Princeton University

CHILLED WATER $\Delta T$
& PLANT UPGRADES

Results & Lessons Learned

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Challenges

- Increase CHW Distribution Capacity (Flow)
- Increase CHW Production Capacity (Tonnage)
- Economic Efficiency
- Big Picture Perspective
Background / Existing

- Single CHW Plant
  - 10,100 tons steam turbine driven chillers
  - 5,650 tons electric driven chillers
- Cogeneration Facility
  - 15 MWe / 300,000 pph steam
- Original $\Delta T = 15^\circ F$
  - Current $\Delta T = 12.3^\circ F$
  - Inefficient / ineffective coil & valve selection/operation
- Flow current capacity limiter, not tonnage
- Tonnage limitation approaching
  - Significant campus growth (about 40% more load planned) 2004 - 2008
Solutions

- Improve $\Delta T$
- Upgrade Distribution Infrastructure
- Real-time Economic Dispatch
- Increase CHW Production Capacity
- Thermal Energy Storage
- Reduce Supply Temperature
**Improve \( \Delta T \)**

- **AHU Evaluation**
  - Coils – old, maintenance challenge, low \( \Delta T \)
  - Identified 28 Coils (10 AHUS)
    - 100-400 tons/ahu
  - Design \( \Delta T \) 14-19° F
    - Recommend 20-24° F
  - No increase \( \Delta P \) water
  - Minimal air \( \Delta P \)
    - Test existing fans
      - CFM vs. \( \Delta P \) for available capacity
**Improve $\Delta T$ – Coil Replacement**

- Improvement potential 0.4° F CHW
  - Projected flow savings 675 gpm
  - Effective 560 ton capacity bldg @ 20° $\Delta T$
  - No new pumping

- **Conclusion**
  - Review conventional design standards
    - No right answer for all situations
  - Opportunity for additional flow capacity warrants evaluation of overall system benefits
\[ \Delta T \] – Valve / Coil Relation

- Typically oversized coils in design
  - Cause valves to hunt
- 50% Flow can equal 90% Heat Transfer
Typical Cooling Coil

Heat Output vs. Flow

Heat Output, %

Flow, %

0 10 20 30 40 50 60 70 80 90 100

0 10 20 30 40 50 60 70 80 90 100

2004 ASHRAE Handbook – HVAC Systems and Equipment – 42.8, Figure 17
Improve $\Delta T$ - Valves

- At AHUs Performing $\Delta T_{\text{actual}} < \Delta T_{\text{design}}$
  - New PI flow control valves being used
- Last 3 years, Princeton installed 104 valves
  - Improved $\Delta T$ at peak & part load
  - New design standard
- Limit Flow Fluctuations and Now Steadier Service
ΔT Improvement Summary

- Only a portion installed to date
  - 104 valves – approx 1/4 – 1/3 of campus load
  - 5 coils
    - Design standards updated to minimum 20°F ΔT
- To date 1.5°F ΔT Improvement
- No issues with customers where upgrades have been implemented
ΔT Improvement Summary

Chilled Water Temperature Differential, 2005 vs. 2002

![Graph showing the comparison of average temperature differentials between 2005 and 2002. The graph indicates a trend where the average differential (ΔT) increases with the outside air temperature.](attachment:graph.png)
ΔT Improvement Summary

- Coils projected 0.4° F when complete but only 18% to date
- Valve replacement showing dramatic impact
  - More consistently above 13°F ΔT (up to 16)
  - Includes lowering supply temperature impact
- 1.5°F ΔT Overall Campus Improvement
  - Approx 1500 tons more available on design day
  - Distribution capacity increased
  - Reduced pumping $ rest of year
**ΔT Improvement Update**

- **Lowered Supply Temperature**
  - Positive results to date
  - Will do better when:
    - New buildings come on line
    - More valves and coils replaced

- **When Reduced Supply:**
  - Slight *Increase in Return Temp* for Overall Campus
  - Greater *Increase in Return Temp* at Newer Facilities
  - Increase DT achieved
LOWERING SUPPLY TEMPERATURES

Campus CHW Supply & Return
Spring 2006

- CHW Supply Temp, °F
- Degrees F.
- RETURN TEMP
- DIFFERENTIAL TEMP

Graph showing the relationship between CHW Supply Temp and Temperature Differences.
LOWER SUPPLY TEMPERATURES

Lewis Thomas CHW 9/2/05

CHW Temp, F

CHW RETURN T

CHW DT

CHWS Temp, F
Upgrade Distribution
Infrastructure

- Study included existing loads and 10 year projection (60% increase)
- Restore ~500’ (2) 20” lines to service
- 2500 ft. – (2) 16” lines existing
  - Add new 30” supply in parallel
  - Convert existing supply to parallel return
  - Resulted in \( \Delta P \) and Energy Decrease
- 1000 ft – 24” new supply and return
  - In service March 2006
New Distribution Piping
Real Time Economic Dispatch

- Originally day/night/weekend/seasonal tariff
- August 2003 – Electric Deregulation in NJ
- Princeton Purchases @ Wholesale Market
  - Rate
    - Day: as high as $300/MWH
    - Night: often $20/MWH – or less!
    - Princeton marginal cost to self generate
      - $60/MWH – fuel driven
Real Time Economic Dispatch

- Predicts Campus Energy Demands
  - Electricity, steam, & chilled water
- Recommends Most Cost Effective Equipment Combination
- Model Inputs (Real Time)
  - Weather
  - NYMEX Gas & Oil Prices and Futures
  - Campus Demands
  - Equipment Availability
Real Time Economic Dispatch

- Usage / Implementation
  - Expert reference source
  - Operators make final decision considering:
    - Reliability Issues
    - Local Storms
    - Campus Events

- Nov 05 - $28,000 estimated saved
- Projecting $500k - $800k annual savings
Economic Dispatch System
Example Screen
Green lines indicate charging of TES tank in tons
Red lines indicate discharging of TES tank in tons
Blue line indicates price of power in $$/per MWh

Compressors are recovered and charging resumes

Preemptive discharging of TES tank by VIX calculations in even more expensive hours

TES tank capacity is reserved during very expensive hours

Loss of charging compressors caused reduced capacity in TES tank.

charging resumes
Plant Expansion

- $\Delta T$ & $\Delta$ Improvements – Great Start
- Needed more physical tonnage for long term growth
- Considerations/Issues
  - Two plant flow sequencing control
  - Thermal energy storage system
  - Efficiency and turndown
  - Supply temperature reduction
  - Architectural considerations
New Plant/Expansion

- (2) 2500 Ton Dual Compressor Chillers
- (4) 2500 Ton Plate-and-Frame HEX’s
- Distributed Control System
  - Integrate New & Existing CHW Plants
  - Interface with Cogen Plant
  - Upgrade HMI Graphics & Historian
BASIC FLOW SCHEMATIC

- **Cooling Tower**
- **Chiller**
- **Thermal Storage Tank**
- **Plate & Frame Heat Exchanger**

**Flow Details:**
- Warm water from HTX or tank ~ 56°F
- Cold water To HTX or tank ~ 32°F
- Warm water from Campus ~ 58°F
- Cold water To Campus ~ 34°F
- Warm vapor
Two Plant Flow Sequencing
& Control

- Operate in Lead / Lag configuration
- Economic dispatch model recommends lead/lag selection of plants
- Auto control using remote DP; allows lowering DP setpt
  - Approx $14,000/yr saved
  - Will reduce pressure spikes, help older valves
Thermal Energy Storage System (TES)

- 40,000 Ton-Hours
- Decoupled from campus w/ HEX
  - TES System = Atmospheric
  - Campus System = High Pressure
  - Chemical Treatment Isolation
- Plant = 5,000 tons – chillers only
  = 10,000 tons w/TES
- Distribution pumps are true upper ceiling tonnage
Thermal Energy Storage System (TES)

- 32°F CHW with density depressant maximize ton-hours
  - Allows for stratification below 39°F
  - No increase in physical tank
  - @ 24 °F $\Delta T : 40,000$ ton-hours
    - New plant design
  - @ 16 °F $\Delta T : 26,667$ ton-hours
    - Campus design return and 40 °F low limit
Thermal Energy Storage System (TES) - Update

- Additional Optimization
  - Putting colder (32 deg) water in tank, but distributing at 44 deg to campus
    - Extends discharge capacity (time)
    - Beneficial when loads down and not pumping challenged
    - Longer period of increased value available
    - Flexibility to react to dynamic utility costs
Efficiency and Turndown

- Series Chiller Configuration
- Utilize TES for best turndown / low loads
Architectural Considerations

- Extension of Campus Theme / Feel
- No Longer Separate Industrial Area
- Unique Combination Architecture/Engineering
  - Challenges overcome
  - Functionality maintained
Architectural Considerations
Lessons Learned

- Verify Pump Efficiencies
  - Typical flow and head review may not be enough

- Permit Schedule
  - Add even more than typically projected
    - Utility plant vs. Building

- Reduction in Supply T outpaces Reduction in Return T for Existing (older) Facilities

- HEX Decoupling Worthy of Significant Consideration
Lessons Learned

- Getting Contractor on Board Early – Some Benefits
  - Limited Feedback during Reviews
  - Good for Cost Estimating / Hitting Ground Running
- Commissioning Agent on Board During Design
- (5) 8 hour days plus 2nd shift vs. (4) 10’s plus a 5th day
  - (4) 10’s more effective schedule (cogen vs. chw)
Princeton Receives High Marks

- Increased Flow
- Increased Tonnage
- Improve $\Delta T$
- Positioned For Future
- Economic Dispatch
- Capacity, Reliability, Efficiency