Outline

- Unique Aspects & Existing Conditions
- Thesis Approach
- Four Mechanical Redesigns
- Recommended Design
  - Construction Management issues
- 3D CAD & Mechanical Contractors Research
Unique Aspects

- Educational Forces Involved
  - University of Pennsylvania
  - The Philadelphia Public School District
  - The Philadelphia Federation of Teachers

- School Function
  - Community center – Public access to Gym, Library, & CPU Lab
  - Hub for Philadelphia’s public school staff development programs

- University of Pennsylvania’s Unique Involvement
  - Financially
  - Programming & Curriculum Development
  - Relocation incentives – One time grant of $15,000
  - Social Ramifications – National Standard
  - Community Impact – Property Value
Project Players

Owner: University of Pennsylvania
Architect: Atkin, Olshin, Lawson-Bell
MEP/FP Engineer: E & M Engineering
Structural Engineer: CVM Engineering
Civil Engineer: Urban Engineers
Landscape Architect: Olin Partnership
Construction Manager: Turner Construction
Existing Conditions

Located: West Philadelphia,
4243 Spruce Street
4 acre Lot

Size: 88,236 FT²

Construction Costs: $17.1 million
Existing Mechanical System

- 5 Air handlers – 5,000 to 21,000 CFM
- 2 – 123 hp Cast iron hot water boilers, dual fuel (Natural gas & No. 2 fuel oil)
- 2 – 245 ton water cooled electric driven screw chillers
- 2 – 735 gpm Cooling towers on the roof
- Common Spaces are served by VAV boxes with local reheat
- Unit ventilators and fan coil units are used throughout the building’s classrooms and offices
Thesis Approach

- Mechanical Design-Build Contractor
  - Integrated Design And Construction
  - Accurate System Cost Comparisons
  - Optimized Design, Construction, & Future Retrofit Solutions

Main Focus
Annual Energy Cost Reduction
Base Building Monthly Demand

Demand (kW)

0 100 200 300 400 500 600 700

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Base Building Monthly Demand Charge

- January: $6,000
- February: $6,000
- March: $6,000
- April: $6,000
- May: $6,000
- June: $7,000
- July: $8,000
- August: $8,000
- September: $4,000
- October: $6,000
- November: $6,000
- December: $6,000
Goals for Recommended Mechanical Design

- Lower Annual Operating Cost
- Minimal Impact on Schedule
- Good Life Cycle Cost savings compared to the base system
- Cheaper First Cost
Four Mechanical Design Options Considered

1. Natural gas
2. Enthalpy Wheel
3. Ice Storage
4. Ice Storage And Enthalpy Wheel

Recommended Design
Design Option #1

Natural Gas
Natural Gas

To lower existing annual operating cost

- Alternative energy sources need to be considered
  - Steam
  - Natural Gas
# First Cost of Natural Gas

<table>
<thead>
<tr>
<th></th>
<th>Existing System</th>
<th>Proposed System</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>Screw 245 Ton</td>
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<tr>
<td>Chillers</td>
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<td>One 500 Ton Natural Gas Driven</td>
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<td></td>
<td></td>
<td>Chiller</td>
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<td>Two Fuel Oil</td>
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<td>Boilers and</td>
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<td>Equipment</td>
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<td>Gas Boilers</td>
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<tr>
<td>Total First</td>
<td>$493,417</td>
<td>$472,691</td>
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<td>Cost</td>
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<tr>
<td>First Cost</td>
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<tr>
<td>Savings</td>
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<td>$20,726</td>
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</table>
Natural Gas

Monthly Demand Charge Comparison

Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec

$0   | $1,000 | $2,000 | $3,000 | $4,000 | $5,000 | $6,000 | $7,000 | $8,000
### Natural Gas Cost Summary

<table>
<thead>
<tr>
<th>Existing System</th>
<th>Natural Gas</th>
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</thead>
<tbody>
<tr>
<td>Base Building with two 245 Ton Electric Screw Chillers &amp;</td>
<td>Base Building with one 500 ton Natural Gas Engine</td>
</tr>
<tr>
<td>two 4070 MBH Fuel Oil Boilers</td>
<td>Engine Driven Chiller &amp; two 4070 MBH Natural Gas</td>
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<tr>
<td></td>
<td>Boilers</td>
</tr>
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<td>First Cost $493,417</td>
<td>First Cost $472,691</td>
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<td>Annual Energy Cost $183,716</td>
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<td>Annual Maintenance Cost $7,350</td>
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<td>Total Annual Operating Costs $191,066</td>
<td>$169,785</td>
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</tbody>
</table>

Annual Energy Cost Savings of $25,309
Design Option #2

Enthalpy Wheel (EW)
Enthalpy Wheel

- **Goal – Reduce Overall load for the building**
  - In the Winter EW recovers heat and humidity
  - In the Summer EW recovers cooling and dehumidification

- **Total Energy Recovery Wheels**
  - There are Minimal cross contamination issues in a school

- **Reduction in cooling load is 99 tons**

- **Two Carrier 211 ton water cooled electric driven screw chillers**
# Enthalpy Wheel Cost Summary

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<thead>
<tr>
<th>Base Building Cooling Plant</th>
<th>Enthalpy Wheel</th>
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</thead>
<tbody>
<tr>
<td><strong>Base Building with 2 x 245 Ton Electric Screw Chillers</strong></td>
<td><strong>Base Building with Enthalpy Wheels &amp; two 211 Ton Electric Screw Chillers</strong></td>
</tr>
<tr>
<td><strong>First Cost</strong></td>
<td><strong>First Cost</strong></td>
</tr>
<tr>
<td>$118,000</td>
<td>$118,140</td>
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<tr>
<td><strong>Annual Energy Cost</strong></td>
<td><strong>Annual Energy Cost</strong></td>
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<tr>
<td>$183,716</td>
<td>$160,507</td>
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<td><strong>Annual Maintenance Cost</strong></td>
<td><strong>Annual Maintenance Cost</strong></td>
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<td>$7,350</td>
<td>$6,330</td>
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<tr>
<td>$191,066</td>
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<tr>
<td><strong>Pay Back</strong></td>
<td><strong>4 Days</strong></td>
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</tbody>
</table>
Design Option #3

Ice Storage
Ice Storage

Reasons for choosing ice storage

- High Demand Charge – $11.93/kW
- Ratchet clause – 80% of Demand Jun-Sept
- Peak cooling load is much higher than the average load

Partial Storage – Load Leveling

- Full storage is too expensive & there are no advantages to fully shifting the cooling load
- Partial storage – Demand limiting is too control intensive
Ice Storage

- Chiller Priority Partial Storage
- One Carrier 211 ton screw chiller
- 2,150 ton hours of storage

Design Day Load Profile (July 29th)

- Cooling Load
  - (Met By Storage)
- Charging Storage
- Cooling Load
  - (Met By Chiller)
- Charging Storage

Hours: 0-24
Tons: 0-600

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Construction Management

Spring 2003 Senior Thesis
Pennsylvania State University
Ice Storage

- (4) Calmac 1500 C Tanks 570 Ton-Hrs each
- Full Burial
- Located in Playfield
## Ice Storage Cost Summary

<table>
<thead>
<tr>
<th>Base Building with two 245 Ton Electric Screw Chillers</th>
<th>Base Building with Ice Storage &amp; one 211 Ton Electric Screw Chiller</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First Cost</strong></td>
<td><strong>Annual Energy Cost</strong></td>
</tr>
<tr>
<td>$118,000</td>
<td>$183,716</td>
</tr>
<tr>
<td><strong>Total Annual Cost</strong></td>
<td>$191,066</td>
</tr>
<tr>
<td><strong>Pay Back</strong></td>
<td>2.7 Years</td>
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</tbody>
</table>
Design Option #4
Ice Storage & Enthalpy Wheels
Ice Storage & Enthalpy Wheels

- Overall Load Reduction from the enthalpy wheels

**Diagram:**

Design Day Load Profile (July 29th) with Enthalpy Wheel

- **Cooling Load** (Met By Storage)
- **Cooling Load** (Met By Chiller)
- **Charging**
- **Storage**

99 Ton Reduction
Ice Storage & Enthalpy Wheels

- Design Capacity is 1800 ton-Hrs
- (3) Calmac 1500 C Tanks 570 Ton-Hrs each
- (1) Calmac 1098 C Tank 115 Ton-Hrs
- One Carrier 166 ton electric screw chiller
- Full Burial
- Same Location as in previous Analysis
# Ice Storage & Enthalpy Wheels Cost Summary

<table>
<thead>
<tr>
<th></th>
<th>Base Building with two 245 Ton Electric Screw Chillers</th>
<th>Base Building with Ice Storage, Enthalpy Wheels, and one 166 Ton Electric Screw Chiller</th>
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</thead>
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<tr>
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<td>$118,000</td>
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<td><strong>Annual Energy Cost</strong></td>
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<td><strong>Annual Maintenance Cost</strong></td>
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<td><strong>Total Annual Cost</strong></td>
<td><strong>Pay Back</strong></td>
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<td></td>
<td>$191,066</td>
<td><strong>2.2 Years</strong></td>
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<td></td>
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<td><strong>Annual Energy Cost Savings of $80,689</strong></td>
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</table>
Recommended Design
Recommended Design

- Change base building heating plant to natural gas to pay for the increased first cost of cooling plant

First Cost Savings of $263,131

<table>
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<tr>
<th>Two Fuel Oil Boilers and Supplemental Equipment</th>
<th>Two Natural Gas Boilers and Supplemental Equipment</th>
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<tbody>
<tr>
<td>$375,417</td>
<td>$112,286</td>
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</table>

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Recommended Design

Choose Lowest

- Operating Cost
- Highest LCC savings vs. base building over a 20 year period
**Recommended Design First Cost Summary**

<table>
<thead>
<tr>
<th>Existing System</th>
<th>Proposed System</th>
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<tbody>
<tr>
<td>Two Electric Screw 245 Ton Chillers</td>
<td>Ice Storage System</td>
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<td>$118,000</td>
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<tr>
<td>Two Fuel Oil Boilers and Supplemental Equipment</td>
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<td>Two Natural Gas Boilers</td>
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<td>$37,960</td>
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<td>Total First Cost</td>
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<td>$405,452</td>
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**First Cost Savings** $87,966
Recommended Design

Demand Charge Reduction

Monthly Demand Charge

- January
- March
- May
- July
- September
- November

- $0
- $1,000
- $2,000
- $3,000
- $4,000
- $5,000
- $6,000
- $7,000
- $8,000
# Recommended Design Cost Summary

<table>
<thead>
<tr>
<th>Existing Building</th>
<th>Recommended Design</th>
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<tbody>
<tr>
<td>Base Building with two 245 Ton Electric Screw Chillers &amp; two 4070 MBH Dual Fuel Boilers</td>
<td>Base Building with Enthalpy Wheels, Ice Storage, 166 ton Screw Chiller, &amp; two 4070 MBH Natural Gas Boilers</td>
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<tr>
<td>Existing Building</td>
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<td>$183,716</td>
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**ANNUAL ENERGY COST SAVINGS OF $78,615**
Recommended Design

Construction Schedule

Tank Installation

Excavation and Site utilities

2/01  3/01  4/01  5/01  6/01  7/01  8/01  9/01
4/02  5/02  6/02  7/02  8/02  9/02  10/02  11/02  12/02

Mobilize, Install Fence & Gates
Site Demolition
Foundation Excavation
Foundation Concrete East Building
Substructure Begins
Underground Plumbing
Concrete Walls East Building
Site Utilities
Slab on Grade East Building
Foundation Concrete West Building
Slab on Grade West Building
Concrete Walls West Building
Criteria for Recommended Mechanical Design

- Lower Annual Operating Cost $78,615
- Minimal impact on Schedule OK
- Good life cycle cost savings compared to the base system $1,248,411
- Cheaper First Cost $87,966
3D CAD & Mechanical Contractors
3D CAD & Mechanical Contractors

- **Reasons for the study**
  - 3D CAD has been around for a long time
  - Contractors are trying to work out the use, benefit, and owner value of 3D CAD
  - My goal is for other companies to learn from the mechanical contractor’s effective use of 3D CAD, and how 3D CAD might work for their company

- **Why investigate Mechanical Contractors?**
  - Leaders in the industry in use and application of 3D CAD
<table>
<thead>
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<th>Function</th>
<th>Use</th>
<th>Benefit</th>
<th>Owner Value</th>
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<td>Shop Drawings</td>
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<tr>
<td>Fabrication Drawings</td>
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<td>Assembly Drawings</td>
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<td>Prefabrication</td>
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<td>Project Planning/Management</td>
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<td>As-Builds</td>
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3D CAD & Mechanical Contractors

Lessons Learned

- Employ 3D CAD in one area and it will grow into other areas within the company.
- The main challenge is to implement, and effectively manage this technology.
- Take what your company already does well and make it better by using 3D CAD technology.
- Trying to emulate another company’s process, and their use of 3D CAD will only stall the potential benefits.
I WOULD LIKE TO THANK:

Pennsylvania State University
- Dr. Horman
- Dr. bahnfleth
- Dr. Riley
- Dr. Mumma

Turner Construction
- Jeffrey Klinger
- Meghan Shcuster
- Atkin, Olshin, Lawson-Bell
- Stuart Mardeusz
- John J. Kirlin
- Dan Liscinsky

MacDonald-Miller Facility Solutions
- Casey Tomich

University Mechanical Contractors, inc.
- Brett Endres
- McKinstry Co.
- Ben Hampson
- Southland Industries Inc.
- Ted Lynch

My Parents, Brothers, Kimberly, Joe
- DiIenno, Andrew Tech, Becky Mittel, Brent
- Diller, and All my Friends

James W. Meacham
Construction Management
QUESTIONS