AE Senior Thesis 2011

SHA Headquarters

Systems Renovations

Baltimore, MD

Stephanie Kunkel | Mechanical Option | Dr. Bahnfleth

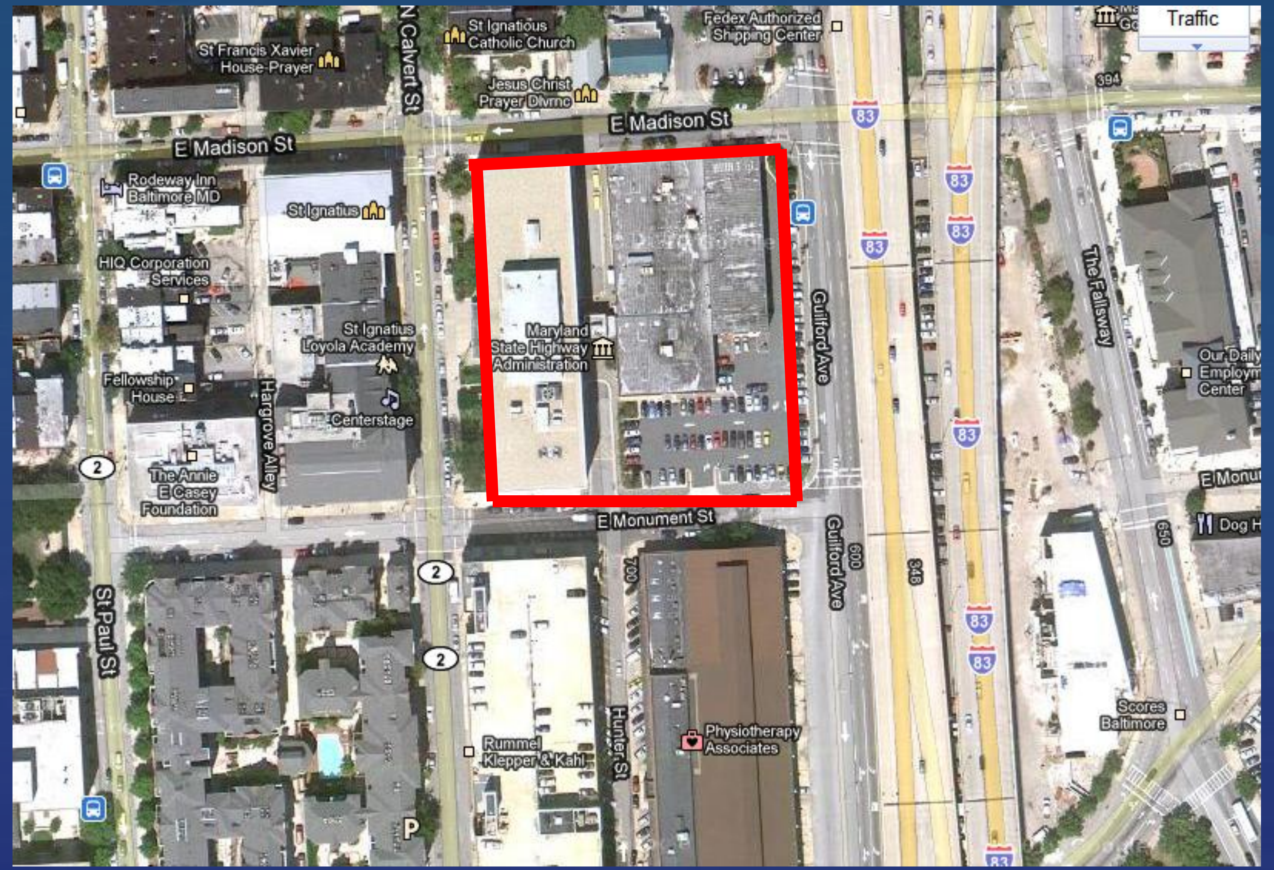
Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

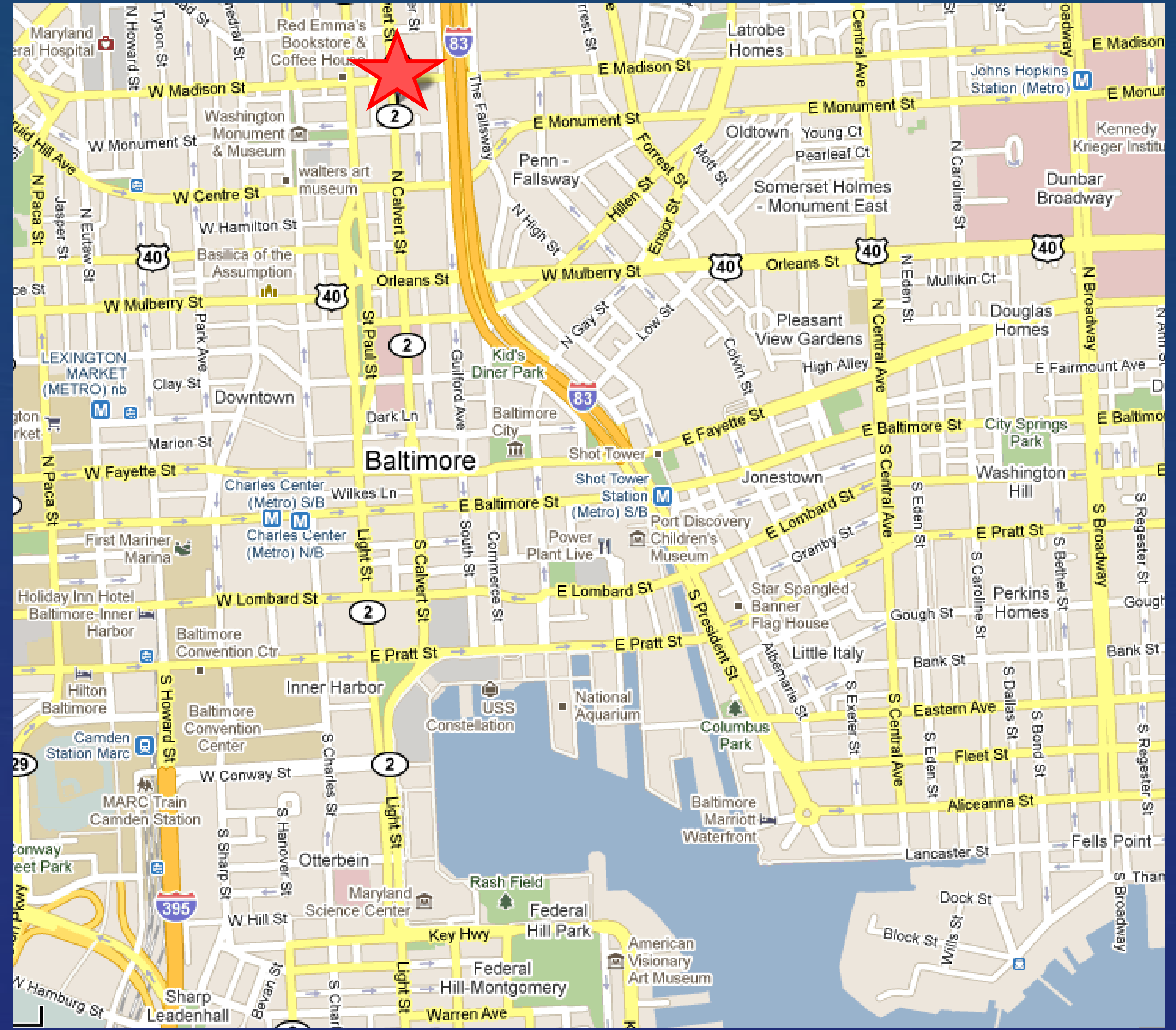
Presentation Outline

- **Project Information**
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

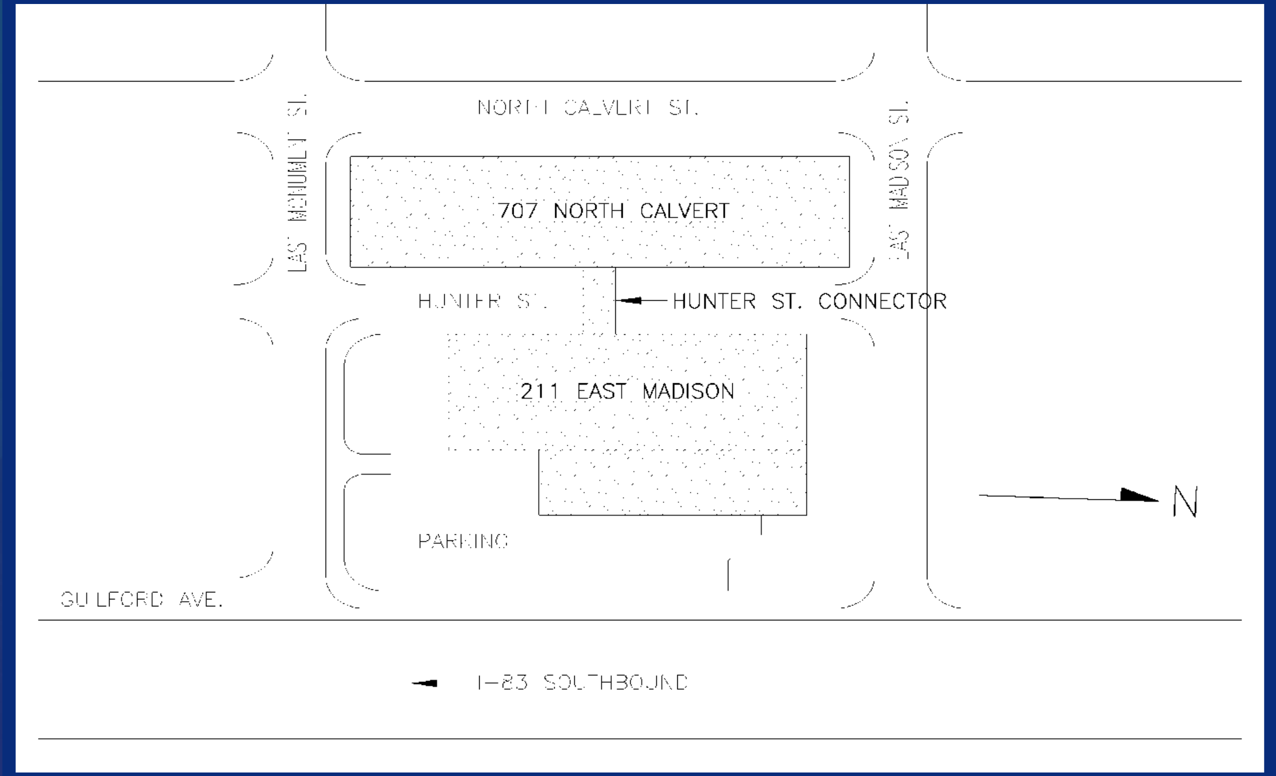
Project Site



Building Location



707 North Calvert Street



General Building Information

Building Name: SHA Headquarters—707 Systems Renovations
Location: Baltimore, MD
Occupancy Type: Office Building
Gross Building Area: 226,000 SF
Total Number of Stories: 8 (including 2 below grade)
Total Renovation Cost: Approx. $4,435,500
Dates of Renovation: 9/2010 — 5/2013
Project Delivery Method: Design-Bid-Build

SHA State Highway Administration
Driven to Excel
Maryland Department of Transportation

The 707 Building

Primary Project Team

AE Firm

JMT
JOHNSON, MIRMIRAN & THOMPSON
Engineering A Brighter Future®

Architect

INTEC
Architects
Engineers
Construction Managers

Mechanical Contractor

GE Tignall & co., inc.

Presentation Outline

- Project Information
- **Existing Mechanical System**
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Existing Mechanical System

Air Side

AHU-S1:

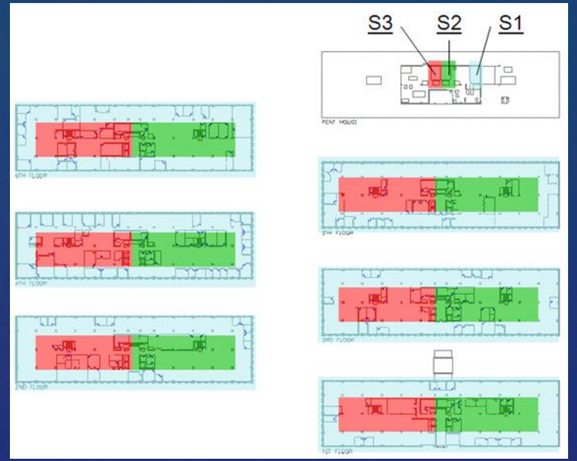
- Built-up air handler with steam preheat, filters, cooling coil, and steam reheat coil
- Constant volume
- Serves perimeter induction units on 6 office floors

AHU-S2 & S3:

- Built-up air handler with filters and cooling coil
- Constant volume
- Serve core of 6 office floors – one north, one south

Induction Units:

- (534) perimeter induction units on 6 office floors



Water Side

Chilled Water:

- Plant includes dual compressor, single condenser, single evaporator chiller and primary chilled water pump
- Induced draft cooling tower

Hot Water:

- (2) gas-fired steam boilers

Presentation Outline

- Project Information
- Existing Mechanical System
- **Mechanical System Redesign - Depth**
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Planned Mechanical System Redesign

Goals

Improve:

- ❑ Energy efficiency
- ❑ Occupancy comfort

Criteria:

- ❑ Disturbance to tenants
- ❑ Maintenance requirements

Air Side

AHU-S1:

- Replace with 32,000 CFM unit
- Constant volume
- Continue serving perimeter of 6 office floors

AHU-S2 & S3:

- Replace with 30,000 and 37,000 CFM units
- Constant volume
- Continue serving core of 6 office floors

Induction Units:

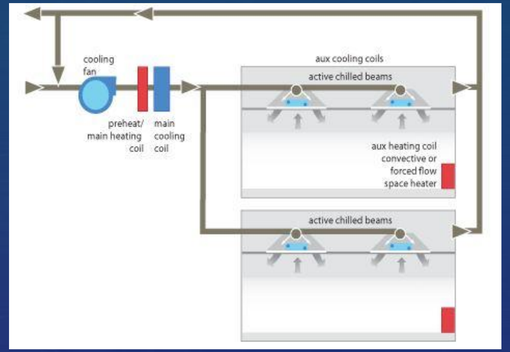
- Replace (534) perimeter induction units on 6 office floors

Water Side

Hot Water:

- (2) hot water boilers – no steam

Mechanical System Redesign Proposal



- Replace induction units with *Active Chilled Beams*
- Redesign water distribution system to *four-pipe*

Benefits

Chilled Beams:

- Enhance occupancy comfort
- Few maintenance requirements
- Highly energy efficient

Four-Pipe:

- Enhance occupancy comfort
- Additional flexibility and control
- Constant availability of heating and cooling

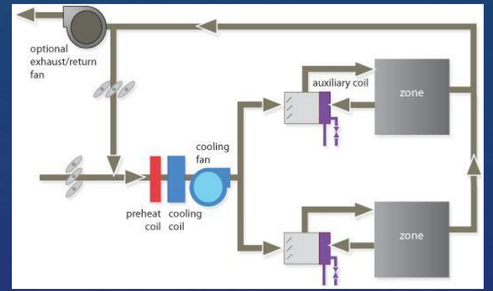
Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - **Two-Pipe to Four-Pipe Conversion**
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

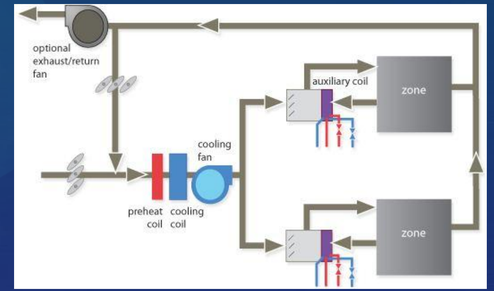
Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - **Background**
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Two-Pipe

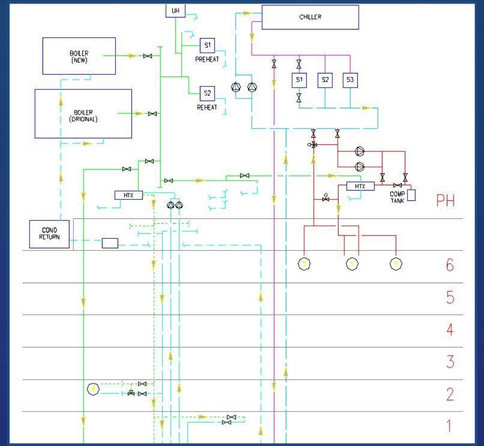


Four-Pipe



Presentation Outline

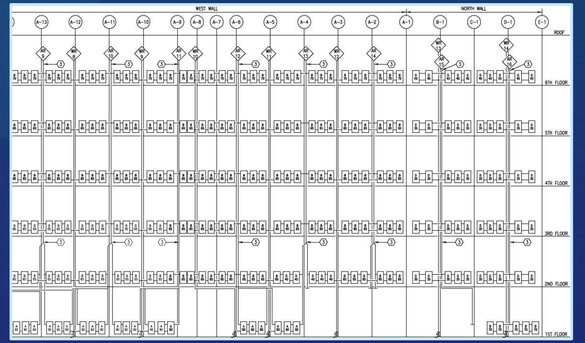
Existing Piping



Induction Air & Water

Two-Pipe:

- 15 vertical runs



Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - **Installation & Results**
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

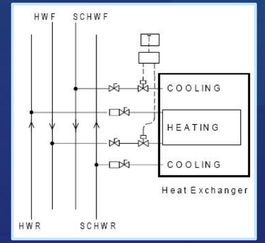
Installation

Four-Pipe:

- 15 vertical runs
- 6,000 LF

Selection:

- Hot water piping of 1-1/2”



Results

Piping Determines:

- Quality of performance
- Ease of operation
- Initial cost

Four-Pipe:

- No zoning of two-pipe system
- No changeover from heating to cooling = decreased energy consumption

Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - **Chilled Beam Renovation**
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - **Background**
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Background

How They Work:

- Can both heat and cool
- Water can transport energy more efficiently than air

Increased Usable Square Footage:

- Area of induction unit ~ 2ft^2

	Total SF
Existing	171,630
Induction Units	1,112
Proposed	172,742

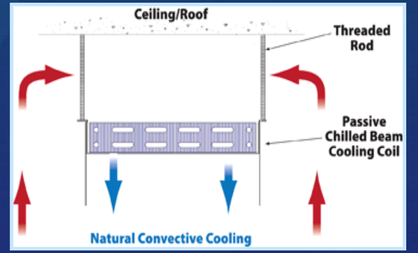
Types:

- Passive
- Active

Passive Chilled Beam

How They Work:

- Only supply cooling
- No fans, ductwork
- Chilled water piped to finned tube heat exchanger coil



Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - **Background**
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

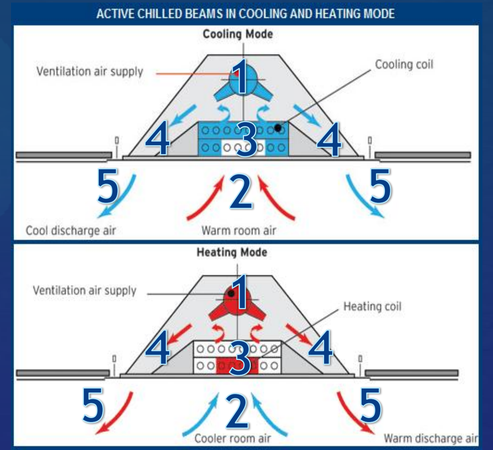
Active Chilled Beam (ACB)

How They Work:

1. Primary air supplied through nozzles
2. Room air rises to ACB
3. Air pulled through secondary water coil & induced air is cooled/heated
4. Primary air and induced air mixed
5. Discharged through diffuser

Summary:

Crucial	Less Concern
✓ Lower operating cost	Noiseless
✓ Lower energy consumption	Higher ceiling heights
✓ Highly efficient	Future tenant flexibility
✓ Greater occupancy comfort	
✓ Little maintenance	
✓ Reduced ductwork	
✓ Increased usable square footage	



Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - **Sizing and Selection**
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Sizing

1. Primary Air:

- Calculate minimum ventilation air from ASHRAE Standard 62.1
- Primary Air Required = 5 CFM/person x People in Zone

2. Sensible Cooling Capacity:

- Sensible cooling refers to dry bulb temperature of the building
- Sensible Cooling Capacity = 1.08 x Primary Air CFM x (T_{room} - T_{supply})

3. Latent Load:

- Latent loads must be satisfied by primary air
- Latent Load = 0.69 x Primary Air CFM x (RH_{room} - RH_{supply})

4. Latent Cooling Capacity:

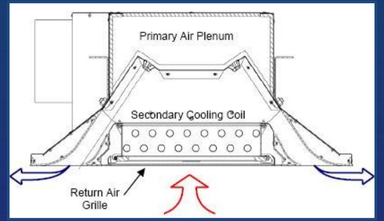
- If Latent Cooling Capacity > Latent Load, primary air can support latent load
- Latent Cooling = 4840 x Primary Air CFM x (W_{room} - $W_{primary}$)

Floor	Zone	People	Primary Air (CFM)	Sensible Cooling Capacity (BTU/hr)	Latent Load (BTU/hr)	Latent Cooling Capacity (BTU/hr)
1st	SW	10	50	1134	148	303

Selection

DADANCO's ACB40:

- 4-pipe ceiling unit
- 2-way supply discharge
- Delivers higher energy efficiency at lower air quantities



Presentation Outline

Sizing

1. Primary Air:

- Calculate minimum ventilation air from ASHRAE Standard 62.1
- Primary Air Required = 5 CFM/person x People in Zone

2. Sensible Cooling Capacity:

- Sensible cooling refers to dry bulb temperature of the building
- Sensible Cooling Capacity = 1.08 x Primary Air CFM x (T_{room} - T_{supply})

3. Latent Load:

- Latent loads must be satisfied by primary air
- Latent Load = 0.69 x Primary Air CFM x (RH_{room} - RH_{supply})

4. Latent Cooling Capacity:

- If Latent Cooling Capacity > Latent Load, primary air can support latent load
- Latent Cooling = 4840 x Primary Air CFM x (W_{room} - $W_{primary}$)

Floor	Zone	People	Primary Air (CFM)	Sensible Cooling Capacity (BTU/hr)	Latent Load (BTU/hr)	Latent Cooling Capacity (BTU/hr)
1st	SW	10	50	1134	148	303

Selection

Primary Airflow (CFM)	Primary Air Cooling		Sensible Cooling (Btuh)							
	Sensible (Btuh)	Latent (Btuh)	Nominal 2 Foot Coil		Nominal 3 Foot Coil		Nominal 4 Foot Coil		Nominal 5 Foot Coil	
			Coil	Total	Coil	Total	Coil	Total	Coil	Total
15	340	90	1075	1415						
20	455	120	1240	1695	1495	1950				
25	570	150	1365	1935	1665	2235	1840	2410		
30	684	180	1385	2070	1835	2520	2005	2690		
35	800	210			2030	2830	2165	2965	2415	3215
40	910	240			2100	3010	2335	3245	2570	3480
45	1025	270			2140	3165	2525	3550	2720	3745
50	1140	300			2150	3290	2565	3705	2880	4020
55	1255	330					2610	3865	3050	4305
60	1365	365					2615	3980	3145	4510
65	1480	395							3230	4710
70	1595	425							3280	4875
75	1710	455							3295	5005
80	1825	485							3305	5130

Amount of ACB's:

- DADANCO's rule of thumb
- Number of Units = Area / 150ft^2

Floor	Zone	Area (ft^2)	Number of Units
1st	South West	1669	12

Total Number of ACB's = 391

Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - **Sizing and Selection**
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Sizing

1. Primary Air:

- Calculate minimum ventilation air from ASHRAE Standard 62.1
- Primary Air Required = 5 CFM/person x People in Zone

2. Sensible Cooling Capacity:

- Sensible cooling refers to dry bulb temperature of the building
- Sensible Cooling Capacity = 1.08 x Primary Air CFM x (T_{room} - T_{supply})

3. Latent Load:

- Latent loads must be satisfied by primary air
- Latent Load = 0.69 x Primary Air CFM x (RH_{room} - RH_{supply})

4. Latent Cooling Capacity:

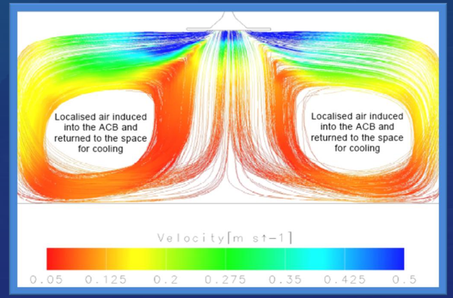
- If Latent Cooling Capacity > Latent Load, primary air can support latent load
- Latent Cooling = 4840 x Primary Air CFM x (W_{room} - $W_{primary}$)

Floor	Zone	People	Primary Air (CFM)	Sensible Cooling Capacity (BTU/hr)	Latent Load (BTU/hr)	Latent Cooling Capacity (BTU/hr)
1st	SW	10	50	1134	148	303

Selection

DADANCO's ACB40:

- Comfort
  - Uniform temperatures throughout
  - Elimination of drafts and hot spots



Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - **Energy Consumption and Operation**
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

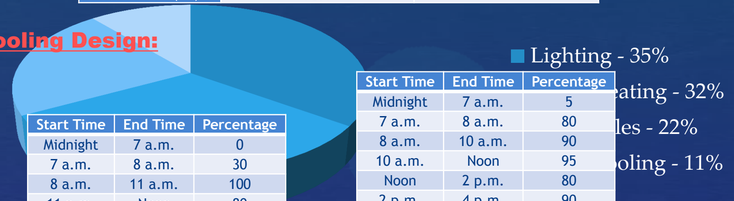
Design Conditions

Baltimore:

ASHRAE HOF Values	Summer Design Cooling (0.4%)	Winter Design Heating (99.6%)
OA Dry Bulb (°F)	93.9	12.9
OA Wet Bulb (°F)	78.1	-

Ene

Cooling Design:

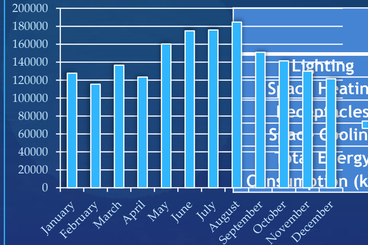


Start Time	End Time	Percentage
Midnight	7 a.m.	0
7 a.m.	8 a.m.	30
8 a.m.	11 a.m.	100
11 a.m.	Noon	80
Noon	1 p.m.	40
1 p.m.	2 p.m.	80
2 p.m.	5 p.m.	100
5 p.m.	6 p.m.	30
6 p.m.	9 p.m.	10
9 p.m.	Midnight	5

Start Time	End Time	Percentage
Midnight	7 a.m.	5
7 a.m.	8 a.m.	80
8 a.m.	10 a.m.	90
10 a.m.	Noon	95
Noon	2 p.m.	80
2 p.m.	4 p.m.	90
4 p.m.	5 p.m.	95
5 p.m.	6 p.m.	80
6 p.m.	7 p.m.	70
7 p.m.	8 p.m.	60
8 p.m.	9 p.m.	40
9 p.m.	10 p.m.	30
10 p.m.	Midnight	20

Energy Consumption & Operating Cost

Monthly Energy Consumption



	Energy (kWh/yr)	Total Energy (%)
Lighting	543,183	35
Space Heating	496,624	32
Space Pumps	341,429	22
Space Cooling	170,714	11
Total Energy Consumption (kWh)	1,551,951	100%

Start Time	End Time	Rate
11 p.m.	7 a.m.	Off-Peak
7 a.m.	10 a.m.	Mid-Peak
10 a.m.	8 p.m.	Peak
8 p.m.	11 p.m.	Mid-Peak

Redesign Total Cost per Year = $178,719 or $1.03/sf

= $200,808 or $1.17/sf

	Demand Charge ($/kW)	Peak ($/kWh)	Mid-Peak (cents/kWh)	Off-Peak (cents/kWh)
Electricity	3.95	0.1155	0.0927	0.0882

	Up to first 10,000 therms ($/therm)	Above 10,000 therms ($/therm)
Natural Gas	0.198	0.095

11%

Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - **Results**
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

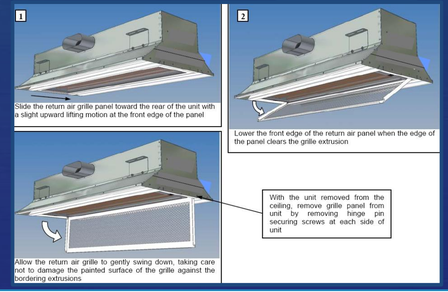
Results

Benefits:

- Lower energy consumption
- Improved comfort
- More usable square footage
- No regular maintenance
- Primary air reduction → duct reduction

Reduced Maintenance:

- No moving parts



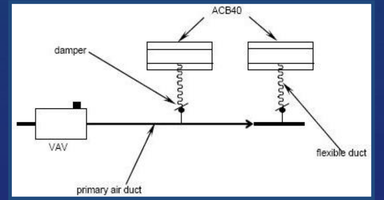
Primary Air Reduction:

- Percent PA Reduction = [1-(Primary Air CFM/Total Current Supply CFM)]*100

Average Percent of PA Reduction = 80%

Duct Reduction:

- With % PA decrease, downsize amount of ductwork
- Flex duct connects PA duct to PA spigot of ACB unit



Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- **Construction Management – Breadth**
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - **Background**
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Background

Potential Savings:

- Installation schedule
- Construction costs

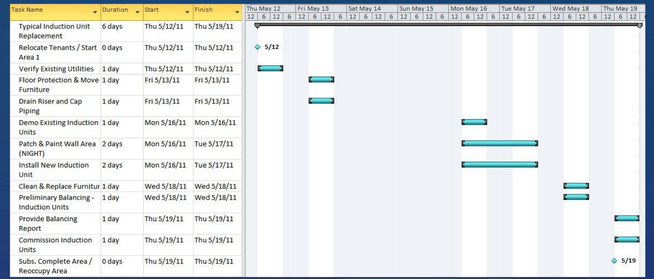
Research Tools:

- Microsoft Project 2010
- Microsoft Excel 2010

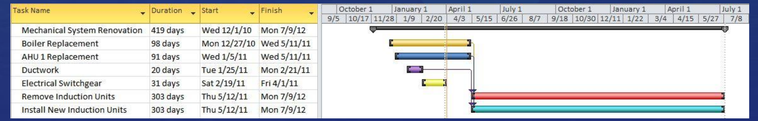
Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - **Schedule**
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Existing System

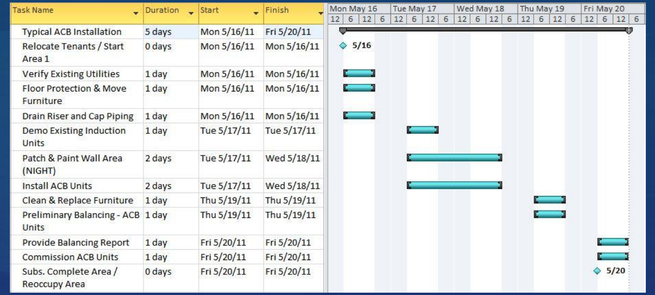


Task Name	Duration	Start	Finish
Typical Induction Unit Replacement	6 days	Thu 5/12/11	Thu 5/19/11
Relocate Tenants / Start Area 1	0 days	Thu 5/12/11	Thu 5/12/11
Verify Existing Utilities	1 day	Thu 5/12/11	Thu 5/12/11
Floor Protection & Move Furniture	1 day	Fri 5/13/11	Fri 5/13/11
Drain Riser and Cap Piping	1 day	Fri 5/13/11	Fri 5/13/11
Demo Existing Induction Units	1 day	Mon 5/16/11	Mon 5/16/11
Patch & Paint Wall Area (NIGHT)	2 days	Mon 5/16/11	Tue 5/17/11
Install New Induction Unit	2 days	Mon 5/16/11	Tue 5/17/11
Clean & Replace Furnitur	1 day	Wed 5/18/11	Wed 5/18/11
Preliminary Balancing - Induction Units	1 day	Wed 5/18/11	Wed 5/18/11
Provide Balancing Report	1 day	Thu 5/19/11	Thu 5/19/11
Commission Induction Units	1 day	Thu 5/19/11	Thu 5/19/11
Subs. Complete Area / Reoccupy Area	0 days	Thu 5/19/11	Thu 5/19/11

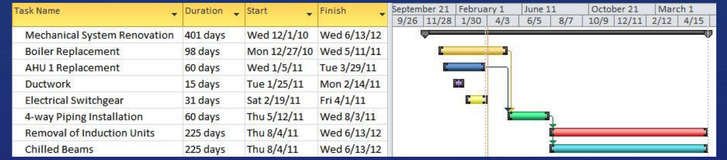


Task Name	Duration	Start	Finish
Mechanical System Renovation	419 days	Wed 12/1/10	Mon 7/9/12
Boiler Replacement	98 days	Mon 12/27/10	Wed 5/11/11
AHU 1 Replacement	91 days	Wed 1/5/11	Wed 5/11/11
Ductwork	20 days	Tue 1/25/11	Mon 2/21/11
Electrical Switchgear	31 days	Sat 2/19/11	Fri 4/1/11
Remove Induction Units	303 days	Thu 5/12/11	Mon 7/9/12
Install New Induction Units	303 days	Thu 5/12/11	Mon 7/9/12

Proposed System



Task Name	Duration	Start	Finish
Typical ACB Installation	5 days	Mon 5/16/11	Fri 5/20/11
Relocate Tenants / Start Area 1	0 days	Mon 5/16/11	Mon 5/16/11
Verify Existing Utilities	1 day	Mon 5/16/11	Mon 5/16/11
Floor Protection & Move Furniture	1 day	Mon 5/16/11	Mon 5/16/11
Drain Riser and Cap Piping	1 day	Mon 5/16/11	Mon 5/16/11
Demo Existing Induction Units	1 day	Tue 5/17/11	Tue 5/17/11
Patch & Paint Wall Area (NIGHT)	2 days	Tue 5/17/11	Wed 5/18/11
Install ACB Units	2 days	Tue 5/17/11	Wed 5/18/11
Clean & Replace Furniture	1 day	Thu 5/19/11	Thu 5/19/11
Preliminary Balancing - ACB Units	1 day	Thu 5/19/11	Thu 5/19/11
Provide Balancing Report	1 day	Fri 5/20/11	Fri 5/20/11
Commission ACB Units	1 day	Fri 5/20/11	Fri 5/20/11
Subs. Complete Area / Reoccupy Area	0 days	Fri 5/20/11	Fri 5/20/11



Task Name	Duration	Start	Finish
Mechanical System Renovation	401 days	Wed 12/1/10	Wed 6/13/12
Boiler Replacement	98 days	Mon 12/27/10	Wed 5/11/11
AHU 1 Replacement	60 days	Wed 1/5/11	Tue 3/29/11
Ductwork	15 days	Tue 1/25/11	Mon 2/14/11
Electrical Switchgear	31 days	Sat 2/19/11	Fri 4/1/11
4-way Piping Installation	60 days	Thu 5/12/11	Wed 8/3/11
Removal of Induction Units	225 days	Thu 8/4/11	Wed 6/13/12
Chilled Beams	225 days	Thu 8/4/11	Wed 6/13/12

Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - **Cost Estimate**
  - Payback Analysis
- Conclusions and Recommendations

Initial Cost Estimate

Existing System

Description	QTY	Unit	Bare Unit Cost - Material	Bare Unit Cost - Labor	Bare Unit Cost - Equipment	Taxes - Material & Equipment	Labor Overhead	Sub-Total
AHU S-1 707	1	EA	$90,000	$12,000	$1,000	$4,550.00	$2,400.00	$109,950.00
Ductwork	2,000	lb.	$0.75	$3.75	$0.50	$0.06	$0.75	$11,625.00
Remove Induction Units	534	EA		$300		$0.00	$60.00	$192,240.00
Install New Induction Units	534	EA	$170	$100		$8.50	$20.00	$159,399.00
Floor by Floor Ductwork Modifications	12	LS	$2,550	$11,000		$127.50	$2,200.00	$190,530.00
Total			$92,721	$23,404	$1,001	$4,686	$4,681	$663,744

Proposed System

Description	QTY	Unit	Bare Unit Cost - Material	Bare Unit Cost - Labor	Bare Unit Cost - Equipment	Taxes - Material & Equipment	Labor Overhead	Sub-Total
New AHU S-1 707	1	EA	$70,000	$10,000	$1,000	$3,550.00	$2,000.00	$86,550.00
Ductwork	1,000	lb.	$0.75	$2.75	$0.50	$0.06	$0.55	$4,612.50
Remove Induction Units	534	EA		$300		$0.00	$60.00	$192,240.00
New Active Chilled Beam Units	391	EA	$750			$37.50	$0.00	$307,912.50
Floor by Floor Ductwork Modifications	12	LS	$2,550	$11,000		$127.50	$2,200.00	$190,530.00
4-way Pipe	6,000	LF	$11.80	$9.65		$0.59	$1.93	$143,820.00
Total			$73,313	$21,312	$1,001	$3,716	$4,262	$925,665

Included

Removal of Induction Units Includes:

- Relocating tenants
- Verifying existing utilities
- Floor protection & furniture moving
- Draining riser & pipe capping
- Patching & painting wall

Initial Cost of:

- Materials
- Labor
- Equipment

Assumptions:

- 5% sales tax
- 20% labor overhead

Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- Conclusions and Recommendations

Cost Estimate

Existing System

Description	QTY	Unit	Bare Unit Cost - Material	Bare Unit Cost - Labor	Bare Unit Cost - Equipment	Taxes - Material & Equipment	Labor Overhead	Sub-Total
AHU S-1 707	1	EA	$90,000	$12,000	$1,000	$4,550.00	$2,400.00	$109,950.00
Ductwork	2,000	lb.	$0.75	$3.75	$0.50	$0.06	$0.75	$11,625.00
Remove Induction Units	534	EA		$300		$0.00	$60.00	$192,240.00
Install New Induction Units	534	EA	$170	$100		$8.50	$20.00	$159,399.00
Floor by Floor Ductwork Modifications	12	LS	$2,550	$11,000		$127.50	$2,200.00	$190,530.00
Total			$92,721	$23,404	$1,001	$4,686	$4,681	$663,744

Proposed System

Description	QTY	Unit	Bare Unit Cost - Material	Bare Unit Cost - Labor	Bare Unit Cost - Equipment	Taxes - Material & Equipment	Labor Overhead	Sub-Total
New AHU S-1 707	1	EA	$70,000	$10,000	$1,000	$3,550.00	$2,000.00	$86,550.00
Ductwork	1,000	lb.	$0.75	$2.75	$0.50	$0.06	$0.55	$4,612.50
Remove Induction Units	534	EA		$300		$0.00	$60.00	$192,240.00
New Active Chilled Beam Units	391	EA	$750			$37.50	$0.00	$307,912.50
Floor by Floor Ductwork Modifications	12	LS	$2,550	$11,000		$127.50	$2,200.00	$190,530.00
4-way Pipe	6,000	LF	$11.80	$9.65		$0.59	$1.93	$143,820.00
Total			$73,313	$21,312	$1,001	$3,716	$4,262	$925,665

Payback

$22,089 energy savings per year

$261,921 initial cost increase

$1.49 / ft^2 increase

Potential payback of 12 years!

Presentation Outline

- Project Information
- Existing Mechanical System
- Mechanical System Redesign - Depth
  - Two-Pipe to Four-Pipe Conversion
    - Background
    - Existing Piping Analysis
    - Installation & Results
  - Chilled Beam Renovation
    - Background
    - Sizing and Selection
    - Energy Consumption and Operation
    - Results
- Construction Management – Breadth
  - Background
  - Schedule
  - Cost Estimate
  - Payback Analysis
- **Conclusions and Recommendations**

Conclusions

Improve:
- ✓ Energy efficiency
- ✓ Occupancy comfort

Criteria:
- ✓ Disturbance to tenants
- ✓ Maintenance requirements

Additionally:
- ✓ Lowered operating cost
- ✓ Reduced ductwork
- ✓ Increased usable square footage

$22,089 energy savings per year

Reasonable payback of 12 years!

Questions?

Acknowledgements

Penn State Architectural Engineering Faculty
Thesis Advisor
- **William Bahnfleth**

Corporate Consultants
- **Matt Keller**, JMT – Facilities Senior Associate
- **Pat Harillal**, JMT – Mechanical Engineer
- **Ron Saunders**, JMT – Environmental Facilities CADD Technician
- **Adam Raver**, JMT – Facilities CADD Technician
- **Jim Hovey**, JMT – Construction Management
- **Alyssa Adams**, McClure Company – Energy Services Specialist
- **Panda Aumpansub**, Havtech Corporation – Application Engineer
- **Cassidy Bowman**, DADANCO – Project Manager
- **Jan Kaczmarek**, SHA Project Manager

Family & **friends**

AE Class of 2011