Titus® FlowBar Diffuser will act as the return air diffuser. The bar will be in the ceiling and in the inner face of the double-skin, ventilated façade.

**MECHANICAL FLOORS & ELEVATOR DIAGRAM**

The mechanical floors are located at Levels 17, 34, 47, and 61. A typical mechanical floor will house boilers, chillers, water softeners, pumps, 100% outside air handling units, and electrical equipment.

**DESIGN CONDITIONS**

**Outdoor Design Conditions**

<table>
<thead>
<tr>
<th>Season</th>
<th>Dry Bulb (°F)</th>
<th>Wet Bulb (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>-10</td>
<td>-</td>
</tr>
<tr>
<td>Summer</td>
<td>95</td>
<td>59</td>
</tr>
</tbody>
</table>

**Indoor Design Conditions**

<table>
<thead>
<tr>
<th>Space Occupancy</th>
<th>Temperature (°F)</th>
<th>Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Spaces</td>
<td>70</td>
<td>50% RH</td>
</tr>
<tr>
<td>Heating Degree Days</td>
<td>6000</td>
<td>750</td>
</tr>
<tr>
<td>Cooling Degree Days</td>
<td>750</td>
<td></td>
</tr>
</tbody>
</table>

**REFLECTION**

The multi-use space needed flexibility and lots of natural light. Usually, a façade composed of entirely glass leads to overheating, even in the winter. This concept led our team to adopting a double-skin, ventilated façade for our tower. Having a "buffer zone" between the exterior and interior climates lessens the heat gains in the tower from exterior conditions. The heat from the sun can be captured in the cavity and exhausted out of the tower before the heat gains are felt by the interior spaces. This allows for a passive system to keep heat gains from the sun down, while still giving the benefits of natural light for the interior spaces.

An under floor air distribution (UFAD) system works well with a double-skin, ventilated façade. The supply air in an UFAD system is low velocity high volume. The conditioned air is supplied at the floor from a pressurized plenum. The conditioned air can be supplied at a temperature closer to the design temperature because the air naturally mixes better. The stratification zone occurs at 4-6 ft above the floor. Once the air mixes, and is warmed by the space, it further stratifies and rises naturally, exhausting into the double skin, ventilated façade. The façade acts as a return air plenum for the return air from the conditioned space.

Since the return air plenum will discharge into the environment, the building will be conditioned with 100% outside air. This provides a greater indoor air quality within the conditioned spaces. The building will be regulated by a Building Management System (BMS). The BMS will consist of a control room and will monitor carbon monoxide levels, VOC’s, supply air temperature, space air temperature, and many other aspects of the building’s mechanical systems, including the lighting. The BMS will provide a greater overall control of the spaces and the energy uses. Having a BMS makes commissioning the building easier. Commissioning is often required with an underfloor air system to make sure the conditioned spaces are at the designed comfort levels.

**AIR FLOW & COMPONENTS**

A double-skin, ventilated façade consists of 2 layers of glass. The inner layer is the "window" for the users of the building. The outer layer is the exterior of the building. The two layers are separated by an air cavity used to exhaust the hot air from the building and act as a "buffer zone."
**WIND LOADS**

**WIND LOADS TO LEVELS**

<table>
<thead>
<tr>
<th>Wind Speed=</th>
<th>120</th>
<th>MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>F=APCd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P=</td>
<td>37</td>
<td>PSF</td>
</tr>
<tr>
<td>Cd=</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BLDG Length</th>
<th>74.5</th>
<th>ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1=</td>
<td>1118</td>
<td>ft²</td>
</tr>
<tr>
<td>A2=</td>
<td>2235</td>
<td>ft²</td>
</tr>
<tr>
<td>A3=</td>
<td>3278</td>
<td>ft²</td>
</tr>
<tr>
<td>A4=</td>
<td>4619</td>
<td>ft²</td>
</tr>
</tbody>
</table>

| F1=         | 82   | KIPS |
| F2=         | 165  | KIPS |
| F3=         | 242  | KIPS |
| F4=         | 341  | KIPS |

**COMPONENTS AND CLADDING PRESSURE**

Risk Category: III; Exposure Category: C; $K_{zt}$ Topo Category: = 1 (ASCE 7 26.8.2)

Effective Wall Wind Area = $15 \text{ ft} \times \frac{1}{3} \text{ span } (= 15')$ = 75 ft² (ASCE Pg. 243)

Effective Roof Wind Area = $35 \text{ ft} \times \frac{1}{3} \text{ span } (= 35')$ = 408 ft² (ASCE Pg. 243)

$p_{net} = \lambda K_{zt} p_{net30}$  

<table>
<thead>
<tr>
<th>Zone</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8.3</td>
<td>8.3</td>
<td>8.3</td>
<td>21.25</td>
<td>22.6</td>
</tr>
</tbody>
</table>

Corrected

|      | -36.261 | -42.993 | -42.993 | -37.944 | -42.993 |
|      | 12.699 | 12.699 | 12.699 | 32.5125 | 34.578 |

Mean Roof Height = 45 ft $\rightarrow \lambda = 1.53$ (ASCE 30.5.1)
# SNOW LOAD

## Center of Mass

<table>
<thead>
<tr>
<th></th>
<th>Rectangular</th>
<th>Approximate Curved Area</th>
<th>Total Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>74.5 x 190</td>
<td>14155 ft²</td>
<td>14610 ft²</td>
</tr>
<tr>
<td>F2</td>
<td>14155 ft²</td>
<td>455</td>
<td>14610 ft²</td>
</tr>
<tr>
<td>F3</td>
<td>14155 ft²</td>
<td>455</td>
<td>14610 ft²</td>
</tr>
<tr>
<td>F4</td>
<td>34.5 x 76</td>
<td>2622 ft²</td>
<td>3077 ft²</td>
</tr>
<tr>
<td>Σ</td>
<td></td>
<td></td>
<td>46907 ft²</td>
</tr>
</tbody>
</table>

## Ground Snow Load
- Ground Snow Load = 30 PSF

## Roof Snow Load
- Roof Snow Load = 30 PSF

## Drift Load
- Drift = 232 PSF

## Drift Calculation

### Flat Roof

- \( p_f = 0.7 C_e C_t p_g \)

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_e )</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( C_t )</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( I_s )</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( p_g )</td>
<td>30 PSF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( p_f )</td>
<td>20.79 PSF</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Drift Load = \( p_d = h_d y = h_d \cdot 0.426p_g + 2.2 \)

- Drift Check
  - \( h_c = 18 \) ft
  - \( h_d = 18 \) ft
  - \( hc/hb = 1 > 0.2 \)
  - Drift length = 8 ft

- Weight of Drift = 232 psf
## SEISMIC LOADS

### BASE SHEAR.

<table>
<thead>
<tr>
<th>Base Shear ($V_b$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CS=SDS/(R/I)$</td>
</tr>
<tr>
<td>SDS= 0.153</td>
</tr>
<tr>
<td>R= 3</td>
</tr>
<tr>
<td>I= 1.25</td>
</tr>
<tr>
<td>$CS= 0.06375$</td>
</tr>
<tr>
<td>$\Sigma = 215$ PSF</td>
</tr>
<tr>
<td>$W = \Sigma F_x$ kips</td>
</tr>
<tr>
<td>$W_1 = 3141$ kips</td>
</tr>
<tr>
<td>$W_2 = 3141$ kips</td>
</tr>
<tr>
<td>$W_3 = 3141$ kips</td>
</tr>
<tr>
<td>$W_4 = 3141$ kips</td>
</tr>
</tbody>
</table>

FROM SD:

<table>
<thead>
<tr>
<th>Floor Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. Structure</td>
</tr>
<tr>
<td>M/E/P</td>
</tr>
<tr>
<td>Ceiling</td>
</tr>
<tr>
<td>F1= 14610 ft²</td>
</tr>
<tr>
<td>F2= 14610 ft³</td>
</tr>
<tr>
<td>F3= 14610 ft⁴</td>
</tr>
<tr>
<td>F4= 3077 ft⁵</td>
</tr>
</tbody>
</table>

$V = CS*W$ kips
$V_1 = 200$ kips
$V_2 = 200$ kips
$V_3 = 200$ kips
$V_4 = 42$ kips

W = $\Sigma F_x$ kips
$W_1 = 3141$ kips
$W_2 = 3141$ kips
$W_3 = 3141$ kips
$W_4 = 3141$ kips
SHEAR DISTRIBUTION
## Rigidity Properties

<table>
<thead>
<tr>
<th>1st Floor</th>
<th>CR</th>
<th>CM</th>
<th>Eccentricity</th>
<th>Torsional Rigidity J (kip/ft²)</th>
<th>Direct Shear</th>
<th>Torsional Shear</th>
<th>Total Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>h (ft)</td>
<td>L</td>
<td>h/ L</td>
<td>(kip/ft n)</td>
<td>x (ft)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rx</td>
<td>3634</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ry</td>
<td>1640</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2nd Floor

<table>
<thead>
<tr>
<th>2nd Floor</th>
<th>CR</th>
<th>CM</th>
<th>Eccentricity</th>
<th>Torsional Rigidity J (kip/ft²)</th>
<th>Direct Shear</th>
<th>Torsional Shear</th>
<th>Total Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>h (ft)</td>
<td>L</td>
<td>h/ L</td>
<td>(kip/ft n)</td>
<td>x (ft)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rx</td>
<td>5503</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ry</td>
<td>2714</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Rigid Shear Distribution

<table>
<thead>
<tr>
<th>3rd Floor</th>
<th>Rigidity Properties</th>
<th>Direct Shear</th>
<th>Torsional Shear</th>
<th>Total Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>h (ft)</td>
<td>L (ft)</td>
<td>R (kip/in)</td>
<td>x (ft)</td>
</tr>
<tr>
<td>A</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>B</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>C</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>D</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>E</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>F</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>G</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>H</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>I</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>J</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td>K</td>
<td>14.</td>
<td>25.</td>
<td>0.</td>
<td>1215</td>
</tr>
<tr>
<td></td>
<td>Rx</td>
<td>5763</td>
<td>6103</td>
<td>1167</td>
</tr>
<tr>
<td></td>
<td>Ry</td>
<td>2873</td>
<td>106</td>
<td>41</td>
</tr>
</tbody>
</table>

**Note:** The table above lists the rigid shear distribution for each floor, including the components such as h, L, R, x, y, CR, CM, Eccentricity, J, Vb, Vd, Vdacc, and MT'. The total shear distribution is calculated for each floor, with Rx and Ry being the reactive forces at the base.
BEAM SIZE

Span: 25’ 6”
Spacing: 6’
Deck: Vulcraft 1.5F20
Slab: 4”

Strength Design:
Framing ~ 5 psf
Deck = 2.09 psf
Slab = 50 psf

$1\"$ concrete $= 12$ psf
$\Sigma = 69.09$ psf
$LL_c = 20$ psf

$$\omega_u = 1.2 D + 1.6 L$$
$$= 1.2 (69.09) + 1.6(20)$$
$$= 114.9 \text{ psf} = 689.5 \text{ plf}$$

$M_u = \frac{\omega_h l^2}{8} = 690 \times \frac{25.5^2}{8} = 56.1 \text{ kft}$

The assumed W21x44 has a capacity well above the required strength @ 112 kft for a 26ft span.

Reconsidering a W14 shape to accommodate depth

Beam Size from AISC pg. W14x34  $M_p = 63kft \ @ \ 26ft \ span; I = 340in^4$

Serviceability Design:

$$\frac{l}{180} \approx 1.7\"$$

$$l_{req} = \frac{0.69kf} * 22.5 * (25.5^4)}{29000 * (1.7\")} = 133.15in^4 \leq 340in^4 \rightarrow OK$$
GIRDER SIZE

Span: 34’ 6”
Deck: Vulcraft 1.5F20
Slab: 4”

Strength Design:
Framing ~ 5 psf
Deck = 2.09 psf
Slab = 50 psf

\[ \delta \text{ concrete} = 12 \text{psf} \]
\[ \Sigma = 69.09 \text{ psf} \rightarrow 1640.89 \text{ plf} \]

Girder Weight = 34 lb. ft. @ 5 girders \[ \rightarrow 5 \times \left( \frac{1}{2}(25.5' + 22') \right) \times 34 = 4037.5 \text{lb} \rightarrow \frac{4037.5}{34.5'} = 117 \text{lb ft} \]
\[ \Sigma = 1757.89 \text{ plf} \]

\[ LL_c = 20 \text{ psf} \rightarrow 475 \text{plf} \]

\[ \omega_u = 1.2D + 1.6L \]
\[ = 1.2 (1789.89) + 1.6(475) \]
\[ = 2869.5 \text{ plf} \]

\[ M_u = \frac{\omega_u l^2}{8} = 2870 \times \frac{34.5^2}{8} = 427 \text{ kft} \]

The assumed W21x44 has a capacity below the required strength @ 231 kft for a 36ft span.

Reconsidering a W27 shape to accommodate depth/strength req: depth + concrete/decking \leq 3ft

Beam Size from AISC pg. W27x161 \[ M_p = 429kft \ @ \ 36ft \ span; l = 6310 \text{in}^4 \]

Serviceability Design:

\[ \frac{l}{180} \approx 2.3'' \]

\[ l_{req} = \frac{2.870 \text{kfl} \times 22.5 \times (34.5^4)}{29000 \times (2.3'')} = 1371.56 \text{in}^4 \]

In hindsight, this is the largest spanning transfer girder in the design and could have been design more economically to have intermediate columns to transfer the gravity loads. Thus greatly reducing the girder size.
OPEN WEB BAR JOIST SIZE

Open Web Bar Joist

1.5F Deck

Live
Snow 30 psf

⇒ F20 @ 6’6” spans

Joist for Regular Roof

Live
30 psf (11') = 330 PLF

Dead
2.09 psf (11') = 23 PLF

= 353 PLF

Use Economical Joist Guide for 40’ length

⇒ 324#7

We realize that this conflicts with the joists we put in our model but there were errors in our first calculations.
COLUMN SIZE

Tributary Area per Floor:

\[ A = \frac{1}{2} (12' + 26') \times \frac{1}{2} (24' + 26' + 8.5') = 555.75 \text{ ft}^2 \]

Loads:

Decking Loads: Using 1.5F20 W=2.09 psf

Concrete Slab: 4” SOD @ 150 \( \frac{\text{lb}}{\text{ft}^3} \) = 50 \( \frac{\text{lb}}{\text{ft}^2} \)

Framing: 5 psf

\[ \Sigma = 57 \text{ psf} \]

Beams: Using 21x44 = 44 plf

5.5 beams perpendicular to H gridline, 1 parallel

5.5 beams \( \times (13' + 7.75') + 1 \times 22.5' = 126.25 \text{ ft} \)

104 \times 44 \( \frac{\text{lb}}{\text{ft}} \) = 6011.5 \( \frac{\text{lb}}{\text{floor}} \)

Mechanical Penthouse Floor Beams:

4 beams \( \times 20.75 + 1 \times 16.5 = 99.5 \text{ ft} \)

99.5 \times 44 \( \frac{\text{lb}}{\text{ft}} \) = 4378 lb

Roof Supports:

2 Types: 24k4 W=7.8 plf \( \times 3 \) Joists\( \times 7.8 \frac{\text{lb}}{\text{ft}} \) \( \times 16.5' = 386.1 \text{ lb} \)

20k3 W=6.5 plf \( \times 3 \) Joists\( \times 6.5 \frac{\text{lb}}{\text{ft}} \) \( \times 6' = 117 \text{ lb} \)

\( LL = 50\text{psf} \)

Roof Live Load: 20psf

Snow Load: 30psf

Mech. Equipment: 150 psf

Load Case: \( P_n = 1.2D + 1.6L \)

Roof Load Case \( P_n = 1.2D + 1.6S + L \)

\[ \Phi_cP_n = \Phi_c((1.2((\text{Decking + slab + framing}) + \text{Beams + Joists} + \text{Mech. Equip. psf}) \times A + 1.6 (L.L.c or S for roof) \times A ) \]

\[ = \Phi_c((1.2 \times 57 + 1.6 \times 50)555.75 \times 3 \text{ floors} + 1.2(6011.5 \times 3 \text{ floors} + 4378 + 386.1 + 117) + 1.2 \times 150 \times 293.25 + (1.2 \times 57 + 1.6 \times 30 + 20) \times 555.75 ) \]

\[ = \Phi_c(435520 \text{ lb}) = 0.9(435.5 \text{ kip}) = 392\text{kip} \]

AISC: W12x53 has \( \Phi_cP_n = 478 \text{ kip} \) for unbraced 15’ effective length.
INTERIOR FOOTING SIZE & REINFORCEMENT

Column 6-3

Allowable soil bearing pressure = 2000 psf

Load

Dead

- Office: 50 psf
- Partition: 20 psf
- Superimpose: 15 psf
- L/M/E: 10 psf

95 psf = 100 psf

Tributary Area

\[ \text{Tb} = 886 \text{ ft}^2 \text{ for 1 floor} \]
\[ \frac{x}{1769 \text{ ft}^2} \]
\[ \frac{x}{100 \text{ psf}} \]
\[ \frac{176900 \text{ lbs}}{177 \text{ kips}} \]

\[ \text{Tb} = 885 \text{ ft}^2 \]
\[ \frac{x}{82.09 \text{ psf}} \rightarrow \text{roof live load} \]
\[ \frac{28,400 \text{ lbs}}{28 \text{ kips}} \]

Total load on footing = 205 kips

Our footings are 18" deep

\[ W_c - f_a = 150 \text{ psf} \times (1.5') = 225 \text{ psf} \]

\[ W_s = f_s d_s = (115 \text{ psf}) \times (4' - 1.5') = 287.5 \text{ psf} \]

\[ q_{\text{eff}} = q_s - W_c - W_s = 3000 - 225 - 287.5 = 2487.5 \text{ psf} \]

\[ \text{Area of footing} \]

\[ \frac{205 \text{ kips}}{2499 \text{ kips}} = 82.3 \text{ ft}^2 \Rightarrow \text{Foot ing side} = 9.1 \text{ ft} \]

50psi 10ft
**Actual Loads** =

\[ DL = 50 \text{ psf} + 15 \text{ psf} + 10 \text{ psf} + 5 \text{ psf} \times 885 \times 2 \]
\[ = 2916 \text{k} \]

\[ UL = 20 \text{ psf} \times 885 \times 2 \times 35 \times 2 \]
\[ = 186 \text{k} \]

Actual Loads = 1.4DL + UL
\[ = 1.4(2916) + 186 \text{k} = 2916 \text{k} \]

\[ q_{in} = \frac{2916 \text{k}}{100 \text{ ft}^2} = 29.16 \text{k} / \text{ft}^2 \]

\[ d = h - \text{cover} - 1.5d_b \]
\[ = 18 - 3 \text{ in} - 1.5(1.0) \]
\[ = 13.5 \text{ in} \]

\[ c = 10 \text{ in} \]

\[ b_s = 4(c+d) = 4(10 \text{ in} + 13.5 \text{ in}) = 94 \text{ in} \]

\[ c + d = (10 \text{ in} + 13.5 \text{ in})(1\frac{1}{2}) = 23.75 \text{ ft} \]

\[ V_u = P_u - q_{in} (c+d)^2 \]
\[ = 2916 - 29.16(23.75)^2 = 185 \]

\[ \beta = \frac{10 \text{ ft}}{10 \text{ ft}} = 1 \]
Interior Footing Design Column E-3

\[ d = \frac{V_{Mu}}{\phi 4nF_c b_0} = \frac{7.85 (1800)}{0.85(4)4500(94)} \]
\[ d = 3.3 \text{ in} \]

\[ d = \frac{785000}{0.85 \left( \frac{10(13.5)}{94} \right) + 2} \left( \frac{4500}{94} \right) = 16.87 \text{ in} \]
\[ d = \frac{V_{Mu}}{\phi 2\sqrt{1-k}} = 20.8 \]

\[ 20.8 > 18.5 \Rightarrow \text{so use } a = 18 \text{ in} \]

\[ M_n = 9n \left( \frac{b - c}{2} \right) \left( \frac{L - c}{2} \right) b = 2.91 \times 10^5 \left( \frac{10}{2} - \frac{10}{2} \right) \left( \frac{10 - 10/2}{2} \right) \]
\[ M_n = 311 \text{ k-ft} \]

\[ R_n = \frac{M_n}{b'd'} = \frac{311}{10 \times 9.8} = 3.2 \text{ ksf} \]

\[ w = 1.1 - \sqrt{1.7^2 - 4 \left( 1.1 \frac{0.9(18)}{6(18)} \right)} = 0.08452 \]

\[ \rho f_u = \frac{f_{c'}}{f'_c} = 1.5 (0.06452) = 0.05289 \]

\[ A_5 = 0.00289 (10)(18) = 5.11 \text{ in}^2 \]

\[ #7 \quad A = 0.09 \text{ in}^2 \]

\[ \frac{5.11}{0.6} = 8.51 \text{ in}^2 \]
COLUMN BASE PLATE

Concentric Axial Compressive Load with concrete confinement for a W12x53 beam

Required axial compressive strength: \( P_u = 392 \) kips

Required base plate area with strength increase for concrete confinement:

\[
A_{1, \text{req}} = \frac{P_u}{2\Phi_c 0.85 f'_c} = \frac{392}{2(0.65)0.85 (3 \text{ksi})} = 118.25 \text{ in}^2
\]

Optimize base plate dimensions, N & B

\[
\Delta = \frac{0.95d - 0.8b_f}{2} = \frac{0.95(12.1) - 0.8(10.0)}{2} = 1.7475 \text{ in.}
\]

\[
N \approx \sqrt{A_{1, \text{req}} + \Delta} = \sqrt{118.25 + 1.75} = 12.62 \text{ in.}
\]

Try N = 14 in. \( \Rightarrow B = \frac{118.25 \text{ in}^2}{14 \text{ in}} = 8.4464 \text{ in.} \)

Try B = 12 \( \Rightarrow A_1 = 14 \times 12 = 168 \text{ in}^2 > 118.25 \text{ in}^2 \text{ o.k.} \)

\[
N_2 = 120 \text{ in.}
\]

\[
\text{Ratio: } \frac{B}{N} = \frac{8.45}{12.67} = 0.6663 \text{ in.}
\]

\[
B_2 = 0.666 \times 120 \text{ in.} = 79.92 \text{ in.}
\]

\[
A_2 = 120 \times 79.92 = 9590.4 \text{ in}^2
\]

9590 \text{ in}^2 = 4A_1 = 4 \times 168 = 672 \text{ in}^2 \Rightarrow \text{AISC 3.1 Case II applies.}

\( R_u \leq \phi_c P_p = 2\phi_c f'_c A_1 = 2 \times 0.65 \times 0.85 \times 3 \text{ ksi} \times (168 \text{ in}^2) = 556.9 \text{ kips} > 392 \text{ kips o.k.} \)

Req’d base plate thickness:

\[
m = \frac{N - 0.95d}{2} = \frac{14 - 0.95 \times 12.1}{2} = 1.25 \text{ in.}
\]

\[
n = \frac{B - 0.8b_f}{2} = \frac{12 - 0.8 \times 10.0}{2} = 2.0 \text{ in.}
\]

\[
X = \left[ \frac{4db_f}{(d + b_f)^2} \right] \frac{P_u}{\phi P_p} = \left[ \frac{4 \times 12.1 \times 10.0}{(12.1 + 10.0)^2} \right] \frac{392}{557} = 0.704
\]

\[
\lambda = \frac{2\sqrt{X}}{1 + \sqrt{1 - X}} \leq 1
\]

\[
\lambda = \frac{2\sqrt{0.704}}{1 + \sqrt{1 - 0.704}} = 1.086 \rightarrow 1
\]

\[
\lambda n' = \lambda \frac{\sqrt{db_f}}{4} = (1) \frac{\sqrt{12.1 \times 10.0}}{4} = 2.75 \text{ in.}
\]

\[
l = \max(m, n, \lambda n') = \max(1.25, 2.0, 2.75) = 2.75 \text{ in.}
\]

\[
t_{\text{min}} = l \frac{2P_u}{\phi P_p BY N} = (2.75) \frac{2 \times 392 \text{ kips}}{(0.9)(36 \text{ ksi})12 \times 14} = 1.04 \text{ in.} \Rightarrow \text{Use } 1 \frac{1}{4} \text{ in.}
\]
Concrete Base Plate Continued:

Concrete embedment strength:
\[
\phi N_{cb} = \phi \psi 24 \sqrt{f'_c} h_{sf}\frac{A_N}{A_{No}} = 0.7 \times 1.25 \times 24 \sqrt{3000} \times 6^{1.5} \text{(for uncracked concrete)} = 16.9 \text{ kips}
\]

Tensile Strength of a 1 ½ in. anchor rod: 
\[R_n = 0.75 F_u A_p = 0.75 \times 58 \text{ ksi} \times 1.77 \text{ in}^2 = 76.99 \text{ kips}\]

Available Tensile Strength:
\[\phi R_n = 0.75 \times R_n = 0.75 \times 77 = 57.75 \text{ kips}\]

\[f_{ta} = \frac{P_{u\text{max}}}{A} = \frac{392}{12(1.77 \text{ in}^2)} = 18.46 \text{ ksi}\]

\[M_t = 42 \text{ kips} \times \frac{\left(t_{\text{min}}(= 1.25\text{"}) + 0.25\text{" (plate washer)}\right)}{2} = 7.875 \text{ ksi}\]

\[Z = \frac{d^3}{6} = \frac{1.5^3}{6} = 0.563 \text{ in}^3\]

\[f_{tb} = \frac{M_t}{Z} = \frac{7.875}{0.563} = 13.99 \text{ ksi}\]

\[f_t = f_{ta} + f_{tb} = 18.46 + 13.99 = 32.45 \text{ ksi}\]

\[\phi F_{nt}' = \phi \left[1.3 F_{nt} - \frac{F_{nt}}{\phi F_{nv}} f_v\right] \leq \phi F_{nt}\]

\[F_{nt} = 0.75 F_u = 0.75 \times 58 \text{ ksi} = 43.5 \text{ ksi}\]

\[F_{nv} = 0.4 F_u = 0.4 \times 58 \text{ ksi} = 23.2 \text{ ksi (Threads: N)}\]

\[f_v = \frac{42 \text{ kips}}{12 \times 1.77\text{ in}^2} = 1.98 \text{ ksi}\]

\[\phi F_{nt}' = 0.75 \left[1.3 \times 43.5 - \frac{43.5}{0.75 \times 23.2} \times 1.98\right] = 38.7 \text{ ksi}\]

38.7 ksi $\geq$ 0.75 x 43.5 ksi = 32.6 ksi $\rightarrow$ Use 32.6 ksi

$32.45 \text{ ksi} < 32.6 \text{ ksi o.k.}$
BEAM TO GIRDER CONNECTION

Using the calculated beam and girder sizes and support reactions from above:

Beam: W14x34  ASTM A992  $t_w = 0.285$ in.
Girder: W27x161 ASTM A992  $t_w = 0.660$ in.

$$R_u = \frac{\omega \Delta}{2} = \frac{690 \text{ ptf} \times 25.5'}{2} = 8.8 \text{ kips}$$

Try All-Bolted Double Angle @ ¼ in. thick, $F_y = 36 \text{ ksi}$, & 3 – ¾ in. bolts: (ASCE 10-1)

$\Phi R_n = 76.4 \text{ kips} > 8.8 \text{ kips}$ o.k.

Uncoped, $L_{eh} = 1 \frac{1}{2}$ in.

$\Phi R_n = 263 \text{ kips}(0.285\text{ in.}) = 74.96 \text{ kips} > 8.8 \text{ kips}$ o.k.

Bolt bearing:

$\Phi R_n = 526 \text{ kips}(0.660\text{ in.}) = 347.16 \text{ kips} > 8.8 \text{ kips}$ o.k.

GIRDER TO COLUMN CONNECTION

Using the calculated beam and girder sizes and support reactions from above:

Girder: W21x44 ASTM A992  $t_w = 0.350$ in.
Column: W12x53 ASTM A992  $t_f = 0.345$ in.

$$R_u = \frac{2900 \text{ ptf} \times 30'}{2} = 43.5 \text{ kips}$$

Try All-Bolted Double Angle @ ¼ in. thick, $F_y = 36 \text{ ksi}$, & 4 – ¾ in. bolts: (ASCE 10-1)

$\Phi R_n = 101 \text{ kips} > 43.5 \text{ kips}$ o.k.

Uncoped, $L_{eh} = 1 \frac{1}{2}$ in.

$\Phi R_n = 351 \text{ kips}(0.350\text{ in.}) = 122.85 \text{ kips} > 43.5 \text{ kips}$ o.k.

Bolt bearing:

$\Phi R_n = 702 \text{ kips}(0.345\text{ in.}) = 242.2 \text{ kips} > 43.5 \text{ kips}$ o.k.
EXTERIOR COLD-FORMED STEEL STUD SIZE

Using SSMA Technical Guide – Curtain Wall Limiting Heights for a Single Span pg. 25

P = 37 psf from Wind Load Calculations;
15’ min span height
Studs on 16” centers typ.;
Using L/360 deflection

SSMA designates *600S162-54 50ksi* cold formed steel stud as the minimally compliant sizing.
This is a 50 ksi steel stud member, with a web depth of 6”, a flange width of \( \frac{5}{8} “ \), and thickness of 54 mils.
GENERAL NOTES

1. GENERAL Notes:
   - All notes are understood to be supplemental to the structural drawings. 
   - These notes shall be unambiguous and shall cover changes and additions to the structural design.
   - All notes shall be understood to be a part of the contract documents and shall be part of the contract documents.
   - All notes shall be understood to be a part of the contract documents and shall be part of the contract documents.

2. General Requirements:
   - The structural engineer shall be responsible for the design of all structural elements.
   - The structural engineer shall be responsible for the design of all structural elements.

3. General Notes:
   - All notes shall be understood to be a part of the contract documents.
   - All notes shall be understood to be a part of the contract documents.

4. General Notes:
   - All notes shall be understood to be a part of the contract documents.
   - All notes shall be understood to be a part of the contract documents.

5. General Notes:
   - All notes shall be understood to be a part of the contract documents.
   - All notes shall be understood to be a part of the contract documents.

6. General Notes:
   - All notes shall be understood to be a part of the contract documents.
   - All notes shall be understood to be a part of the contract documents.

7. General Notes:
   - All notes shall be understood to be a part of the contract documents.
   - All notes shall be understood to be a part of the contract documents.

8. General Notes:
   - All notes shall be understood to be a part of the contract documents.
   - All notes shall be understood to be a part of the contract documents.

9. General Notes:
   - All notes shall be understood to be a part of the contract documents.
   - All notes shall be understood to be a part of the contract documents.

10. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

11. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

12. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

13. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

14. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

15. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

16. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

17. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

18. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

19. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.

20. General Notes:
    - All notes shall be understood to be a part of the contract documents.
    - All notes shall be understood to be a part of the contract documents.
CONCRETE DESIGN CRITERIA & NOTES

1. GENERAL:
   1A. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete and the latest edition of ACI 318 - Building Code Requirements for Structural Concrete and the latest edition of ACI 301 - Building Code Requirements for Structural Concrete.
   1B. Field mixing is not permitted. A special mixing and placing permit must be obtained prior to the start of construction.

2. REINFORCING STEEL:
   2A. All reinforcement shall be cold drawn and straightened. The minimum yield strength shall be 60,000 psi. The maximum tensile strength shall be 70,000 psi. The maximum elongation at break shall be 10%.
   2B. All reinforcement shall be deformed bar reinforcement. The minimum bar size shall be 1/2 inch. The maximum bar size shall be 2 inches.
   2C. All reinforcement shall be of the same size and shape. The maximum number of bars in a given area shall not exceed 8 bars.
   2D. All reinforcement shall be placed in accordance with the construction drawings and specifications.

3. CEMENT AND AGGREGATES:
   3A. All cement shall be Type I or Type II portland cement. The minimum cement content shall be 500 psi. The maximum water-cement ratio shall be 0.5.
   3B. All aggregates shall be clean and free of debris. The maximum size of aggregate shall be 1 inch.
   3C. All aggregates shall be of the same size and shape. The maximum number of aggregate sizes in a given area shall not exceed 3 sizes.

4. PLACING AND FINISHING:
   4A. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum slump shall be 4 inches. The maximum slump shall be 8 inches.
   4B. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum compaction effort shall be 2000 pounds per square inch. The maximum compaction effort shall be 3000 pounds per square inch.
   4C. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum finishing shall be done with a trowel. The maximum finishing shall be done with a float.

5. Curing:
   5A. All concrete shall be cured in accordance with the construction drawings and specifications. The minimum curing time shall be 7 days. The maximum curing time shall be 14 days.
   5B. All concrete shall be cured in accordance with the construction drawings and specifications. The minimum curing temperature shall be 50°F. The maximum curing temperature shall be 100°F.
   5C. All concrete shall be cured in accordance with the construction drawings and specifications. The minimum curing humidity shall be 50%. The maximum curing humidity shall be 90%.

6. STRENGTH ANDDurability:
   6A. All concrete shall conform with the latest edition of ACI 318 - Building Code Requirements for Structural Concrete. The minimum concrete strength shall be 2000 psi. The maximum concrete strength shall be 4000 psi.
   6B. All concrete shall conform with the latest edition of ACI 318 - Building Code Requirements for Structural Concrete. The minimum durability shall be 75%. The maximum durability shall be 90%.

7. DESIGN CRITERIA:
   7A. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete. The minimum design criteria shall be 1.5. The maximum design criteria shall be 2.0.
   7B. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete. The minimum load factor shall be 1.0. The maximum load factor shall be 1.5.
   7C. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete. The minimum safety factor shall be 2.0. The maximum safety factor shall be 3.0.

8. QUALITY CONTROL:
   8A. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum quality control checks shall be performed. The maximum quality control checks shall be performed.
   8B. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum quality control reports shall be submitted. The maximum quality control reports shall be submitted.
   8C. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum quality control inspections shall be performed. The maximum quality control inspections shall be performed.

FOUNDER DESIGN CRITERIA & NOTES

1. GENERAL:
   1A. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete. The minimum design criteria shall be 1.5. The maximum design criteria shall be 2.0.
   1B. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete. The minimum load factor shall be 1.0. The maximum load factor shall be 1.5.
   1C. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete. The minimum safety factor shall be 2.0. The maximum safety factor shall be 3.0.

2. FOUNDATION WALLS:
   2A. All foundation walls shall be designed in accordance with the construction drawings and specifications. The minimum wall thickness shall be 12 inches. The maximum wall thickness shall be 24 inches.
   2B. All foundation walls shall be designed in accordance with the construction drawings and specifications. The minimum wall height shall be 8 feet. The maximum wall height shall be 16 feet.
   2C. All foundation walls shall be designed in accordance with the construction drawings and specifications. The minimum wall length shall be 20 feet. The maximum wall length shall be 50 feet.

3. REINFORCING STEEL:
   3A. All reinforcing steel shall be designed in accordance with the construction drawings and specifications. The minimum reinforcing steel shall be 60,000 psi. The maximum reinforcing steel shall be 70,000 psi.
   3B. All reinforcing steel shall be designed in accordance with the construction drawings and specifications. The minimum reinforcing steel shall be deformed bar reinforcement. The maximum reinforcing steel shall be deformed bar reinforcement.
   3C. All reinforcing steel shall be designed in accordance with the construction drawings and specifications. The minimum reinforcing steel shall be of the same size and shape. The maximum reinforcing steel shall be of the same size and shape.

4. PLACING AND FINISHING:
   4A. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum slump shall be 4 inches. The maximum slump shall be 8 inches.
   4B. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum compaction effort shall be 2000 pounds per square inch. The maximum compaction effort shall be 3000 pounds per square inch.
   4C. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum finishing shall be done with a trowel. The maximum finishing shall be done with a float.

5. Curing:
   5A. All concrete shall be cured in accordance with the construction drawings and specifications. The minimum curing time shall be 7 days. The maximum curing time shall be 14 days.
   5B. All concrete shall be cured in accordance with the construction drawings and specifications. The minimum curing temperature shall be 50°F. The maximum curing temperature shall be 100°F.
   5C. All concrete shall be cured in accordance with the construction drawings and specifications. The minimum curing humidity shall be 50%. The maximum curing humidity shall be 90%.

6. STRENGTH AND Durability:
   6A. All concrete shall conform with the latest edition of ACI 318 - Building Code Requirements for Structural Concrete. The minimum concrete strength shall be 2000 psi. The maximum concrete strength shall be 4000 psi.
   6B. All concrete shall conform with the latest edition of ACI 318 - Building Code Requirements for Structural Concrete. The minimum durability shall be 75%. The maximum durability shall be 90%.
   6C. All concrete shall conform with the latest edition of ACI 318 - Building Code Requirements for Structural Concrete. The minimum cycling resistance shall be 75%. The maximum cycling resistance shall be 90%.

7. QUALITY CONTROL:
   7A. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum quality control checks shall be performed. The maximum quality control checks shall be performed.
   7B. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum quality control reports shall be submitted. The maximum quality control reports shall be submitted.
   7C. All concrete shall be placed in accordance with the construction drawings and specifications. The minimum quality control inspections shall be performed. The maximum quality control inspections shall be performed.

8. DESIGN CRITERIA:
   8A. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete. The minimum design criteria shall be 1.5. The maximum design criteria shall be 2.0.
   8B. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete. The minimum load factor shall be 1.0. The maximum load factor shall be 1.5.
   8C. All work shall conform with the latest edition of ASCE 318 - Building Code Requirements for Structural Concrete. The minimum safety factor shall be 2.0. The maximum safety factor shall be 3.0.
SLABS−ON−GRADE:
1. SEE REFERENCE DETAIL KEY BELOW FOR TYPICAL REQUIREMENTS OF SLAB−ON−GRADE CONSTRUCTION.
2. SEE ARCHITECTURAL AND MECHANICAL DRAWINGS FOR SLAB SLOPES, DEPRESSIONS, FILL, PADS, AND CURBS NOT SHOWN ON THE STRUCTURAL DRAWINGS.

FOOTINGS:
1. SEE REFERENCE DETAIL KEY BELOW FOR TYPICAL REQUIREMENTS OF FOOTING CONSTRUCTION.
2. TOP OF FOOTING ELEVATION (T.O.F.) = 96'−0", TYP U.N.O.
3. ALL FOOTINGS AND COLUMNS ARE CENTERED ON GRIDS UNLESS DIMENSIONED OTHERWISE.

FOUNDATION WALLS:
1. SEE REFERENCE DETAIL KEY BELOW FOR TYPICAL REQUIREMENTS OF FOUNDATION WALL CONSTRUCTION.
2. TOP OF FOUNDATION WALL ELEVATION (T.O.W.) = 100'−0", TYP U.N.O.
3. TOP OF PILASTER ELEVATION (T.O.C.) = 99'−4", TYP U.N.O.
4. COORDINATE ALL T.O.W. BLOCKOUTS AND DEPRESSIONS W/ ARCHITECTURAL PLANS.

FOUNDATION PLAN NOTES
GLASS OR GLASS TEAM:
1. SEE REFERENCE DETAIL KEY BELOW FOR TYPICAL REQUIREMENTS OF GLASS OR GLASS TEAM.
2. SEE ARCHITECTURAL AND MECHANICAL DRAWINGS FOR GLASS OR GLASS TEAM.
3. TYPICAL ELEVATIONS FOR GLASS OR GLASS TEAM SHOWN ON THE STRUCTURAL DRAWINGS.

FOUNDATION LEGEND
SYMBOL DESCRIPTION
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
DECK TYPE
DECK SPAN DIRECTION
SLAB TYPE
SLAB THICKNESS
T/SLAB AT SLAB−ON−DECK
TOP OF FOOTING ELEVATION
TOP OF FOUNDATION ELEVATION
STEEL FRAMING PLAN NOTES
BEAMS:
1. SEE PLAN FOR TOP OF STEEL ELEVATION (T.O.S.).
2. BEAMS ARE EQUALLY SPACED BETWEEN GRID LINES OR ALONG GIRDER UNLESS DIMENSIONS OTHERWISE.
3. DIMENSIONS ARE TO CENTERLINE OF MEMBER UNLESS NOTED OTHERWISE. CHANNELS ARE DIMENSIONED TO FACE OF HEEL SIDE.

COLUMNS:
1. ALL COLUMNS CENTERED ON THE INTERSECTION OF GRIDLINES UNLESS DIMENSIONED OTHERWISE.

JOISTS:
1. JOISTS ARE EQUALLY SPACED BETWEEN GRID LINES OR ALONG GIRDER UNLESS DIMENSIONED OTHERWISE.
2. JOIST BEARING SEATS SHALL HAVE THE FOLLOWING DEPTH UNLESS NOTED OTHERWISE:
   - 'K' SERIES = 3".

METAL DECK:
1. WHERE BEAMS SUPPORT DECK DIRECTLY TOP OF STEEL ELEVATION IS AT BOTTOM OF DECK UNLESS NOTED OTHERWISE.
2. WHERE BEAMS SUPPORT JOISTS TOP OF STEEL IS AT JOIST BEARING UNLESS NOTED OTHERWISE.
3. TOS ELEVATION = BOTTOM OF DECK UNO. MEMBERS SPANNING BETWEEN OR PERPENDICULAR TO LABELED ELEVATIONS (SLOPED MEMBERS) SHALL FOLLOW THE DECK PLANE ESTABLISHED BETWEEN MEMBER WITH MARKED ELEVATIONS.
4. NOT ALL OPENINGS IN METAL DECK FLOOR SLABS & ROOFS ARE SHOWN ON PLAN. SEE ARCH & MEP DRAWINGS FOR SIZE, LOCATION & QUANTITY OF OPENINGS NOT SHOWN.
STEEL FRAMING PLAN NOTES

BEAMS:
1. SEE PLAN FOR TOP OF STEEL ELEVATION (T.O.S.).
2. BEAMS ARE EQUALLY SPACED BETWEEN GRID LINES OR ALONG GIRDER UNLESS DIMENSIONS OTHERWISE.
3. DIMENSIONS ARE TO CENTERLINE OF MEMBER UNLESS NOTED OTHERWISE. CHANNELS ARE DIMENSIONED TO FACE OF HEEL SIDE.

COLUMNS:
1. ALL COLUMNS CENTERED ON THE INTERSECTION OF GRIDLINES UNLESS DIMENSIONED OTHERWISE.

JOISTS:
1. JOISTS ARE EQUALLY SPACED BETWEEN GRID LINES OR ALONG GIRDER UNLESS DIMENSIONED OTHERWISE.
2. JOIST BEARING SEATS SHALL HAVE THE FOLLOWING DEPTH UNLESS NOTED OTHERWISE:
   - 'K' SERIES = 3"

METAL DECK:
1. WHERE BEAMS SUPPORT DECK DIRECTLY TOP OF STEEL ELEVATION IS AT BOTTOM OF DECK UNLESS NOTED OTHERWISE.
2. WHERE BEAMS SUPPORT JOISTS TOP OF STEEL IS AT JOIST BEARING UNLESS NOTED OTHERWISE.
3. TOS ELEVATION = BOTTOM OF DECK UNLESS MEMBERS SPANNING BETWEEN OR PERPENDICULAR TO LABELED ELEVATIONS (SLOPED MEMBERS) SHALL FOLLOW THE DECK PLANE ESTABLISHED BETWEEN MEMBERS WITH MARKED ELEVATIONS.
4. NOT ALL OPENINGS IN METAL DECK FLOOR SLABS & ROOFS ARE SHOWN ON PLAN. SEE ARCH & MEP DRAWINGS FOR SIZE, LOCATION & QUANTITY OF OPENINGS NOT SHOWN.

FRAMING PLAN LEGEND

DECK TYPE
20K3X.XXA
DISPLAY CONCRETE THICKNESS

SYMBOL
DESCRIPTION
KEY PLAN

MARIAN H. ROCHELLE GATEWAY CENTER
THIRD FLOOR FRAMING PLAN

Drake, Lange & Wessel Engineering
1000 E. Ivins Street
Laramie, Wyoming
Phone: (307) 555-4321

Revisions
NORTH 06-11-13

Project Number
MARIAN H. ROCHELLE GATEWAY CENTER

100% CONSTRUCTION DESIGN

H:\Personal\Gateway Center_pdrake2@uwyo.edu.rvt
STEEL FRAMING PLAN NOTES

BEAMS:
1. SEE PLAN FOR TOP OF STEEL ELEVATION (T.O.S.).
2. BEAMS ARE EQUALLY SPACED BETWEEN GRID LINES OR ALONG GIRDER UNLESS DIMENSIONS OTHERWISE.
3. DIMENSIONS ARE TO CENTERLINE OF MEMBER UNLESS NOTED OTHERWISE. CHANNELS ARE DIMENSIONED TO FACE OF HEEL SIDE.

COLUMNS:
1. ALL COLUMNS CENTERED ON THE INTERSECTION OF GRIDLINES UNLESS DIMENSIONED OTHERWISE.

JOISTS:
1. JOISTS ARE EQUALLY SPACED BETWEEN GRID LINES OR ALONG GIRDER UNLESS DIMENSIONED OTHERWISE.
2. JOIST BEARING SEATS SHALL HAVE THE FOLLOWING DEPTH UNLESS NOTED OTHERWISE:
   - 'K' SERIES = 3"

METAL DECK:
1. WHERE BEAMS SUPPORT DECK DIRECTLY TOP OF STEEL ELEVATION IS AT BOTTOM OF DECK UNLESS NOTED OTHERWISE.
2. WHERE BEAMS SUPPORT JOISTS TOP OF STEEL IS AT JOIST BEARING UNLESS NOTED OTHERWISE.
3. T.O.S ELEVATION = BOTTOM OF DECK UNO. MEMBERS SPANNING BETWEEN OR PERPENDICULAR TO LABELED ELEVATIONS (SLOPED MEMBERS) SHALL FOLLOW THE DECK PLANE ESTABLISHED BETWEEN MEMBER WITH MARKED ELEVATIONS.
4. NOT ALL OPENINGS IN METAL DECK FLOOR SLABS & ROOFS ARE SHOWN ON PLAN. SEE ARCH & MEP DRAWINGS FOR SIZE, LOCATION & QUANTITY OF OPENINGS NOT SHOWN.

FRAMING PLAN LEGEND

SYMBOL DESCRIPTION

DECK TYPE: ABOVE DECK CONCRETE THICKNESS

TYPE

STANDARD EXCEEDS 100% DESIGN
STEEL FRAMING PLAN NOTES

BEAMS:
1. SEE PLAN FOR TOP OF STEEL ELEVATION (T.O.S.).
2. BEAMS ARE EQUALLY SPACED BETWEEN GRID LINES OR ALONG GIRDERS UNLESS DIMENSIONS OTHERWISE.
3. DIMENSIONS ARE TO CENTERLINE OF MEMBER UNLESS NOTED OTHERWISE. CHANNELS ARE DIMENSIONED TO FACE OF HEEL SIDE.

COLUMNS:
1. ALL COLUMNS CENTERED (CENTER LINE OF GRID INTERSECTION UNLESS DIMENSIONS OTHERWISE).

JOISTS:
1. JOISTS ARE EQUALLY SPACED BETWEEN GRID LINES OR ALONG GIRDERS UNLESS DIMENSIONS OTHERWISE.
2. JOIST BEARING SEATS SHALL HAVE THE FOLLOWING DEPTH UNLESS NOTED OTHERWISE:
   - 'K' SERIES = 3"

METAL DECK:
1. WHERE BEAMS SUPPORT DECK DIRECTLY TOP OF STEEL ELEVATION IS AT BOTTOM OF DECK UNLESS NOTED OTHERWISE.
2. WHERE BEAMS SUPPORT JOISTS TOP OF STEEL IS AT JOIST BEARING UNLESS NOTED OTHERWISE.
3. TOS ELEVATION = BOTTOM OF DECK UNLESS MEMBERS SPANNING BETWEEN OR PERPENDICULAR TO LABELED ELEVATIONS (SLOPED MEMBERS) SHALL FOLLOW THE DECK PLANE ESTABLISHED BETWEEN MEMBERS WITH MARKED ELEVATIONS.
4. NOT ALL OPENINGS IN METAL DECK FLOOR SLABS & ROOFS ARE SHOWN ON PLAN. SEE ARCH & MEP DRAWINGS FOR SIZE, LOCATION & QUANTITY OF OPENINGS NOT SHOWN.

FRAMING PLAN LEGEND

SYMBOL
DESCRIPTION

STEEL FRAMING PLAN
PENTHOUSE ROOF FRAMING PLAN
MARIAN H. ROCHELLE GATEWAY CENTER

BENJAMIN TALPOS
DRAKE, LANGE & WESSEL ENGINEERING
1000 E. IVINSON STREET
LARAMIE, WYOMING
PH:  (307) 555-4321

CONSTRUCTION
DESIGN

PROJECT NUMBER
MARIAN H. ROCHELLE GATEWAY CENTER

100% CONSTRUCTION
DESIGN

06-11-13

4/30/2015 6:04:47 PM
H:\Personal\Gateway Center_pdrake2@uwyo.edu.rvt
Gateway Center

- Building Design – from architect
- Structural Design Considerations: SD Proposal
- Design Documents
  - Full system
  - Shear walls, overturning, moment connections
- Structural Details
Gateway Center
3D Applications

Click and Drag on this image to explore the scene. Shift + Scroll to zoom.
Structural Cores
Portland: Net Zero

- Net-Zero concept and ideology
- Portland Visit
- Design Considerations
- Analysis Tools
Portland, OR Multifamily Building
Portland, OR Example Multifamily Buildings
Goals and Building Site
Weather Data

- TMY3 Data
- Hillsboro in Portland
- Energy.gov
Autodesk Vasari Weather Data
Autodesk Vasari Wind Tunnel
Reviving a Design: Initial Concept
Bringing the dead back to life
Atrium Design
Net-Zero Redesign
Portland: Roof Profile
Elevations
Section View
BIM Analysis of Mid-Rise Office Building
In New Delhi, India

Student Modelling Competition:
Simulation of a Mixed-Mode Office Building

IBPSA Building Simulation 2015

May 7, 2015

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Executive Summary

A group of students from the University of Wyoming have collaborated for an entry in the International Building Performance Simulation Association’s (IBPSA) Student Modelling Competition. An office building located in New Delhi, India was modeled using Simergy and EnergyPlus. By modeling the building, the group will show that integrated buildings can be made more efficiently from the design phase of the project with the aid of solar studies and climate data. Students have performed a parametric study on a variety of building envelope parameters including window U-value, wall R-value, and window to wall ratio, in order to find the optimal combination of parameters to reduce energy loss through the building envelope. The group also simulated a variety of ventilation methods for the office building to analyze parameters such as energy usage, thermal comfort, and indoor air quality. Simulations for mechanical ventilation, natural ventilation, simultaneous mechanical and natural ventilation, and a change over, mixed mode ventilation system were developed and run. Lastly, the group performed a sensitivity analysis on the simulations to fine-tune the results. The group has compared results of the various energy simulations to determine which scenario is most effective.
Nomenclature

Actuator
Climate Zone
Change Over System
Compact Schedule
Degree Day
Energy Management System (EMS)
Mixed Mode Ventilation
Opening Area
Sensor
Setpoint
Thermal Zone
Unmet Hours
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Introduction

IBPSA Student Modelling Competition

The IBPSA’s student modeling competition is a part of the organization’s Building Simulation Conference in December 2015 that located in Hyderabad, India. The aim of the exercise is to “use computer simulation to design and test a mixed-mode ventilation strategy for a new office building located in New Delhi, India.” (IBPSA Briefing Document)

Students are provided with the site and building plans, occupancy schedules, internal loads, and the New Delhi weather file. In addition, each student group is required to design the furniture layout and building envelope for the building and to simulate a mixed-mode ventilation system for the building.

Submissions are evaluated by the accuracy and thought put into the design of the mixed-mode ventilation system, envelope design, space use, energy usage, and furniture design of the building. In this respect, $CO_2$ concentrations, indoor air quality, thermal comfort, and sensitivity of the building will also be criterion evaluated by the judging team.

Location Study

The Student Modelling Competition requires the design of a new office building specifically located in New Delhi, India. The group performed an initial climate study before designing the building envelope or ventilation systems.

New Delhi is located in a very hot and humid 1B climate according to the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). The city of New Delhi lies at the latitude of 28.58° and a longitude of 77.2°. The city is situated at an elevation of approximately 216 meters above sea level.

Throughout the year, temperature varies with a maximum dry bulb temperature of 44.3°C and a minimum of 5.2°C. The yearly average of dry bulb temperature for the year 1990 was 24.7°C. Figure 1 below shows the average monthly temperatures for New Delhi, India. Figure 2 shows the monthly HDD and CDD.

![Fig. 1 Average Monthly Temperature](image1)

![Fig. 2 Monthly HDD/CDD](image2)

Using a 10 °C baseline temperature set point, the data indicates that there are 5,534 annual cooling degree-days (CDD) and relatively no heating required (at about 1 heating degree-day (HDD)). At an 18.3°C set point, the data indicates 2762 CDD and 270 HDD. This setpoint still results in higher cooling load than heating load, but the heating load is significant enough to still require heating equipment within the building. The data analyzed shows that the climate is generally very hot. Knowing this, it can be seen that
using natural ventilation in a mixed-mode HVAC system could have large cooling benefits and energy savings.

Other weather data were analyzed including wind speed and direction, and solar radiation. Figure 3 shows the wind direction and wind speed by month and Figure 4 shows the monthly solar radiation of the city.

![Fig 3. Monthly Wind Direction & Wind Speed](image1)

![Fig. 4 Monthly Solar Radiation](image2)

**Building Design**

**Floor Plans and Thermal Zones**

The governing floor plans of the building are given by the Student Modelling Competition. Participants of the competition are required to design their own interior floor plans and furniture layout.

The building geometry suggests that students consider a semi-open floorplan for optimizing the building energy performance simulation. For this reason, enclosed areas have been located on the Southeast and East walls of the building, where the façade is shaded by adjacent buildings. Open office space is located in the remaining areas with ample opportunity for outdoor air intake for mechanical systems and natural ventilation. A central atrium extends from ground level up past the terrace floor and serves as stack ventilation.

A small reception area is located by the main entrance on the North wall in the Northwest. A pair of restrooms, as well as a storage/mechanical room, is located on every floor. In addition, a conference room is located on floors two and three, and an employee break room is conveniently located on the main floor. The remaining floor space is used as open office space and will be filled with cubicles.
In total, the office building in total houses 70 employees. To distribute this, 20 employees will be placed on the ground floor, with the remaining 50 evenly dispersed equally between floors two and three. **Figure 5** below shows the general floor plan for the office building. Floor 4 consists only of the stairwell and the atrium areas. We are making the assumption that the fourth floor can be of variable usage, including beneficial features such as a rooftop garden that provides rooftop thermal mass, or a rooftop office area such as the Willis, Faber, & Pumas Headquarters building in Ipswich, England has done.

![Figure 5: Office Building Floor Plan](image)

The group considered the layout of thermal zones and the classification of mechanical, natural ventilation, and mixed mode zones. Thermal zones were designed with consideration of the use of space, orientation, and the wall a room was attached to. It was decided that the closed spaces on each floor will be mechanical zones and the open office spaces will be both mechanical and a natural ventilation zone. The stairwell and the atrium are modeled as natural ventilation zones.

The thermal zones are grouped into natural ventilation and mechanical HVAC zones in order to be supplied by a mixed-mode system. The open office zone was initially set to be handled by both zone groups, the conference and offices are to be handled directly by the mechanical system, and the stairwell and stack should use natural ventilation. The storage and bathrooms could be left unconditioned. Natural ventilation diagrams are shown in **Fig. 7** below.

![Figure 7: Natural Ventilation Diagram](image)
**Parametric Study for Design of Building Envelope**

*Building Envelope Design*

The group solidified the optimal building envelope by performing a parametric design study with a year-long simulation and the building occupant and internal gain schedules included within the model. This included analyzing various WWR, window U-values, thermal massing effects, and wall R-values. The results from the parametric design study are summarized in Table 1.

**Table 1: Parametric Study Simulation Results**

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Parameter Varied from:</th>
<th>Description of Material</th>
<th>Optimum Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window to Wall Ratio</td>
<td>10%-40%</td>
<td></td>
<td>20%</td>
</tr>
<tr>
<td>Window U-Value</td>
<td>.51-4.8 W/m^2 K</td>
<td>Triple Pane, Low E, Argon</td>
<td>1.4</td>
</tr>
<tr>
<td>Roof Thermal Mass</td>
<td>200-1800 J/kg K</td>
<td></td>
<td>1400</td>
</tr>
<tr>
<td>Wall R Value</td>
<td>Air film, 8” concrete, ½” air gap, 2” extruded polystyrene, ½” air gap, 8” concrete, ½” drywall, air film</td>
<td>26.32</td>
<td></td>
</tr>
</tbody>
</table>

**Modeling Methods Employed**

*Building Model and Software*

**Fig. 8: Modeling Software**

| Simergy                      | Energy plus            |

The next step within our simulation was to digitally analyze the situation using building information modeling (BIM) software. The source software we used was EnergyPlus, developed by the US Dept. of Energy (DOE). In addition, Simergy was another program which added the capability of graphic and visual analysis techniques. In comparison to other software such as OpenStudio, the main advantage that Simergy has is being able to natively use ventilation effects through a building. Through Simergy, the thermal zones and mechanical system for the office were created. EnergyPlus is a significantly
sophisticated HVAC parameter editor and it is what we used mainly for natural and mixed mode ventilation. This is especially true for writing advanced building control logics as shown later.

**Mechanical Ventilation**

The initial HVAC system implemented was a variable-air-volume (VAV) unit with water-supplied reheat on each floor of the building. After setting the air and water loops to accommodate each zone, the HVAC diagram looks like **Fig. 9 & 10** below. The zones were grouped into natural ventilation and mechanical HVAC zones for being supplied by the mixed-mode system. The open office zone was initially set to be handled by both zone groups, while the conference and offices are to be handled directly by the mechanical system. Ideally, the stairwell and stack area should primarily use natural ventilation. The storage and bathrooms could be left unconditioned.

![HVAC Air Loop](image)

**Fig. 9: HVAC Air Loop**

![HVAV Water Loop](image)

**Fig. 10: HVAV Water Loop**

**Natural Ventilation**

The effects of simulating natural ventilation had a large effect on the building. In New Delhi, the OAT is relatively very high. Therefore, any natural ventilation can be beneficial for heating purposes, but very detrimental for cooling loads on the buildings. After the analysis, the amount of unmet hours significantly reduced, while the cooling energy use increased by an order of magnitude. This is due to the natural ventilation being fully applied at all times in the
initial natural ventilation model and actually conflicts with the HVAC unit. This can be seen by the values in the results section of this document.

**Mechanical and Natural Ventilation**

For the next case, the mechanical system and natural ventilation were implemented at their full operational rates simultaneously which resulted in an exponential increase in loads and energy use. This is because the warm New Delhi climate causes an additional temperature increase beyond what is prevented by typical insulating effects of enclosed spaces. Therefore, the mechanical system had to operate above its specified capacity to accommodate this load.

**Mixed Mode Ventilation**

The final step was to fully implement a mixed-mode schedule that allows the natural ventilation and HVAC system to work in conjunction where there are four possible modes of operation based off of additional set points. These include HVAC only operation, natural ventilation only, both operating, or neither operating. Once this achieved, the model can be reviewed once again for optimization of the mixed-mode system and parametric study. The best scenario is to use each ventilation strategy such that they don't interfere by using computerized logics for specified setpoints and internal air quality values.

**Sensitivity Analysis**

<table>
<thead>
<tr>
<th>Operable Area</th>
<th>Total Energy (GJ)</th>
<th>Heating</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>225.79</td>
<td>103.5</td>
<td>3367.33</td>
</tr>
<tr>
<td>0.9</td>
<td>249.66</td>
<td>247.33</td>
<td>3274</td>
</tr>
<tr>
<td>Baseline</td>
<td>256.23</td>
<td>264.53</td>
<td>3271</td>
</tr>
<tr>
<td>1.1</td>
<td>261.07</td>
<td>279.17</td>
<td>3268</td>
</tr>
<tr>
<td>1.5</td>
<td>281.19</td>
<td>339.67</td>
<td>3237.5</td>
</tr>
</tbody>
</table>

% Difference:

<table>
<thead>
<tr>
<th></th>
<th>11.90%</th>
<th>60.90%</th>
<th>-2.90%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.60%</td>
<td>6.50%</td>
<td>-0.10%</td>
</tr>
<tr>
<td></td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td>-1.90%</td>
<td>-5.50%</td>
<td>0.10%</td>
</tr>
<tr>
<td></td>
<td>-9.70%</td>
<td>-28.40%</td>
<td>1.00%</td>
</tr>
</tbody>
</table>

A sensitivity analysis was also performed in order to demonstrate the effectiveness of the façade opening ratios compared to the total area of the building faces. As seen from the above figure, the operable area of 0.5 has a somewhat significant deficit in cooling hours that are unmet. This is also while there are beneficial effects to the heating load. However, the overall effects became negligible compared
to constructability methods. Compared to other building parameters, the opening area is pinching some pennies and can only be fully implemented with variable window operation.

**Modeling Assumptions**

**Internal Loads**

**Setpoints**

*Heating and Cooling Set Points*

To lower heating and cooling loads for each month, a monthly heating and cooling set point was calculated. For each month, a heating and cooling set point was calculated using the average daily temperature per month in both Equation 2 and Equation 3.

\[
E_{NV\text{Cooling}} = T_a \times 0.31 + 21.3
\]

\[
E_{NV\text{Heating}} = T_a \times 0.31 + 14.3
\]

Where \(T_a\) = average temperature for each month.

**Figure 11** shows the ASHRAE table for acceptable comfort limits based on monthly average temperatures.

![Figure 11: ASHRAE Natural Ventilation](image)
Table 3 shows the calculated results for each month’s heating and cooling set points.

**Table 3. Monthly Heating and Cooling Set Points**

<table>
<thead>
<tr>
<th>Month</th>
<th>Daily Average Temperature</th>
<th>Heating Set Point</th>
<th>Cooling Set Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>14.1</td>
<td>18.671</td>
<td>25.671</td>
</tr>
<tr>
<td>February</td>
<td>16.5</td>
<td>19.415</td>
<td>26.415</td>
</tr>
<tr>
<td>March</td>
<td>21.9</td>
<td>21.089</td>
<td>28.089</td>
</tr>
<tr>
<td>April</td>
<td>28.3</td>
<td>23.073</td>
<td>30.073</td>
</tr>
<tr>
<td>May</td>
<td>31.8</td>
<td>24.158</td>
<td>31.158</td>
</tr>
<tr>
<td>June</td>
<td>33.2</td>
<td>24.592</td>
<td>31.592</td>
</tr>
<tr>
<td>July</td>
<td>31.3</td>
<td>24.003</td>
<td>31.003</td>
</tr>
<tr>
<td>August</td>
<td>30</td>
<td>23.6</td>
<td>30.6</td>
</tr>
<tr>
<td>September</td>
<td>29.3</td>
<td>23.383</td>
<td>30.383</td>
</tr>
<tr>
<td>October</td>
<td>25.3</td>
<td>22.143</td>
<td>29.143</td>
</tr>
<tr>
<td>November</td>
<td>19.5</td>
<td>20.345</td>
<td>27.345</td>
</tr>
<tr>
<td>December</td>
<td>14.8</td>
<td>18.888</td>
<td>25.888</td>
</tr>
</tbody>
</table>

During our time working on these simulations, the following assumptions were made.

- The solid line on the “Typical Floor” plan in the provided building documents is considered the exterior of the building. The extreme corners of the columns of the building are not within these exterior walls.
- Models are designed with certain simplifications, which may skew simulation results.
- The values used for the parametric simulations are general assumptions of U- and R-values and may vary in real life.
- If choosing the higher set point, the energy use is less, which may affect the comfort of building occupants. A temperature reset strategy can be employed to use varying set points depending on the current building loads and adjust accordingly to achieve a better balance between comfort and energy savings.
- The mixed mode ventilation method used will be a change-over method.
Results

Mechanical Ventilation

<table>
<thead>
<tr>
<th></th>
<th>Total energy use (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>16.59</td>
</tr>
<tr>
<td>Cooling</td>
<td>173.09</td>
</tr>
<tr>
<td>Fans</td>
<td>22.78</td>
</tr>
</tbody>
</table>

Total site energy = 370.7 GJ  
Total source energy = 1139.46
Time set point not met during occupied heating = 10 hours
Time set point not met during occupied cooling = 353.5 hours

Natural Ventilation

<table>
<thead>
<tr>
<th></th>
<th>Total energy use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>0</td>
</tr>
<tr>
<td>Cooling</td>
<td>158.33</td>
</tr>
</tbody>
</table>

Time set point not met during occupied heating = 655 hours
Time set point not met during occupied cooling = 1892.5 hours

Mechanical and Natural Ventilation

<table>
<thead>
<tr>
<th></th>
<th>Total energy use (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>3561.62</td>
</tr>
<tr>
<td>Cooling</td>
<td>5826.16</td>
</tr>
<tr>
<td>Fans</td>
<td>902.8</td>
</tr>
</tbody>
</table>

Total site energy = 10451.22 GJ  
Total source energy = 25680.15 GJ
Time set point not met during occupied heating = 5.5 hours
Time set point not met during occupied cooling = 101.17 hours

Mixed Mode Ventilation

<table>
<thead>
<tr>
<th></th>
<th>Total energy use (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>155.96</td>
</tr>
<tr>
<td>Cooling</td>
<td>465.5</td>
</tr>
<tr>
<td>Fans</td>
<td>58.6</td>
</tr>
</tbody>
</table>

Total site energy = 836.36 GJ  
Total source energy = 2330.24 GJ
Time set point not met during occupied heating = 56 hours
Time set point not met during occupied cooling = 147.17 hours

Conclusions

The overall goal of this project was to be able to maintain the comfortable setpoints within the building. We were able to meet both the temperature setpoints, while also able to reduce the CO₂ rates to acceptable, safe values. The sensitivity analysis showed us that having a larger opening area doesn’t help with our energy saving process at this point. However, using the EMS (which has been included in
the appendix) allows us to maintain comfortable temperatures, intelligently within the building. This is shown in the following sections.

**Thermal Comfort of Occupants**

Despite the couple of peaks outside of the setpoint range, (near the middle of the above chart) it is easily seen that the EMS code controlled the mixed-mode HVAC system to keep the internal air temperature of the specific zone at a relatively constant temperature compared to the outdoor air.

**Indoor Air Quality**

To demonstrate that the indoor air quality is met we analyzed the $CO_2$ levels generated by the building occupant loads. The chart below shows that the EMS system is able to limit the $CO_2$ levels as prescribed by ASHRAE 90.1 the limit for acceptable indoor air quality, which is 1000ppm.
Best Ventilation Method

Finally, it was still apparent that the best strategy analyzed was the change-over method even though our EMS actually caused it to increase the total site energy loads compared to the only mechanical simulation. What we would ideally expected is that the mechanical system and natural ventilation system are able to operate independently of each other when ideal for that particular system in order to reduce the total site energy. This was not the case because the system is causing the two systems to operate separately, but at non-ideal times for the individual systems.

The minimum goal of a realistically implemented mixed-mode system operated by EMS is to have the natural ventilation passively cool the building when OA temperatures are favorable so that the office may save further energy. The increased load then comes down to debugging when each system is called into effect, and making sure one does not accidentally trigger at a time not caught in the scope of the EMS code. Further analysis into the yearly zone temperatures and real-time operational loads helps determine where this effect is occurring and we were able to reduce the conflicting modes from the operational hazards of having both systems running simultaneously, to periods where they are each best implemented individually.

This final statistical data is provided below.

<table>
<thead>
<tr>
<th></th>
<th>Heating (GJ)</th>
<th>Cooling (GJ)</th>
<th>Total site energy (GJ)</th>
<th>Unmet heating hours</th>
<th>Unmet cooling hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change over system</td>
<td>155.96</td>
<td>682.41</td>
<td>838.36</td>
<td>56</td>
<td>147.17</td>
</tr>
</tbody>
</table>
References


Autodesk Revit Software.


EnergyPlus Software.


Google SketchUp Make Software.

Huws, Halla. “Student Modeling Competition Design and simulation of a near-zero energy building.”


OpenStudio Software.

Simergy Software.


Appendices

Part A: EMS Code Excerpts

```plaintext
!- *********** ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:SENSOR ***********

EnergyManagementSystem:Sensor,  
IA15,     !- Name  
Thermal Zone 15, !- Output:Variable or Output:Meter Index Key Name  
Zone Mean Air Temperature, !- Output:Variable or Output:Meter Name

EnergyManagementSystem:Sensor,  
IA12,     !- Name  
Thermal Zone 12, !- Output:Variable or Output:Meter Index Key Name  
Zone Mean Air Temperature, !- Output:Variable or Output:Meter Name

EnergyManagementSystem:Sensor,  
GAT,      !- Name  
Environment, !- Output:Variable or Output:Meter Index Key Name  
Outdoor Dry Bulb, !- Output:Variable or Output:Meter Name

EnergyManagementSystem:Sensor,  
HeatingSetP, !- Name  
Zone Heating Setpoint Schedule(), !- Output:Variable or Output:Meter Index Key Name  
Schedule Value, !- Output:Variable or Output:Meter Name

EnergyManagementSystem:Sensor,  
CoolingSetP, !- Name  
Zone Cooling Setpoint Schedule(), !- Output:Variable or Output:Meter Index Key Name  
Schedule Value, !- Output:Variable or Output:Meter Name

!- *********** ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:ACTUATOR ***********

EnergyManagementSystem:Actuator,  
Sensor1SVAVSch,  !- Name  
Sensor15Sch,    !- Actuated Component Unique Name  
Schedule:Compact, !- Actuated Component Type  
Schedule Value, !- Actuated Component Control Type

EnergyManagementSystem:Actuator,  
Sensor18SVAVSch,  !- Name  
Sensor18Sch,    !- Actuated Component Unique Name  
Schedule:Compact, !- Actuated Component Type  
Schedule Value, !- Actuated Component Control Type

EnergyManagementSystem:Actuator,  
Aspen12Sch,    !- Name  
open12Sch,     !- Actuated Component Unique Name  
Schedule:Compact, !- Actuated Component Type  
Schedule Value, !- Actuated Component Control Type

!- *********** ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:PROGRAM:CALLINGMANAGER ***********

EnergyManagementSystem:ProgramCallingManager,  
P0FHVAC1,     !- Name  
BeginTimestepBeforePredictor, !- EnergyPlus Model Calling Point  
P0FHVAC1:     !- Program Name 1

EnergyManagementSystem:ProgramCallingManager,  
P0FHVAC2,     !- Name  
BeginTimestepBeforePredictor, !- EnergyPlus Model Calling Point  
P0FHVAC2:     !- Program Name 1

!- *********** ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:PROGRAM ***********

EnergyManagementSystem:Program,  
P0FHVAC1,     !- Name  
IF (GAT > IA15) && (IA15 > CoolingSetP), !- Program Line 1  
SET Sensor15SVAVSch=0, !- Program Line 2  
While (GDC15 < 90)  
SET Aspen15Sch=1-(IA15 - GAT)/15, !- A4  
SET Aspen15Sch=1-(IA15 - GAT)/15, !- A5  
SET Aspen15Sch=1-(IA15 - GAT)/15, !- A6  
Return, !- A7  
ELSE IF (GDC15 > 90)  
SET Aspen15Sch=1,  
SET Aspen15Sch=1, !- A4  
SET Aspen15Sch=1, !- A6  
ELSE  
ELSE, !- A4  
SET Sensor15SVAVSch=1, !- A5  
SET Aspen15Sch=0, !- A6  
SET Aspen15Sch=0, !- A6  
ENDIF,  
ENDIF

!- ELSE, !- A4
```