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Baltimore, MD

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Construction Progress in October 2008

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- Alternative Delivery Method (MAE)
- Chilled Beam Cost & Schedule Impact (Mech. Breadth)
- Case Study: Concrete Over-pour on Decks Due to Steel Deflection (Structural Breadth)
- Thesis Conclusions
- Acknowledgements
- Questions???

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Project Background

Johns Hopkins Hospital

- Ranked #1 Hospital since 1992 by U.S. News & World Report
- Annual Operating Budget = $4.1 Billion (2007)
- 82,523 Admissions, 72,797 Surgeries, 205,034 ER Visits
- 4.2 Million Square Feet of Building Space

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New Clinical Building

- Two Towers – Adult and Children's with Connector
- 1.6 Million SF
- $573 Million GMP
- Oct. 2006 – Dec. 2010
- Design-Bid-Build, Fast-track schedule
- Surrounded by operating hospitals throughout construction

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"Explore alternatives and procedures that could have been implemented on the NCB to avoid or reduce the number of changes and constructability challenges."

WEIGHT MATRIX

Description	Research	Value Engineering	Constructability Review	Schedule Reduction	Total
Alter. Delivery Method	20%	5%		10%	35%
Chilled Beams	10%	10%	5%	15%	40%
Conc. Over-pour on Decks			25%		25%
Total	**30%**	**15%**	**30%**	**25%**	**100%**

Alternative Delivery Method (MAE)

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Problem Statement

- Traditional Design-bid-build with Fast-track
- 60 CCD's
- 2,700 RFI's
- 700 CO's
  - Design Omissions/Errors
  - Donor Enhancements
  - Latest & Greatest Medical Technology
- Cost Increase = $250 M (44%)
- 7 Month Delay (1st pass)
- Bid was done with GMP Docs
  - CD's Due April 2007
  - Issued 2 Floors per Month
  - Final Set Arrived January 2009

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Alternative Delivery Method (MAE)

Goal

- Demonstrate that an alternative delivery method could have more effectively managed the changes while meeting the Owner's goals.

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Alternative Delivery Method (MAE)

Analysis

- Construction Industry Institute's Project Delivery and Contract Strategies (PDCS) Tool
- 12 Possible Delivery Method Outcomes

Possible Project Delivery Outcomes

1. Traditional Design-bid-build
2. Traditional with Early Procurement
3. Traditional with Project Manager
4. Traditional with Construction Manager
5. Traditional with Early Procurement and CM
6. CM at Risk
7. Design-Build
8. Multiple Design-Build
9. Parallel Primes
10. Traditional with Staged Development
11. Turnkey
12. Fast Track

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Alternative Delivery Method (MAE)

Analysis

- Construction Industry Institute's Project Delivery and Contract Strategies (PDCS) Tool
- 12 Possible Delivery Method Outcomes
- 20 Selection Factors

Selection Factors

1. Completion within Budget
2. Minimal Cost
3. Cash Flow is Constrained
4. Owner Requires Early Cost Figures for Planning
5. Owner Assumes Minimal Financial Risk
6. Completion within Schedule
7. Early Completion
8. Early Procurement for Long Lead Items
9. Above Average Number of Changes are Anticipated
10. Below Average Number of Changes are Anticipated
11. Confidentiality of Business/Engineering Details
12. Local Conditions are Favorable
13. Owner Desires High Degree of Control
14. Owner Desires Low Degree of Control
15. Owner Desires Use of Own Resources
16. Owner Desires Minimal Use of Own Resources
17. Project Well Defined at Bid
18. Project Not Well Defined at Bid
19. Owner Prefers Minimal Number of Parties Responsible
20. Project is Complex, Innovative or Non-Standard

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- 12 Possible Delivery Method Outcomes
- 20 Selection Factors
- Surveyed Owner, A/E, and CM Principles

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Alternative Delivery Method (MAE)

Analysis

- Construction Industry Institute's Project Delivery and Contract Strategies (PDCS) Tool
- 12 Possible Delivery Method Outcomes
- 20 Selection Factors
- Surveyed Owner, A/E, and CM Principles
- PDCS Results
- Top 3 Delivery Methods
  - Integrated Project Delivery
  - Design-Build
  - Traditional with Early Procurement and Project Manager

Owner's PDCS Results
Turkey – 81.13
Design-Build – 77.64

CM's PDCS Results
CM@Risk – 68.05
Turkey – 64.91

A/E's PDCS Results
Traditional Design-Bid-Build – 76.25
Traditional with CM – 74.52

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Alternative Delivery Method (MAE)

Integrated Project Delivery

- Not Included in PDCS
- Critical Industry Issue
- Sutter Health System – Camino Medical Center
  - $98M
  - Saved $9M and 6 Months Over Traditional Methods

Alternative Delivery Method (MAE)

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Integrated Project Delivery
- Not Included in PDCS
- Critical Industry Issue
- Sutter Health System – Camino Medical Center
    - $98M
    - Saved $9M and 6 Months Over Traditional Methods
- Principles of IPD

IPD Principals

1. Mutual Respect & Trust
2. Mutual Benefit and Reward
3. Collaborative Innovation and Decision Making
4. Early Involvement of Key Participants
5. Early Goal Definition
6. Intensified Planning
7. Open Communication
8. Appropriate Technology
9. Organization and Leadership

Alternative Delivery Method (MAE)

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Integrated Project Delivery

Advantages
- BIM
- Reduce Project Disputes
- Involve Specialty Contractors Early
- Well Defined Scope for All Team Players
- Open Communication, Pricing, Schedule, and Quality – Better CO Management

Disadvantages
- Not a Familiar Delivery Method in Region
- More Risk for Bidders
- Not a Proven Delivery Method – Too Risky for this Project

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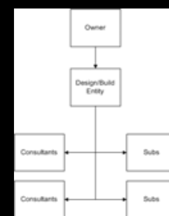
Alternative Delivery Method (MAE)

Design-Build

Advantages
- Team Approach
- Constructability Issues Addressed Early in Design
- Better Control of Budget in Design and Construction Phase

Disadvantages
- Would Not Accelerate Project
- No Checks and Balance
- Risk of Sacrificing Design Quality to Protect Design-Builder's Profits



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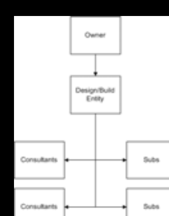
Alternative Delivery Method (MAE)

Design-Build MEP
- Changes have Increased MEP Trades Contracts by 17%
- Severely Impacted Coordination and Prefabrication
- Last-minute Drawings
- Eliminated All of the Float
- D/B MEP would have Cost 5% More Initially

Advantages
- Involved Early in Design
- V/E
- Schedule Input
- Early Coordination, Procurement, and Prefabrication

Disadvantages
- Initial Cost



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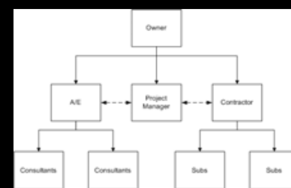
Alternative Delivery Method (MAE)

Traditional w/Early Procurement and PM
- Same Delivery Method Except for PM
- KLMK Group

Advantages
- PM has Extensive Experience
- PM Familiar with Team Players
- Checks and Balance
- Assist Owner with Managing CO's
- Assist with Close-out and Occupancy
- Assist with Master Planning

Disadvantages
- Initial Cost of 1% of Total Project Cost
- May Create Hostile Environment



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Alternative Delivery Method (MAE)

Conclusion
- PDCS Did Not Identify Best Delivery Method
- Hindsight is 20/20
- Best Alternative is a Mix of the Top 3
  - PM
  - D/B MEP
  - IPD Principles
- Manage CO's More Efficiently

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Chilled Beams Cost & Schedule Impact (Mechanical)

Problem Statement

- Top 2 Goals for the Owner, A/E, and CM are Not Being Met
- 1st Package of Changes (CCD 1-38)
  - 7 Months Delay
  - Cost to Accelerate to 3 Months Delay = $2M
  - Mechanical System is Impacted the Most

Goal

- Demonstrate that Chilled Beam HVAC Systems in Non-Invasive Spaces have the *Potential* to Lower Cost (Initial and Life-Cycle) and Accelerate the Schedule.

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Chilled Beams Cost & Schedule Impact (Mechanical)

Current Design

- VAV System with Reheat Coils on Each VAV Box
- Mech. Package Accounts for 29.1% of Construction Cost
- HVAC System Totals 13.9% or $79,444,970
- Critical Path Largely Involves HVAC Overhead
- Central Utility Plant Provides Chilled Water and Steam

Method

- Research Chilled Beams
- Contact Industry Experts
- Size Chilled Beams
- Evaluate Initial Cost
- Evaluate Life-Cycle Cost
- Evaluate Schedule Impact

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Chilled Beams Cost & Schedule Impact (Mechanical)

Chilled Beam System
- Emerging Technology from Europe
- Few Projects in the U.S.A.
  - Constitution Center in D.C.
  - Yale Hospital Expansion in New Haven, CT

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- Save Energy
- Reduce Sizes of Ductwork, AHUs, Fans, etc.

Chilled Beams Cost & Schedule Impact (Mechanical)

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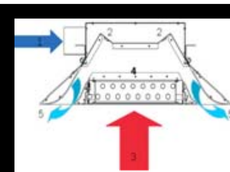
  - Constitution Center in D.C.
  - Yale Hospital Expansion in New Haven, CT
- Save Energy
- Reduce Sizes of Ductwork, AHUs, Fans, etc.
- Two Types of Chilled Beams
  - Passive
  - Active



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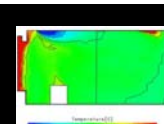
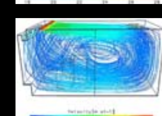
Chilled Beam System
- Emerging Technology from Europe
- Few Projects in the U.S.A.
  - Constitution Center in D.C.
  - Yale Hospital Expansion in New Haven, CT
- Save Energy
- Reduce Sizes of Ductwork, AHUs, Fans, etc.
- Two Types of Chilled Beams
  - Passive
  - Active
- Many Advantages
  - Low Energy Consumption
  - Space Savings
  - Improved Comfort
  - Easy Commissioning





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Chilled Beams Cost & Schedule Impact (Mechanical)

Sizing the Chilled Beam System
- Current VAV System will Remain in Invasive Spaces (ORs, Trauma, Exam Rooms, etc.)
- Examine Typical Areas of Non-Invasive Spaces
  - Offices
  - Patient Rooms
- Extrapolate Results to Remaining Areas

Sizing Calculations
- Size Primary Air to Meet OA or Latent Requirements
- Chilled Beam will be Sized to Handle Rest of Sensible Load
- Assume Supply CFM on Drawings Represent Design Loads
- Sizing is Based on Cooling
- Heating Coil will be Required on Perimeter Spaces

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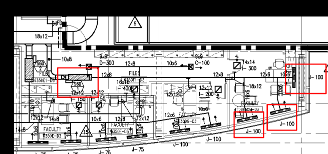
Chilled Beams Cost & Schedule Impact (Mechanical)

Sizing Example
- Typ. Office Space on Level 6
- VAV Box S6D-1
  - Total Supply = 300 CFM
  - 6 Person Occupancy
  - 1 Room is Served by VAV
  - Room Temp = 70˚F
  - Supply Temp = 55˚F



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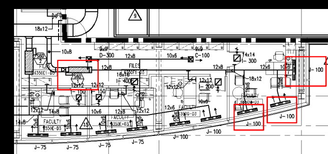
Chilled Beams Cost & Schedule Impact (Mechanical)

1. Total Sensible Design Load = 1.08 x Total Supply CFM x (Room Temp – Supply Temp)
= 1.08 x 300 CFM x (70˚F - 55˚F)
= 4,860 BTU/hr



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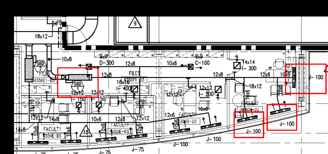

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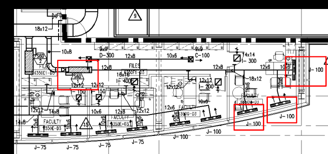
3. Ventilation Air Required = 25 CFM/person x 6 persons = 150 CFM



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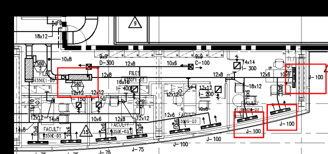
2. Ventilation air required per ASHRAE 62.1 – 2007 is 25 CFM/person for patient rooms. Office spaces are not shown. To be on the conservative side, 25 CFM/person will be used for both the office and patient rooms.

3. Ventilation Air Required = 25 CFM/person x 6 persons = 150 CFM

4. Assume that ventilation air governs primary air supply right now and then check to see if it is greater than the latent load air requirement later.



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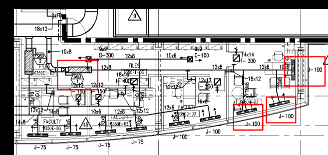
1. Total Sensible Design Load = 1.08 x Total Supply CFM x (Room Temp – Supply Temp)
   = 1.08 x 300 CFM x (70˚F - 55˚F)
   = 4,860 BTU/hr

2. Ventilation air required per ASHRAE 62.1 – 2007 is 25 CFM/person for patient rooms. Office spaces are not shown. To be on the conservative side, 25 CFM/person will be used for both the office and patient rooms.

3. Ventilation Air Required = 25 CFM/person x 6 persons = 150 CFM

4. Assume that ventilation air governs primary air supply right now and then check to see if it is greater than the latent load air requirement later.

5. Sensible Cooling Capacity of Primary Air = 1.08 x Vent. Air CFM x (Room Temp – Supply Temp)
   = 1.08 x 150 CFM x (70˚F - 55˚F)
   = 2,430 BTU/hr



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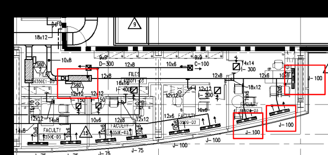
6. Sensible Cooling by Chilled Beam = Total Sensible Load – Sensible Capacity of Primary Air
   = 4,860 BTU/hr – 2,430 BTU/hr
   = 2,430 BTU/hr



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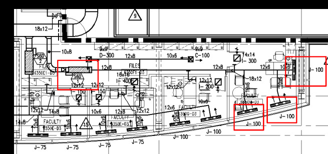
6. Sensible Cooling by Chilled Beam = Total Sensible Load – Sensible Capacity of Primary Air
= 4,860 BTU/hr – 2,430 BTU/hr
= 2,430 BTU/hr

7. Latent load in the room can be approximated by the general rule of thumb that each person gives off 200 BTU/hr of latent load.



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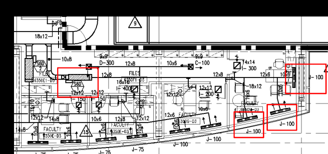
8. Latent Load = 200 BTU/hr/person x 6 person = 1,200 BTU/hr



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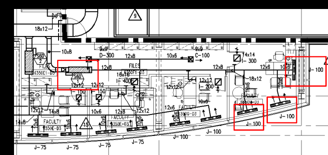
8. Latent Load = 200 BTU/hr/person x 6 person = 1,200 BTU/hr

9. Latent Cooling Capacity of Primary Air = 4,840 x Vent. Air CFM x (W_{Room} – $W_{Primary}$)
= 4,840 x 150 CFM (0.009 – 0.007)
= 1,452 BTU/hr



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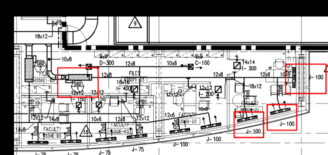
= 4,840 x 150 CFM (0.009 – 0.007)
= 1,452 BTU/hr

10. The latent cooling capacity of primary air is greater than the latent load. Therefore, the ventilation air is adequate in supporting the latent load for the zone.



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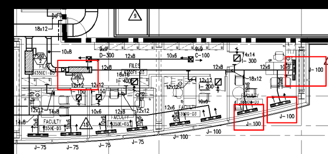
Chilled Beams Cost & Schedule Impact (Mechanical)

11. On average, a chilled beam can produce 1,000 BTU/hr/ft of sensible cooling capacity.



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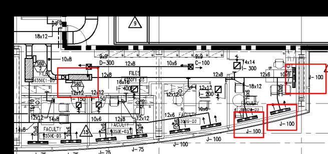
11. On average, a chilled beam can produce 1,000 BTU/hr/ft of sensible cooling capacity.
12. Chilled Beam Size = 2,430 BTU/hr ÷ 1,000 BTU/hr/ft = 2.43 ft Chilled Beam ≈ 3 ft Chilled Beam



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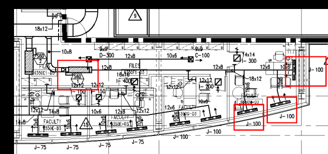
12. Chilled Beam Size = 2,430 BTU/hr ÷ 1,000 BTU/hr/ft = 2.43 ft Chilled Beam = 3 ft Chilled Beam

13. Primary Air Reduction = 1 – (Primary Air CFM ÷ Total Current Supply CFM)
= 1 – (150 CFM ÷ 300 CFM)
= 50%



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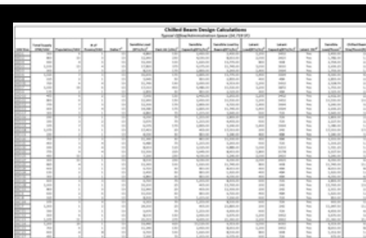
Typ. Office Space
- Primary Air Reduction = 79%
- Average Chilled Beam Size per Room = 5 ft
- Total Cost of VAVs for Typical Area = $15,078 = $0.61/SF
- Total Cost of Chilled Beams for Typical Area = $102,760 = $4.16/SF
- Percent Increase of Chilled Beams over VAV Boxes = 682%



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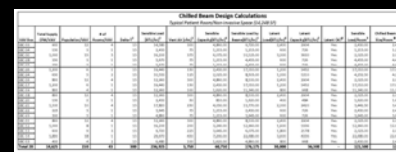
- Percent Increase of Chilled Beams over VAV Boxes = 682%

Typ. Patient Rooms
- Primary Air Reduction = 74%
- Average Chilled Beam Size per Room = 6 ft
- Total Cost of VAVs for Typical Area = $6,854 = $0.48/SF
- Total Cost of Chilled Beams for Typical Area = $49,280 = $3.46/SF
- Percent Increase of Chilled Beams over VAV Boxes = 719%



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Chilled Beams Cost & Schedule Impact (Mechanical)

Cost Impact
- Total HVAC Cost
- Break-down Material and Labor

Total Project HVAC Cost

Description	Material	Labor	Total	% Total
Variable Frequency Drives	$1,019,375	$168,125	$1,187,500	1.5
Hydronic Pump Package	$159,283	$85,702	$244,985	0.3
Condensate Pump Sets	$31,035	$10,813	$41,848	0.1
Steam Specialties	$537,011	$388,896	$925,907	1.2
VAV Boxes & Terminals	$760,743	$267,290	$1,028,033	1.3
Fans & Accessories	$503,782	$95,602	$599,384	0.8
Clean Steam Generators	$134,086	$29,446	$163,520	0.2
Duct Humidifiers	$41,002	$8,398	$49,400	0.1
Custom AHUs	$5,772,000	$1,628,000	$7,400,000	9.3
Ductwork	$15,368,723	$23,053,085	$38,421,808	48.4
Controls	$3,591,315	$1,933,785	$5,525,100	7.0
Mechanical Insulation	$1,320,602	$1,980,904	$3,301,506	4.2
Test & Balance	-	$725,000	$725,000	0.9
Chilled Water Piping	$3,366,041	$1,891,780	$5,257,821	6.6
Heating Hot Water Piping	$4,883,147	$6,600,553	$11,483,700	14.5
Steam & Condensate Piping	$1,312,869	$1,776,589	$3,089,458	3.9
Grand Total	**$38,801,014**	**$40,643,956**	**$79,444,970**	**100**

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Chilled Beams Cost & Schedule Impact (Mechanical)

Cost Impact
- Total HVAC Cost
- Break-down Material and Labor
- Non-Invasive Space HVAC Cost
    - 60% of Total Building Area Non-Invasive Space
    - Assume 25% Extra Cost for Invasive Space
    - 50% of Total HVAC Cost is for Non-Invasive Space

Non-Invasive HVAC Cost

Description	Material	Labor	Total	% Total
Variable Frequency Drives	$509,688	$84,063	$593,750	1.5
Hydronic Pump Package	$79,642	$42,851	$122,493	0.3
Condensate Pump Sets	$15,518	$5,407	$20,924	0.1
Steam Specialties	$268,506	$194,448	$462,965	1.2
VAV Boxes & Terminals	$380,372	$133,645	$514,017	1.3
Fans & Accessories	$251,891	$47,801	$299,692	0.8
Clean Steam Generators	$67,043	$14,723	$81,760	0.2
Duct Humidifiers	$20,501	$4,199	$24,700	0.1
Custom AHUs	$2,886,000	$814,000	$3,700,000	9.3
Ductwork	$7,684,362	$11,526,543	$19,210,904	48.4
Controls	$1,795,658	$966,893	$2,762,550	7.0
Mechanical Insulation	$660,301	$990,452	$1,650,753	4.2
Test & Balance	-	$362,500	$362,500	0.9
Chilled Water Piping	$1,683,021	$945,890	$2,628,911	6.6
Heating Hot Water Piping	$2,441,574	$3,300,277	$5,741,850	14.5
Steam & Condensate Piping			$1,544,729	3.9
	$656,435	$888,295		
Grand Total	**$19,400,507**	**$20,321,978**	**$39,722,485**	**100**

Labor Cost Savings = $11,526,543 x 0.7 = $8,068,580
Total Ductwork Cost = $11,910,761

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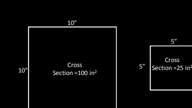
Chilled Beams Cost & Schedule Impact (Mechanical)

Ductwork
- 75% Reduction in Cross-Section
- 50% Reduction in Area => Material
- 30% Savings in Labor

Material Cost Savings = $7,684,362 x 0.5 = $3,842,181
Labor Cost Savings = $11,526,543 x 0.7 = $8,068,580

Total Ductwork Cost = **$11,910,761**



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Chilled Beams Cost & Schedule Impact (Mechanical)

AHUs, Fans, Variable Frequency Drives
- 75% Reduction in Capacity
- P&K Estimate
- 60% Material Savings
- 40% Labor Savings

AHU Material Cost Savings = $2,886,000 x 0.4 = $1,154,400
AHU Labor Cost Savings = $814,000 x 0.6 = $488,400
Total AHU Cost = **$1,642,800**

Fans Material Cost Savings = $251,891 x 0.4 = $100,756
Fans Labor Cost Savings = $47,801 x 0.6% = $28,680
Total Fans Cost = **$129,436**

VFD Material Cost Savings = $509,688 x 0.4 = $203,875
VFD Labor Cost Savings = 84,063 x 0.6 = $50,438
Total VFD Cost = **$254,313**

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Chilled Beams Cost & Schedule Impact (Mechanical)

Chilled Water Piping
- VAV Box Reheat Coil Piping
  - $71.77/ft.
- Analyze a Typ. Space
- 2-Pipe System in Interior (Cooling Only)
- 4-Pipe System around Exterior (Cooling and Heating)

Total Pipe per Area = 2,994 lf ÷ 14,364 SF = 0.21 lf/SF
Non-invasive Area = 1.6M SF x 60% = 960,000 SF
Cost of Chilled Water Pipe to Chilled Beam = 960,000 SF x 0.21 lf/SF x $71.77/lf
= $14,468,832

Add Chilled Water Pipe from Central Utility Plant to AHUs
Total Cost of Chilled Water Piping = $14,468,832 + $2,628,911 = **$17,097,743**

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Chilled Beams Cost & Schedule Impact (Mechanical)

Chilled Beams
- Substitute Chilled Beams for VAV Boxes
- VAV Box Unit Cost = $1,028,033 ÷ 3,000 units = $342.68 (includes diffusers)
- Average Cost of Chilled Beam = $140/ft (Source: Pierces Associates)
- Average Cost of Installing Chilled Beam = $140/ft (Source: Pierces Associates)

Total Cost of Chilled Beams = 960,000 SF x $3.81/SF = **$3,657,600**

	Office Rooms	Patient Rooms	Average
VAV Boxes	$0.61/SF	$0.48/SF	$0.55/SF
Chilled Beams	$4.16/SF	$3.46/SF	$3.81/SF
% Increase	682%	721%	693%

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Chilled Beams Cost & Schedule Impact (Mechanical)

Chilled Beam HVAC System Initial Cost
- Add VAV and Chilled Beam Cost Together
- Total Savings in HVAC Cost = $572,832
- Most of the Savings came from Labor
- Significant Savings in Ductwork
- Savings Offset by Increase Cost of Piping

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Chilled Beams Cost & Schedule Impact (Mechanical)

Building Façade Cost Impact
- Floor-Floor Average Height = 15’
- Ceiling Tile Located 8’-10’ AFF
- Ceiling Plenum Ranges 6’-4” to 4’-4”
- Typ. Girder is W21x57
- Critical Clear Space 2’-7”
- Reduce Clear Space by 50%

Total amount of façade SF reduced = 1’-4”/floor x 15 floors x 2,515’ x 0.6 = 30,180 SF
Total amount of Precast SF reduced = 30,180 SF x 0.43 = 12,977 SF
Total amount of Curtain Wall SF reduced = 30,180 SF x 0.57 = 17,203 SF

Total Savings in Precast = 12,977 SF x $45.77/SF = **$593,957**

Total Savings in Curtain Wall = 17,203 SF x $102.18/SF = **$1,757,803**

Labor Cost Savings = $11,526,543 x 0.7 = $8,068,580
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Chilled Beams Cost & Schedule Impact (Mechanical)

Structural Steel Cost Impact
- Columns can be Reduced by 1’-4”
- 219 Columns per Floor
- Average Weight = 91.6 lbs/ft.

Total Reduction in Steel = 219 columns x 91.6 lbs/ft/column x 1’-4”/floor x 15 floors x 0.6
= 120.3 tons

Total Savings in Structural Steel = 120.3 tons x $2,352/ton = **$283,092**

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Chilled Beams Cost & Schedule Impact (Mechanical)

Energy Savings

- Estimated Annual HVAC Energy Cost = $2.35/SF = $3,760,000
- 50% of Load for Non-Invasive Space => 50% of Energy Cost
- Detailed Energy Model Needed to Predict Energy Savings
  - Constitution Center Saved 23.8%
  - Industry Experts Predict 20-35% Savings
- 3 Scenarios – 15%, 25%, and 35% Savings
- Assume 3% Inflation

5 Year Savings for 15% Efficiency = $1,497,176
5 Year Savings for 25% Efficiency = $2,495,294
5 Year Savings for 35% Efficiency = $3,493,411

10 Year Savings for 15% Efficiency = $3,232,814
10 Year Savings for 25% Efficiency = $5,388,023
10 Year Savings for 35% Efficiency = $7,543,233

20 Year Savings for 15% Efficiency = $7,577,446
20 Year Savings for 25% Efficiency = $12,629,076
20 Year Savings for 35% Efficiency = $17,680,706

30 Year Savings for 15% Efficiency = $13,416,267
30 Year Savings for 25% Efficiency = $22,360,445
30 Year Savings for 35% Efficiency = $31,304,624

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Chilled Beams Cost & Schedule Impact (Mechanical)

Space Savings

- Reduce Mechanical Shaft Space by 50%
- Reduce Mechanical Room Space by 25%
- NCB Generates a Yearly Revenue of $983/SF

Total Space Saving by Mechanical Shaft = 9 x 8' x 26' x 15 floors x 0.5 x 0.6 = 8,434 SF

Total Revenue Generated by Mechanical Shaft = 8,434 SF x $983/SF/Year = $8,280,792/Year

Total Space Saving by Mechanical Room = 80,118 SF x 0.25 x 0.5 = 10,015 SF

Total Revenue Generated by Mechanical Room = 10,015 SF x $983/SF/Year = $9,844,745/Year

Total Revenue from Space Savings = $8,280,792/Year + $9,844,745/Year = **$18,125,537/Year**

Labor Cost Savings = $11,526,543 x 0.7 = $8,068,580
Total Ductwork Cost = $11,910,761

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Chilled Beams Cost & Schedule Impact (Mechanical)

Schedule Impact
- Analyze Typ. Floor
- Baseline Schedule
- Note the Amount of Float for Each Activity

Baseline Typ. Floor Mech. Overhead

Labor Cost Savings = $11,526,543 x 0.7 = $8,068,580
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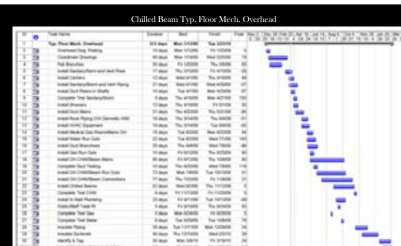
Chilled Beams Cost & Schedule Impact (Mechanical)

Schedule Impact
- Analyze Typ. Floor
- Baseline Schedule
- Note the Amount of Float for Each Activity

Install Duct Risers in Shafts – Decrease by 30%
Install Duct Mains – Decrease by 30%
Install HVAC Equipment – Decrease by 40%
Install Duct Branches – Decrease by 30%
Install OH CHW/RHHW/Steam Mains - Delete Reheat Hot Water (RHHW) and add 275%
Install OH CHW/RHHW/Steam RO – Delete Reheat Hot Water and add 275%
Install OH CHW/RHHW/Steam Connections - Delete Reheat Hot Water and add 275%
Install Grilles, Registers & Diffusers – Delete and add Install Chilled Beams

Chilled Beam Typ. Floor Mech. Overhead



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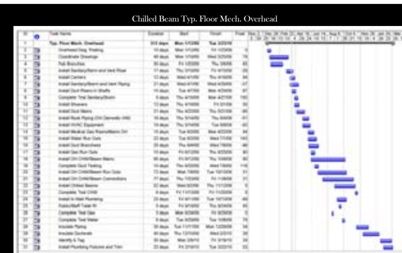
Chilled Beams Cost & Schedule Impact (Mechanical)

Schedule Impact
- Activities that are accelerated are Ductwork and HVAC Equipment
  - Critical Path
  - Accelerates Floor by 31 Working Days
- Activities that Extend the Duration (Piping) are Absorbed in the Float
- Does Not Accelerate the Overall Project Significantly
- Mechanical Overhead is Taken Off the Critical Path
  - Reduce Impact of Changes

Chilled Beam Typ. Floor Mech. Overhead



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Chilled Beams Cost & Schedule Impact (Mechanical)

Conclusion
- Viable Alternative to VAV
- Could Have Taken Mech. System Off Critical Path
- Project Worked Well for Chilled Beams
  - 48% of HVAC Cost was Ductwork
  - Central Utility Plant
  - Small Room Sizes = 1 Chilled Beam/Room
  - High Energy Cost
  - High Revenue per Area
- Many Assumptions
  - More Research and Data Needed

Initial Savings

HVAC Savings = $572,832
Façade Savings = $2,351,760
Steel Savings = $283,092
Total = $3,207,684

Energy Savings

5 Year = $1.5M - $3.5M
10 Year = $3.2M - $7.5M
20 Year = $7.6M - $17.7M
30 Year = $13.4M - $31.3M

Revenue

Total Yearly Revenue Generated = $18,125,537

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Case Study: Concrete Over-pour on Decks Due to Steel Deflection (Structural)

Problem Statement

- Note CP-4
- Contractor Poured Concrete to FF Elevation
- Did Not Check Thickness (Wet-Stick)
- Some Deflections of 2" Mid-Bay
- Contractor Responsible for all Over-pour
- Potential Problems
  - Impact MEP Coordination
  - Overload the Floor
  - Floor Installation
  - Door Jams

CP-4 ALL CONCRETE SLABS ON COMPOSITE METAL DECK AND BEAM CONSTRUCTION SHALL BE UNSHORED, UNLESS OTHERWISE NOTED. CONTRACTOR SHALL SUPPLY THE ADDITIONAL CONCRETE REQUIRED TO LEVEL FLOORS DUE TO DEFLECTION INDUCED BY THE WEIGHT OF THE CONCRETE.

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Case Study: Concrete Over-pour on Decks Due to Steel Deflection (Structural Breadth)

Goal

- Examine How the Concrete Over-pour Issue was Addressed in the Design, Bid, and Construction Phases
- Calculate Typical Bay Deflections
- Strategy for Addressing this Constructability Challenge on Future Projects

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Case Study: Concrete Over-pour on Decks Due to Steel Deflection (Structural Breadth)

Design Phase

- No FL Requirement => Note CP-4
- FF Requirement = 25 (1/4" Over 10')
- Steel Deflection Difficult to Predict
- Camber Girders (Loads Not Predictable)
- Camber Beams (Loads Predictable)
- Engineer Carried 7 PSF for Concrete Over-pour in Construction Load

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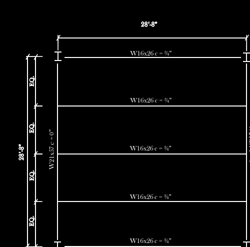
Case Study: Concrete Over-pour on Decks Due to Steel Deflection (Structural Breadth)

Design Phase

- Construction Load 85 PSF (Includes 7 PSF for Over-pour)



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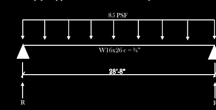
Case Study: Concrete Over-pour on Decks Due to Steel Deflection (Structural Breadth)

Design Phase
- Construction Load 85 PSF (Includes 7 PSF for Over-pour)
- Beam Max Deflection = 1.41" – 0.75" (Camber) = 0.66"

Simply Supported Beam – Uniformly Distributed Load



- Max Deflection (Midspan) = 1.41"
- Up-size beam – W18x35
  - Deflection = 0.83
  - Difference = 0.58"
  - Significant cost – most common steel member

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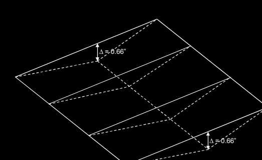

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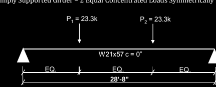
Design Phase

- Construction Load 85 PSF (Includes 7 PSF for Over-pour)
- Beam Max Deflection = 1.41" – 0.75" (Camber) = 0.66"
- Girder Max Deflection = 0.99"

Simply Supported Girder – 2 Equal Concentrated Loads Symmetrically Placed



- Max Deflection (Midspan) = 0.99"
- Up-size beam – W24x55
  - Deflection = 0.85
  - Difference = 0.15"
  - Not Worth Reducing Ceiling Plenum/Height

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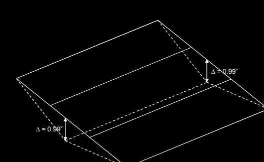

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Design Phase
- Construction Load 85 PSF (Includes 7 PSF for Over-pour)
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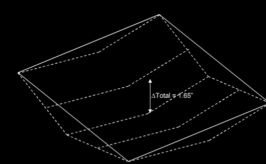
- Total Mid-Bay Deflection = 0.66" + 0.99" = 1.65"



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Design Phase
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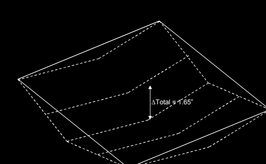
- Beam Max Deflection = 1.41" – 0.75" (Camber) = 0.66"
- Girder Max Deflection = 0.99"
- Total Mid-Bay Deflection = 0.66" + 0.99" = 1.65"

- Total Volume = 2.09 CY
- Load = 10.3 PSF

Assume Total Volume Spread Over Entire Area of Bay

$56.5ft^3 / (28.667')^2 = 0.07' = 7/8"$
Total SF of Building = 1.5M
Total Concrete Over-Pour = 1,500,000 SF x 0.07' = 103,128 ft^3 = 3,820 CY



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Bid Phase

- Clark/Banks Alerted Sub of Note CP-4
- Never Contacted or Asked Question about Anticipated Deflection
- Assumed 10% Extra Concrete
- Carried an Allowance of $100,000 for Reshore and Flash Patching

Case Study: Concrete Over-pour on Decks Due to Steel Deflection (Structural Breadth)

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Construction Phase

- Clark/Banks held Pre-Con Meeting with Concrete Sub
  - Structural Engineer Did Not Attend
- 3 Options to Address Deflection
  - Shore Steel
  - Pour to Thickness then Flash Patch
  - Pour to Level and Pay for Extra Concrete
- 1,200 CY of Over-pour = $100,000
- Used Reshore and Flash Patching Allowance to Cover Cost
- Typical Deflection was 1-1/2" Mid-Bay

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Case Study: Concrete Over-pour on Decks Due to Steel Deflection (Structural Breadth)

Conclusion

- FF, FL, or Notes Similar to CP-4 Should be Clearly Called Out on DWGs and Specs
- CM Should Contact Structural Engineer for Expected Deflections
- Carry an Allowance for Over-pour
- Buildings with Strict FF and FL Requirements Should Consult CM for Constructability
- Survey Deflections
- Check Camber in Shop and Field
- Allow Deflection in MEP Coordination
- Integrated Team Approach would be Very Helpful

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Conclusions

Alternative Delivery Method

A traditional delivery method with early procurement, a project manager, integrated project delivery principles, and design-build MEP contractors would have reduced the risk of changes and managed the rest more efficiently.

Chilled Beams Cost & Schedule Impact

The Chilled Beam HVAC system used in non-invasive spaces could save $3,207,684 initially and an additional $13.4 M - $31.3 M over a 30 year life-cycle. It would also allow JHH to generate an additional income of $18,125,537 per year. This would take the mechanical overhead off the critical path of the building schedule. This system would be able to absorb many of the changes and delays encountered thus far on the NCB project.

Case Study: Concrete Over-pour on Decks Due to Steel Deflection

A failure to communicate early in the design, bid, and construction phases put the concrete contractor at financial risk. The NCB project had a strict levelness specification that required the contractor to over-pour the decks. The result was 1,200 CY of extra concrete that amounted to $100,000 of exposure to the concrete contractor. Further projects can avoid this problem by working with the structural engineer to determine the expected deflections. An allowance should be carried by the contractor to avoid the financial risk associated with this problem.

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