Water and Air Handling Systems at the Advanced Photon Source

Environmental Control for Critical Applications

Water and Air Handling Systems

- **Water and air systems provide a means of heat transfer to cool and temperature stabilize technical equipment and to control space environments.**
- **Key parameters include:**

Heat transfer rate

Temperature Stability

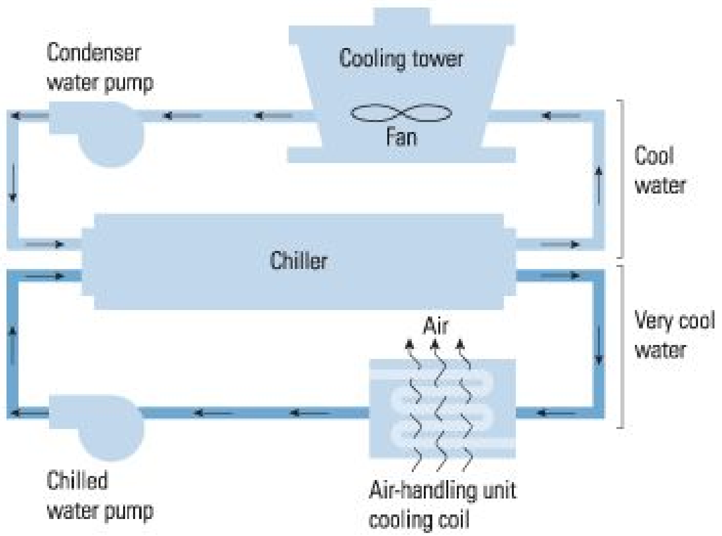
Noise

Vibration

Moisture control

<u>Systems that directly control space and equipment temperatures rely primarily on water and air as working fluids for heat transfer and air for moisture control.</u>

With the air systems integrated into the water cooling loop.



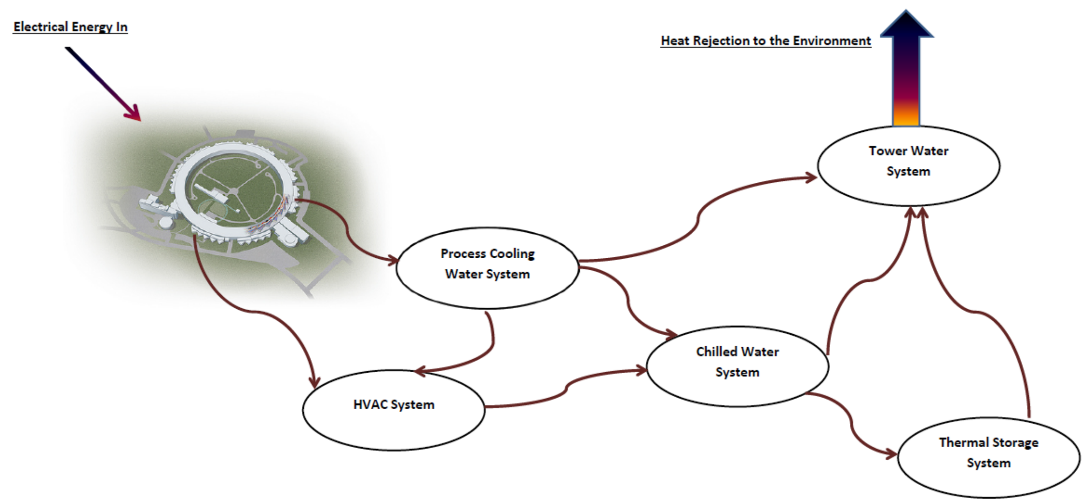
Courtesy: E source; adapted from EPA

Water Cooling Systems

The APS Cooling Water System (CWS) is a multi-stage fully integrated cooling network that includes the following subsystem components:

- **Cooling Tower Water Subsystem (TWS)**
- **Primary Refrigeration/Chiller Subsystem (PCHWS)**
- **Secondary Chilled Water Distribution Subsystem (SCHWS)**
- **Deionized Process Cooling Water Subsystem (PWS)**
- **Ice Thermal Storage and Distribution Subsystem (TSS)**

Energy flow path for the APS system:



APS Cooling Water System Energy Flow Path

Cooling Tower Water System

- **Cooling Tower Water System (TWS)**
  - Consists of 3 Cooling towers
    - Two 3 cell towers
    - One 2 cell tower

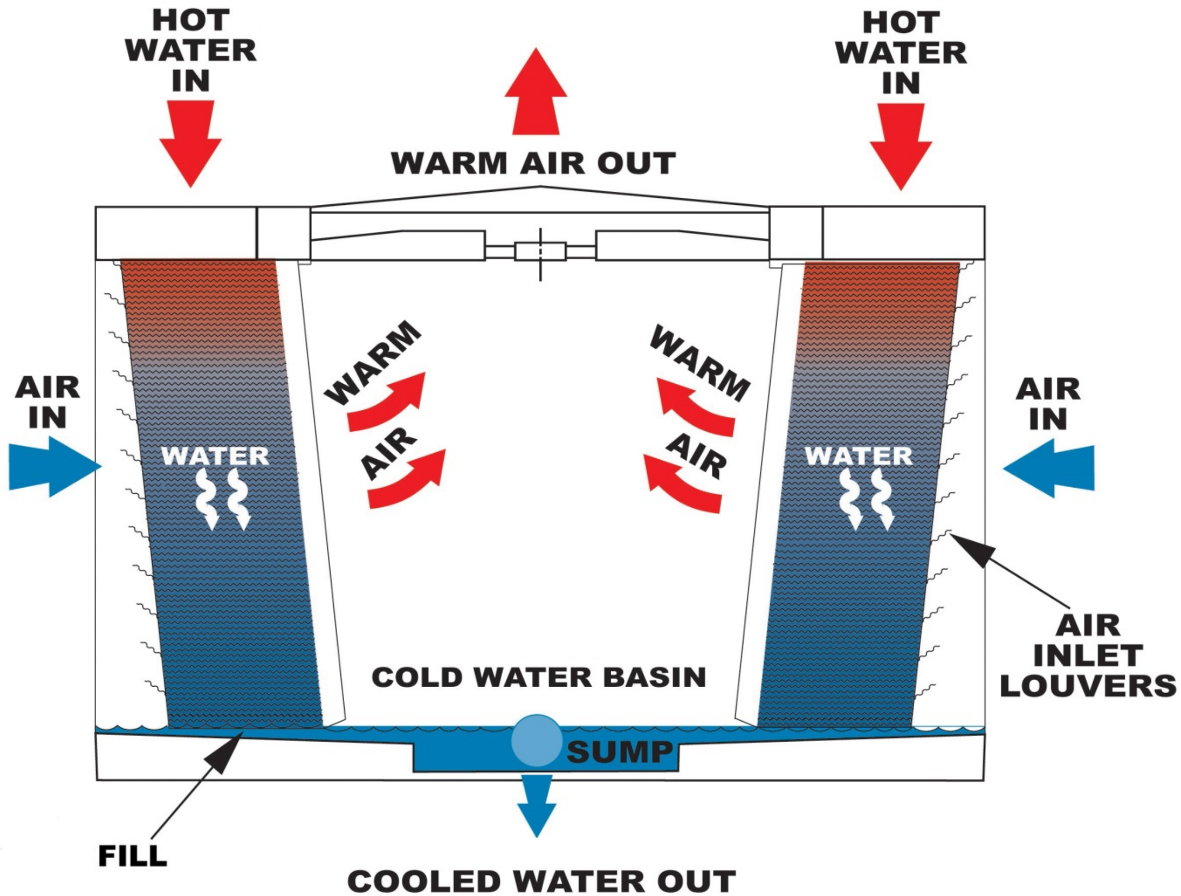
APS Cooling Towers Looking North

APS Cooling Towers - View from LOM 431 Looking East

- **The TWS can reject a total of 18,150 tons (63.8 MW; equivalent):**
  - Water is pumped through a common manifold to:
    - Chilled Water System
    - Deionized Process Cooling Water System
    - Thermal Storage System

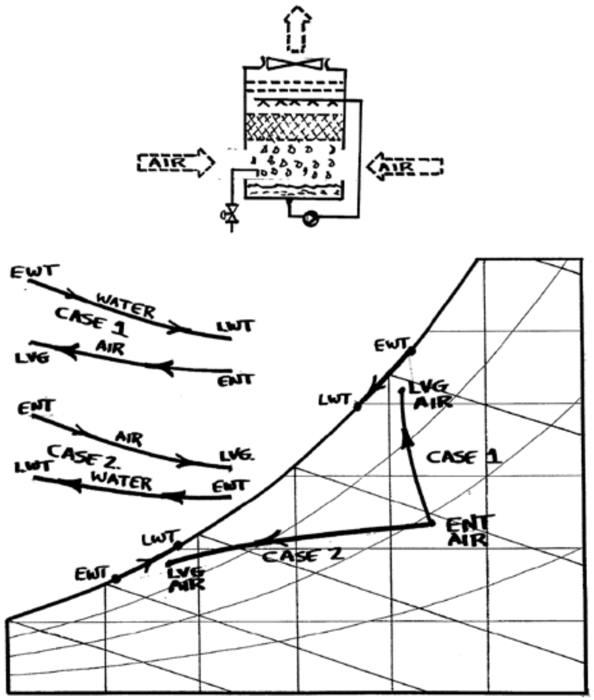
Cooling Tower Water System

Illustration of the mechanics of a forced draft cooling tower



<u>**Typical Cooling Tower Schematic**</u>

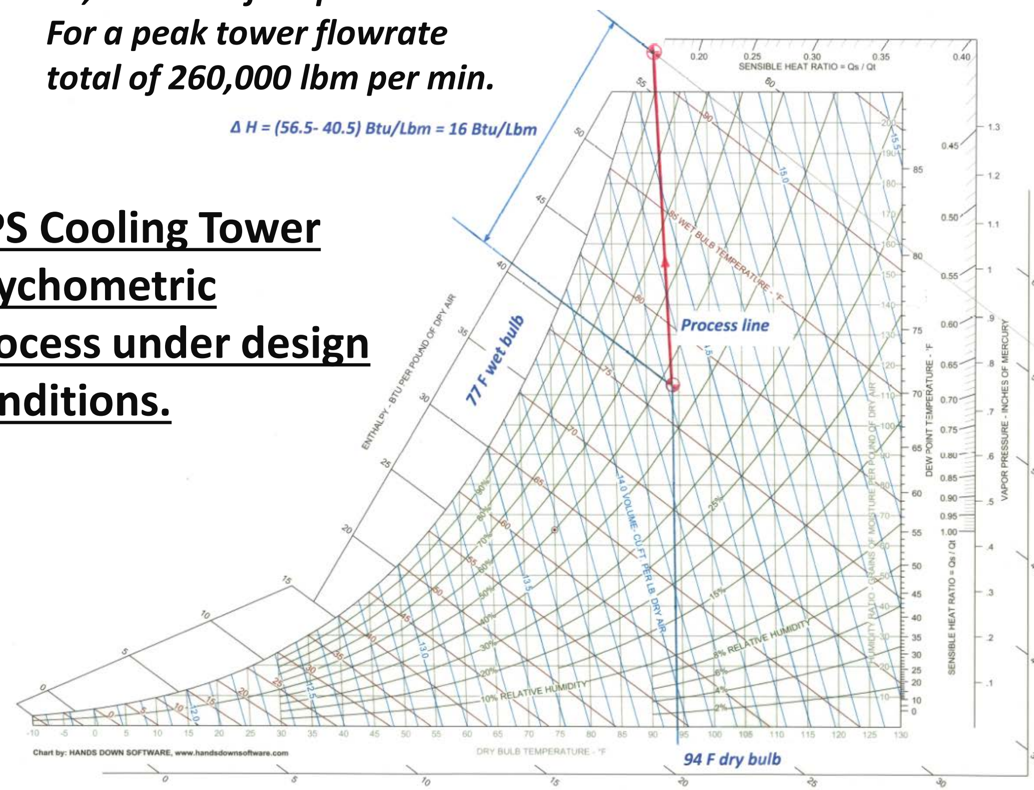
Cooling Tower Water System



Typical Cooling Tower Psychometric Process

Psychometrics of Evaporative Cooling

Each tower cells can flow 33,000 lbm of air per minute. For a peak tower flowrate total of 260,000 lbm per min.



APS Cooling Tower Psychometric Process under design conditions.

Water Cooling Systems

- There are two primary water cooling systems at APS that are connected directly to the heat loads:
  - Chilled Water System (CHWS)
    - Provides cooling to the PWS, air handling units and tertiary process cooling systems.
    - Cooling is provided by vapor compression centrifugal chillers
    - Heat is rejected from the chillers to the APS TWS
  - Deionized Process Cooling Water System (PWS)
    - Primarily used for heat rejection for power supplies, magnets, and beam lines
    - Two Stage Cooling System
      - First stage is evaporative cooling via direct connection to the APS TWS
      - Second stage is chilled water cooling using water from the APS CHWS

Chilled Water System

LET US LOOK AT THE CHILLED WATER SUB SYSTEM

Chilled Water System

- **The APS chilled water system is a district cooling system with a peak capacity of 12,150 tons (42.7 MW; equivalent).**
- **The primary system consists of:**
  - **Three (3) 2100 ton R-22 centrifugal chillers installed in 1992**
  - **12,000 ton-hour ice water thermal storage system (R-22)**
  - **1400 ton R-134a centrifugal chiller and two 1700 ton R-134a centrifugal chillers.**

Chilled Water System
Chiller Refrigeration Cycle

Chilled Water System

Primary - Secondary Water Distribution Systems

- These systems are employed to achieve any or all of a combination of the following:
  - Fluid Separation
  - Temperature Control
  - Pressure Elevation

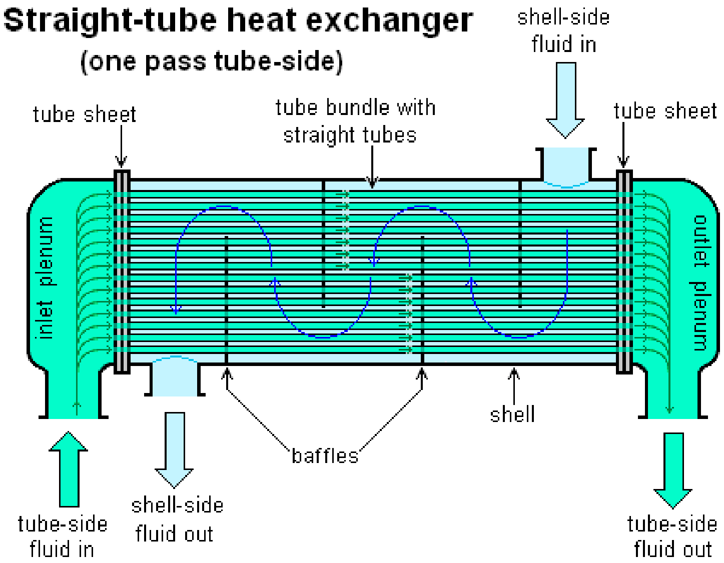
- There are two general methods of creating Primary – Secondary systems. Both methods are used in the APS water systems.

Primary - Secondary Water Distribution Systems

– **The Heat Exchanger Method provides a physical barrier between fluids typical examples are:**

<u>Plate and frame heat exchanger</u>

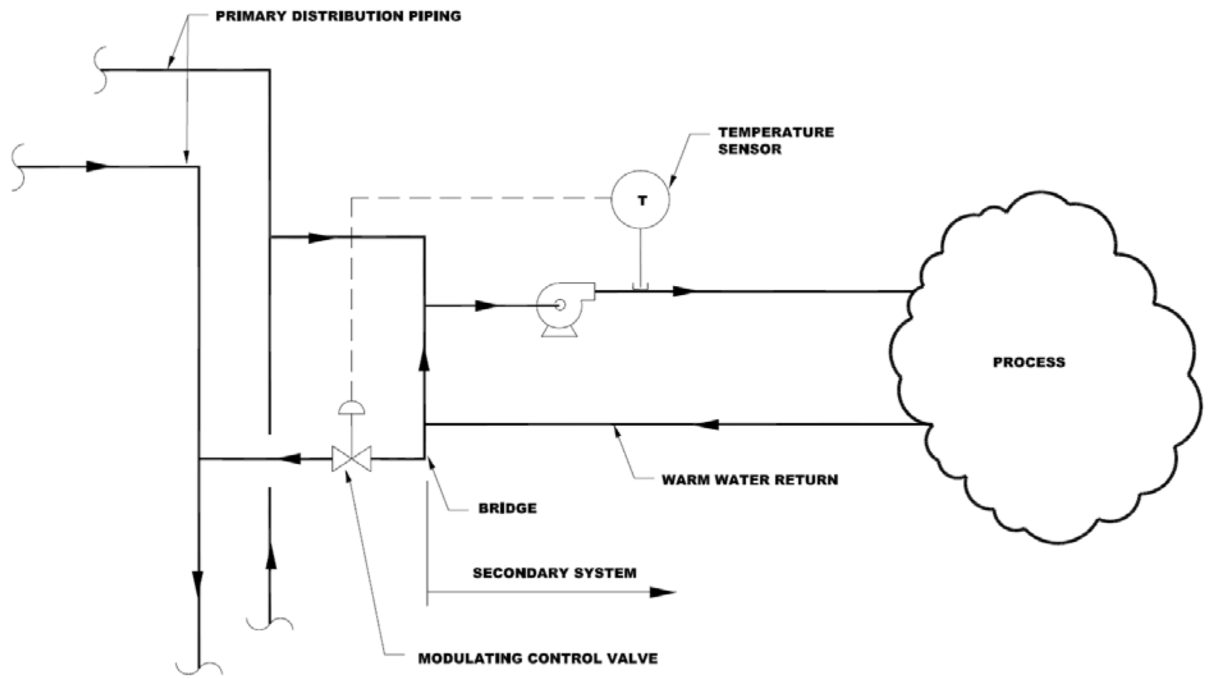
<u>Shell and tube heat exchanger</u>



Primary - Secondary Water Distribution Systems

Integral Primary – Secondary system Method

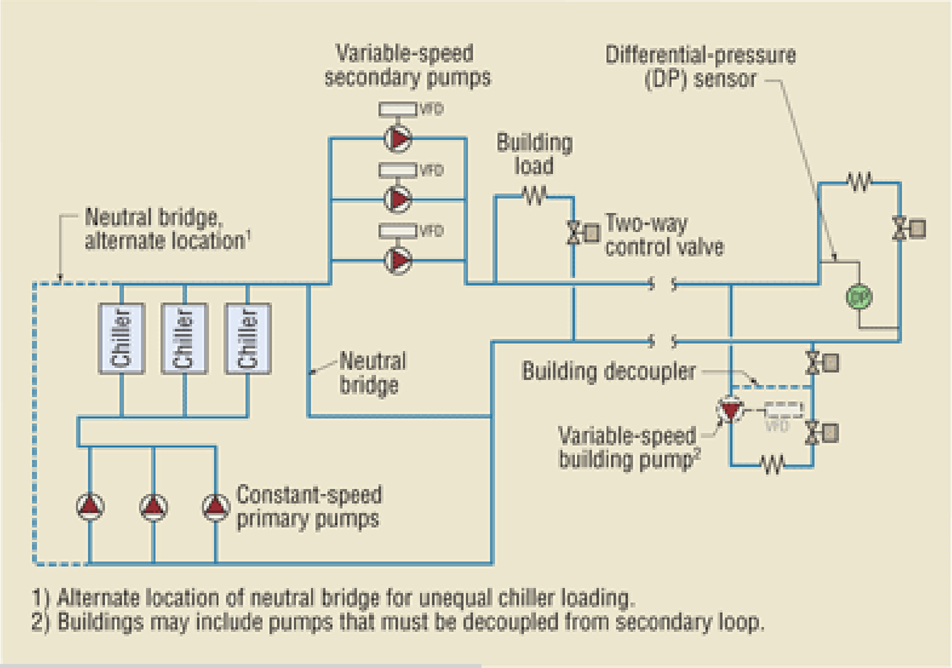
Fluid from one system can traverse the boundary of the other system allowing for mixing or complete exchange of fluid flows



Chilled Water System

- **<u>Returning to our discussion of the Chilled Water System-</u>**
- **The chillers are connected to create the primary water loop for the APS**
  - **Each chiller is provided with a dedicated primary pump to establish water circulation through each machine.**
  - **Secondary pumps are connected to circulate water in the main distribution loop that carries water to its point of use.**

<u>A typical example of this arrangement</u>



<u>Typical primary secondary loop</u>

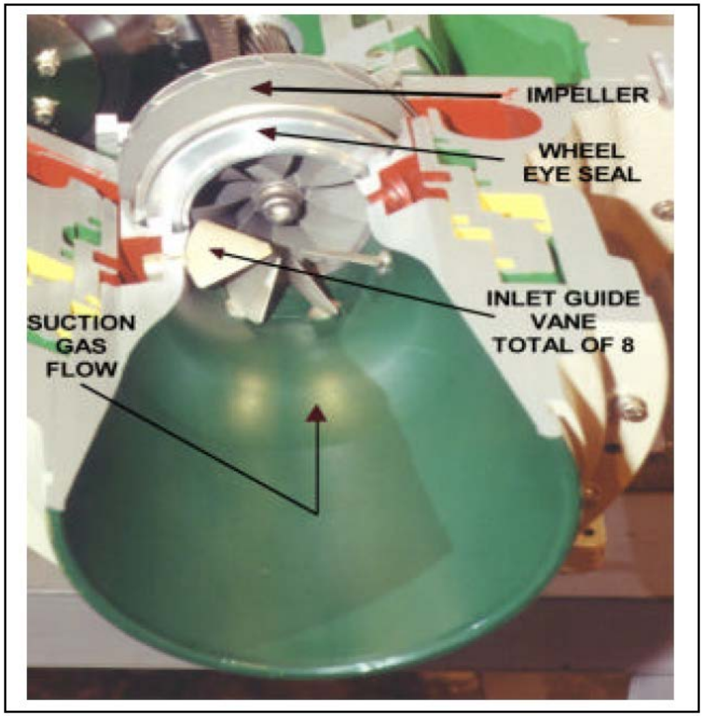
Chilled Water System
Capacity and Temperature Control

- **The primary temperature control of the chilled water is provided internally by the chiller capacity control inlet vanes and the control panel provided with the chiller by the manufacturer.**

The APS chillers are constant water flow units and the water temperature control is maintained by modulating the refrigerant flow within the chiller.

This is accomplished by inlet vanes that open and close restricting the flow into the compressor.

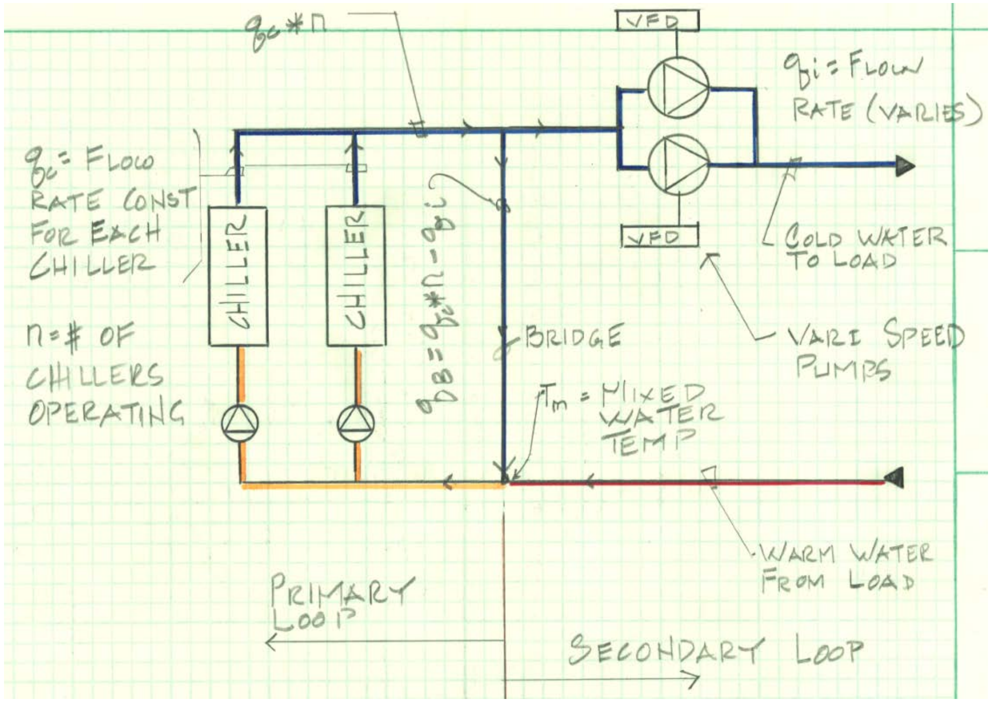
Figure 10, Compressor Inlet Guide Vanes



Chilled Water System
Capacity and Temperature Control

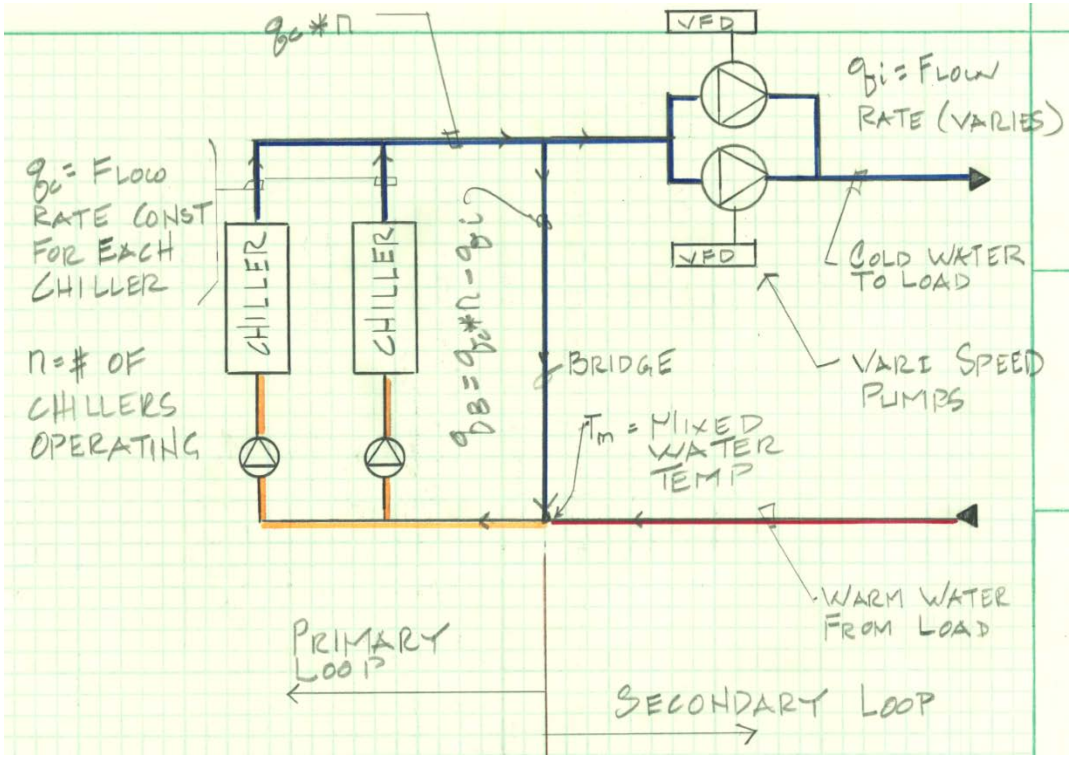
- Capacity control of the system as a whole is based on a combination of:
  - The number of chillers operating
  - Flow rate through the secondary system
  - The temperature of the water returning from the load.

- *Water flow through the secondary loop is variable*
- *While water flow through the primary loop is a step function of the number of chillers operating.*
- *Water balance between the two loops is critical:*
  - *Water flow in the secondary loop must always be less than the flow in the primary loop*



Chilled Water System
Capacity and Temperature Control

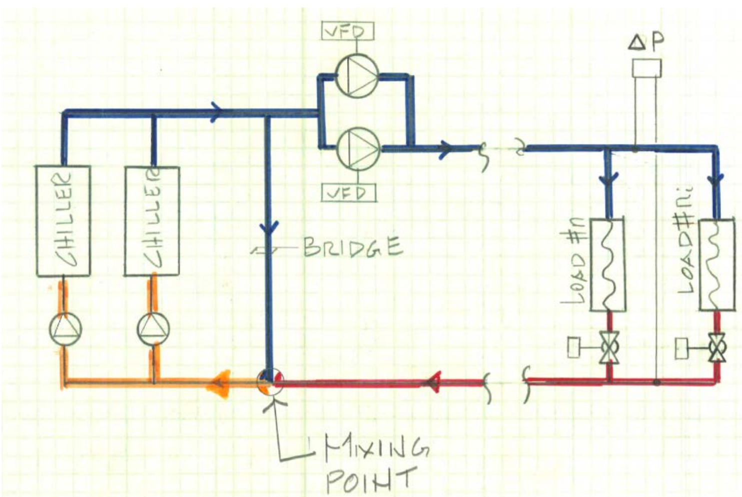
- **Proper capacity control affects the actual chilled water temperature sent to the load**
- **In order to insure temperature stability the flow rates in the system must be properly balanced.**
    - **Chillers will load and unload based on their inlet water temperature.**
    - **This temperature varies based on the `mixing' that takes place at the intersection of the "Bridge" and the return water pipes.**
    - **When properly balanced the chiller's internal controls will control water temperature sent to the loads.**



Chilled Water System
Capacity and Temperature Control

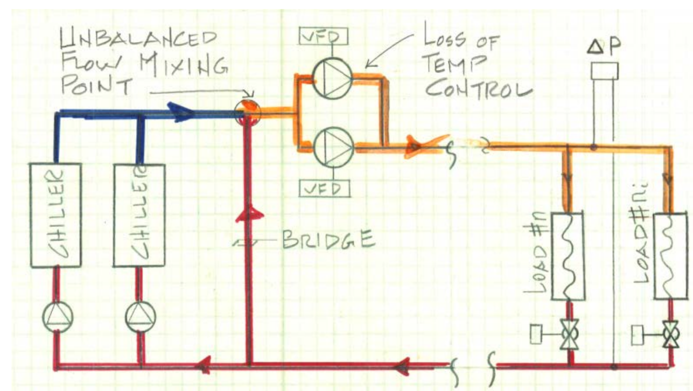
- **Affects of Unbalanced Flows on Chilled Water Temperature Stability**

Balanced Flow Condition



When flows are in balance the mixing point occurs in the correct location and the chillers control the supply water temperatures.

Unbalanced Flow Condition

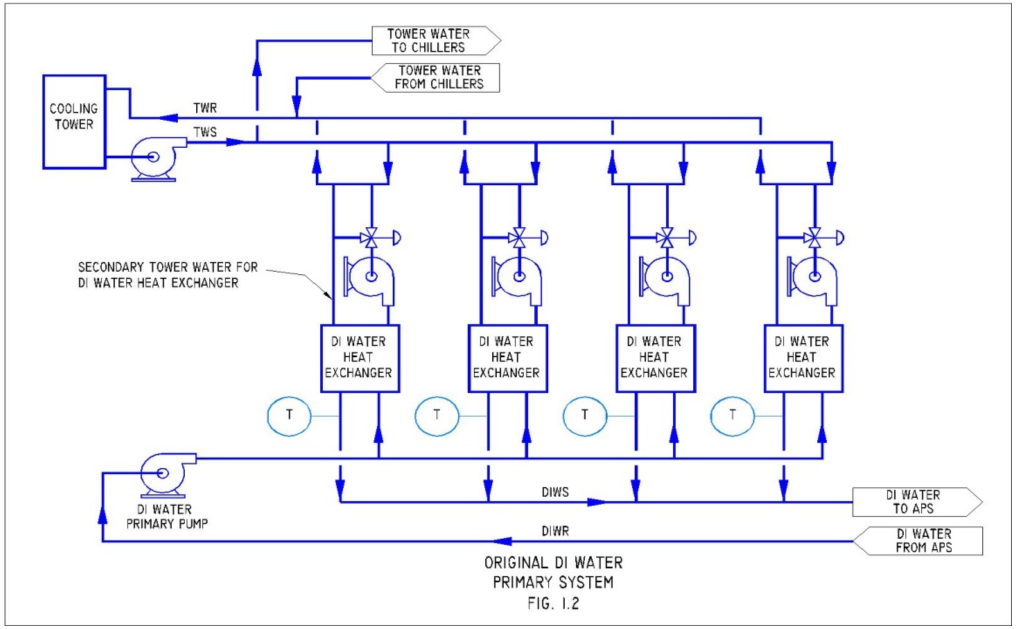


When flows are not in balance the mixing point shifts location and the chillers no longer determine supply water temperature.

Deionized Process Cooling Water System

- The deionized process water system is designed to provide up to 12,000 gpm of cooling water to the APS accelerator components and beam lines. The system currently provides up to 2500 tons (8.8 MW) of heat rejection.

- The original system design was for a single stage of cooling.
- Heat transfer was directly to the APS tower water system and water was to be provided at 90 F.



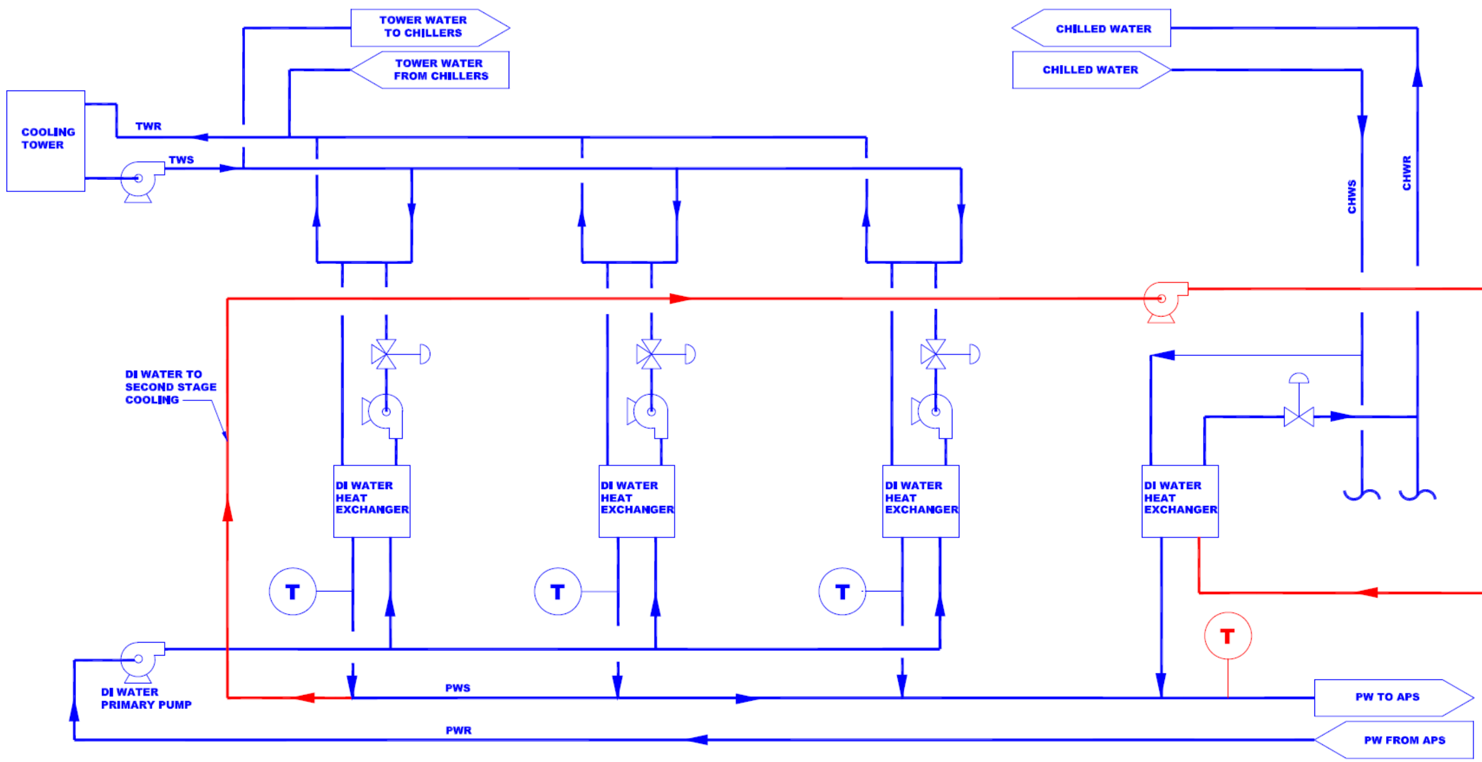
Combination Integral and Heat Exchanger Primary/Secondary System

Deionized Process Cooling Water System

- **Subsequent to the completion of the system construction the operating conditions for the system were changed in order to meet new operating parameters set for the APS storage ring.**
  - **The DI water supply temperature was lowered to 74 F.**
  - **This necessitated a change in the design of the main process cooling loop**
    - **The cooling tower could not produce 74 F during warm and summer operation**
    - **The single stage cooling was modified to a two stage cooling system.**
    - **The second stage of cooling was connected to the APS chilled water system.**

Deionized Process Cooling Water System

- **The new configuration uses tower water for the first cooling stage and chilled water to achieve the final supply water temperature set point.**

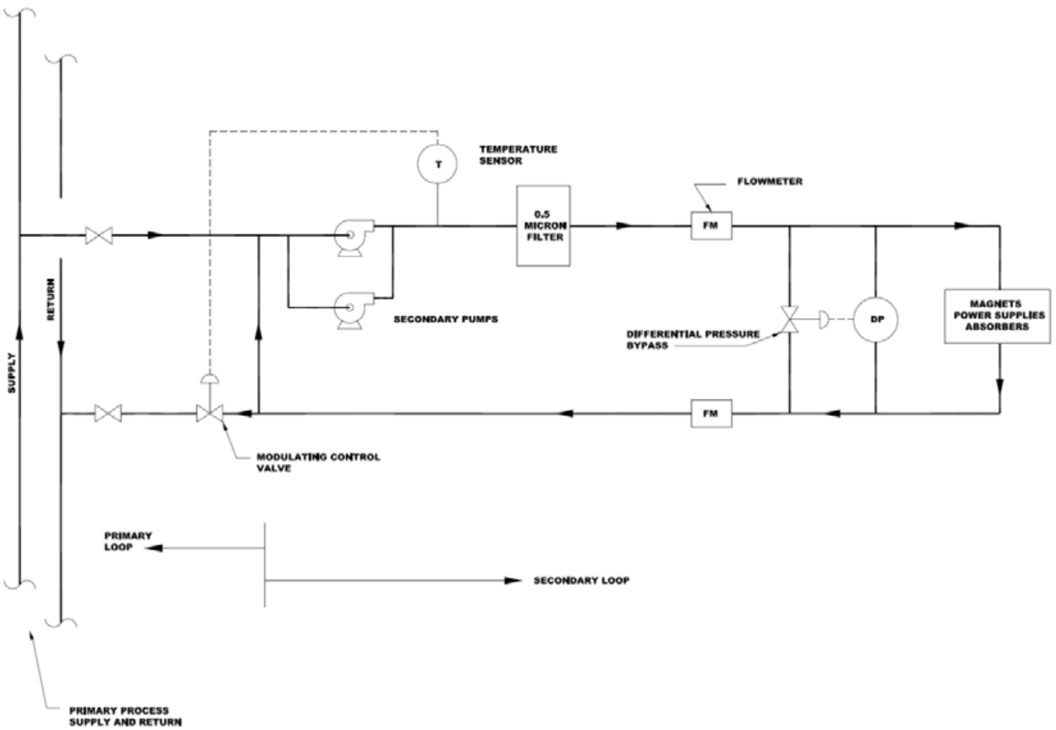


Deionized Process Cooling Water System Distribution System

- **Process water distribution system uses an Integral Primary-Secondary pumping system to that distributes low pressure water to multiple secondary pumping stations.**

Each secondary pumping station creates a semi-independent process water loop :

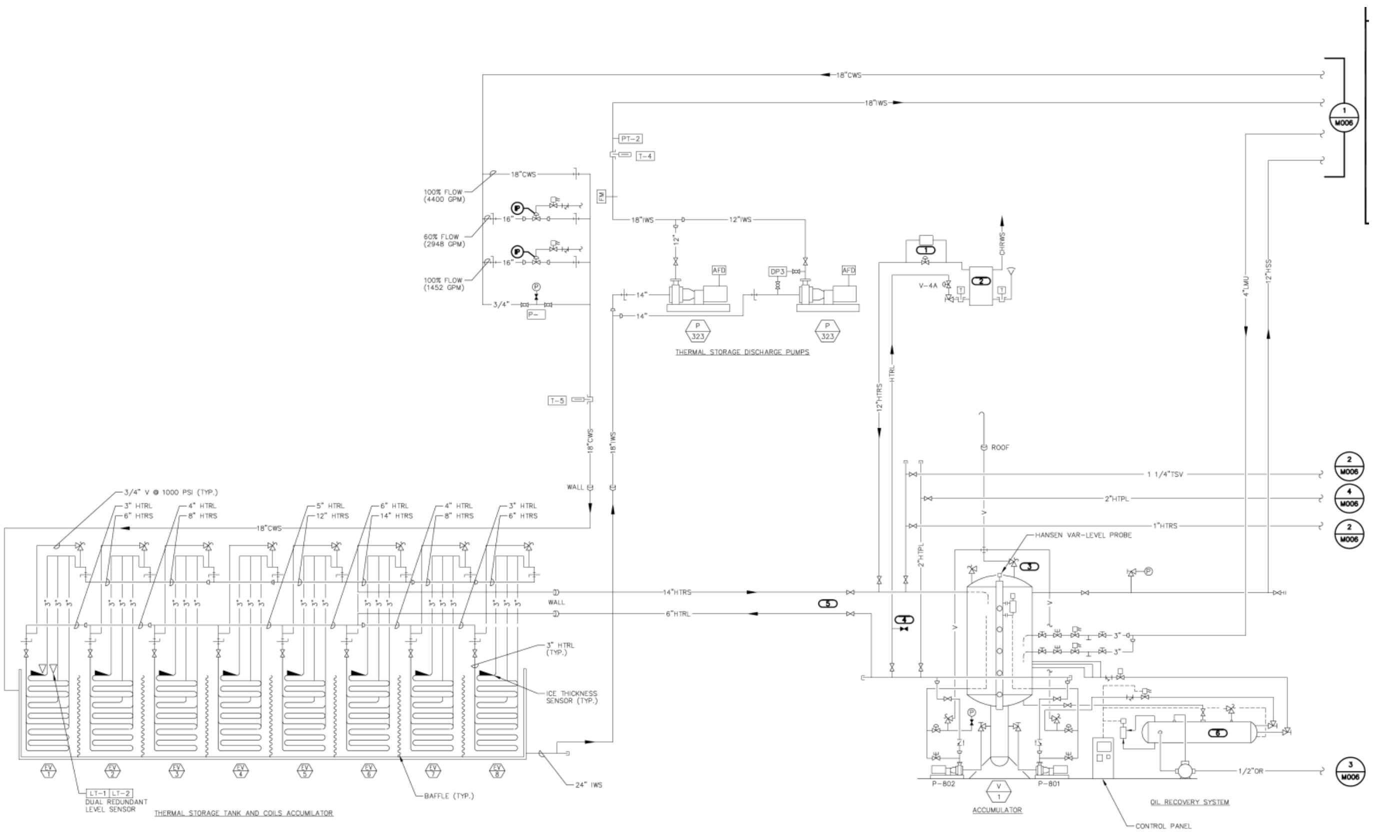
The loop temperature and pressure is controlled by the pump discharge pressure and the degree of mixing between primary and secondary water streams.



Ice Thermal Energy Storage System

Ice Thermal Energy Storage System

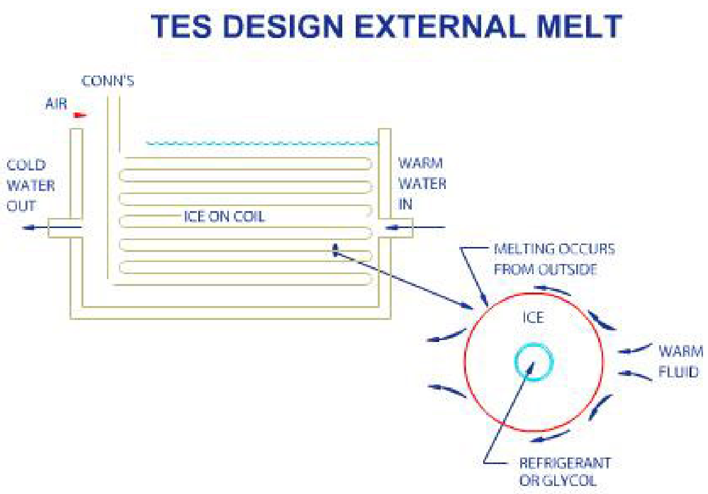
- **The compressors feed a refrigerant accumulator and pump package that supplies liquid refrigerant to the coils in the ice water storage tank.**



1 MECHANICAL FLOW DIAGRAM
SCALE: 1/8"=1'-0"

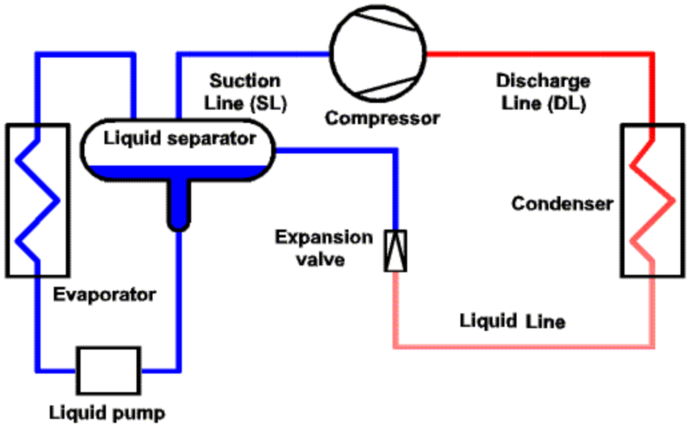
Ice Thermal Energy Storage System

- Ice forms on the exterior of the refrigerant coils.
- The coils are immersed in a 250,000 gallon concrete water storage tank.
- Water is circulated from through the tank in a serpentine pattern to melt the ice and a uniform rate accords the individual coils.



Ice Thermal Energy Storage System

- Methodology of Ice Production
  - A liquid overfeed refrigeration system used to make ice.
    - Liquid refrigerant is accumulated in a storage vessel and pumped at a rate to insure that the refrigerant is at a minimum 70 percent liquid.
    - This insures a constant temperature of refrigerant through the entire length of the coil.
    - Under these conditions the ice thickness along the entire coil length will be uniform.



Ice Thermal Energy Storage System
Integration into the Chilled Water System

- **Utilization of Ice Water**
  - **The ice water is used as a second stage of chilled water cooling.**
    - **Water leaving the chillers is pumped into the chilled water secondary loop.**
    - **Before exiting building 450 the chilled water is redirected to a set of plate and frame heat exchangers.**
    - **Heat is exchanged between the 40° F chilled water and the 32° F water from the ice tank.**
    - **The final temperature of the chilled water is controlled by the amount of chilled water diverted into the these heat exchangers.**

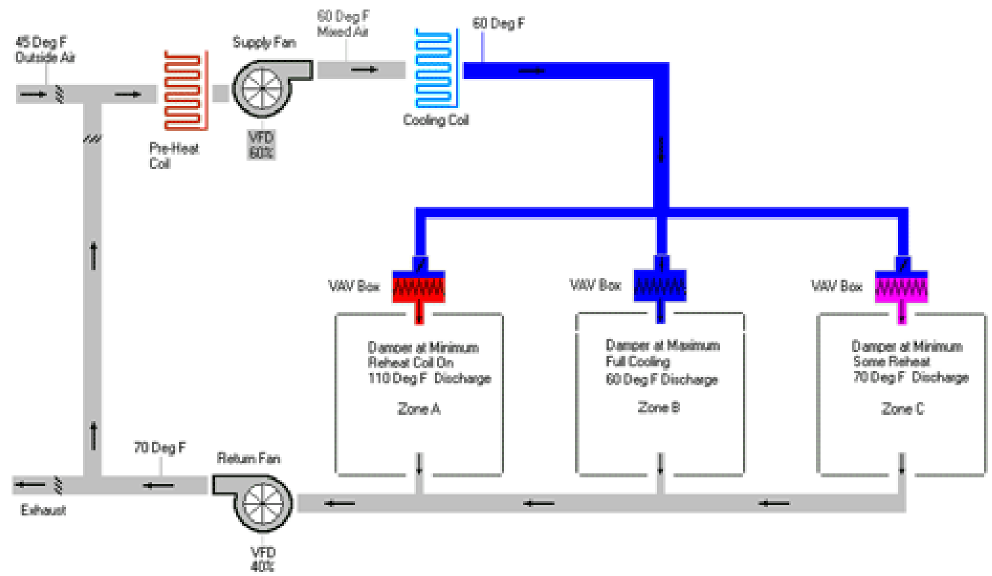
- **Advantages of Ice Water Cooling**
    - **The ice water provides a constant temperature source of cooling that is inherently stable**
    - **The temperature of the tank does not vary; heat transfer is through change of state converting ice to liquid water.**
    - **During humidity excursion in the summer; lower water temperatures provide lower cooling air dew point temperatures for increased space dehumidification**
    - **Ice build takes place at night during off peak electrical hours yielding energy cost savings.**

Air Side Heat Transfer

Air Side Heat Transfer

- The majority of air handling systems at APS are designed to operate with constant supply air temperatures and provide variable air flow rates to satisfy cooling demands and ventilation.

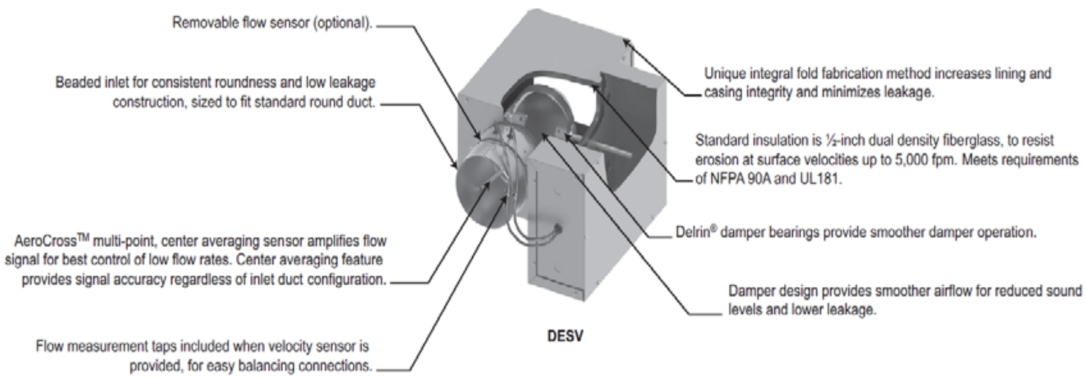
- One system supplies multiple spaces each with differing needs for cooling and heating the system provides a constant cooling air stream.
  - As heat is needed to avoid space sub-cooling air flow to the space is reduced until the minimum ventilation limit is reached.
  - If the space continues to sub-cool heat (reheat) is added at each zone either from air borne waste heat or from the APS LTW heating system.



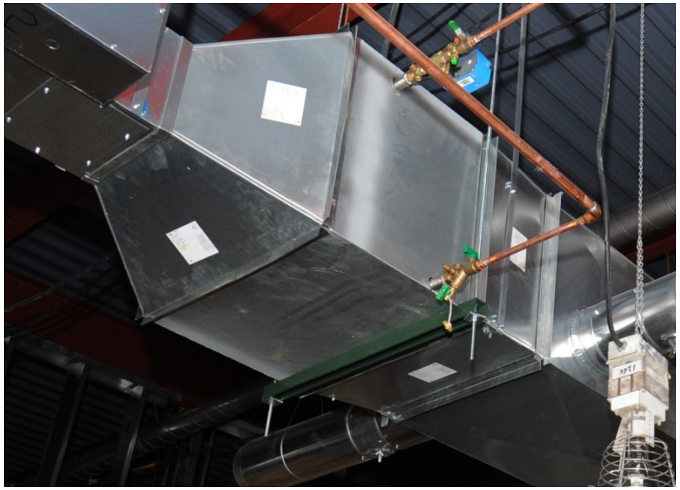
Air Side Zone Temperature Control

Air Side Zone Temperature Control

- Most other buildings and spaces use conventional variable air volume terminal units.
  - These consist of an air flow meter and modulating damper to adjust air flow rate to maintain space temperature.
  - Reheat coils are added to neutralize the cooling effect preventing space sub-cooling when box flow rates reach minimum allowable levels.

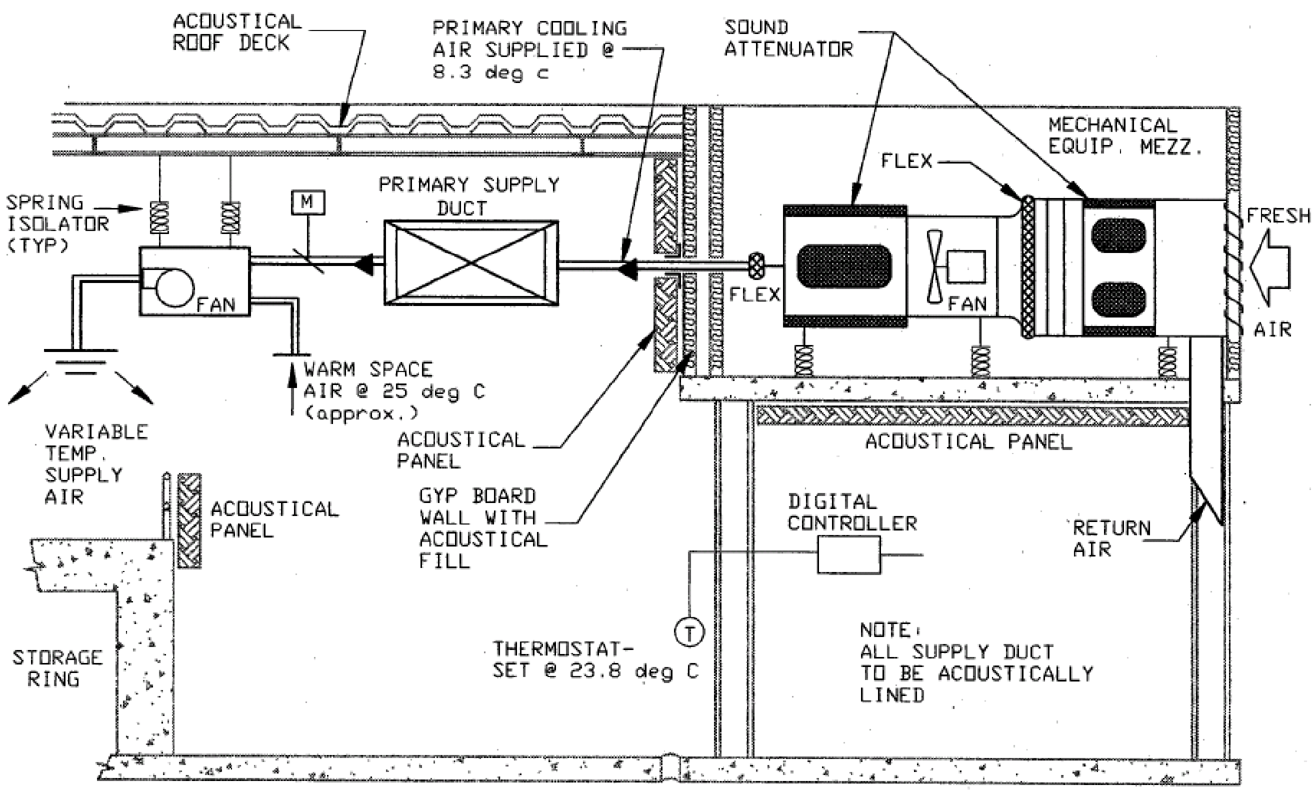


<u>**Cut away of VAV Unit**</u>



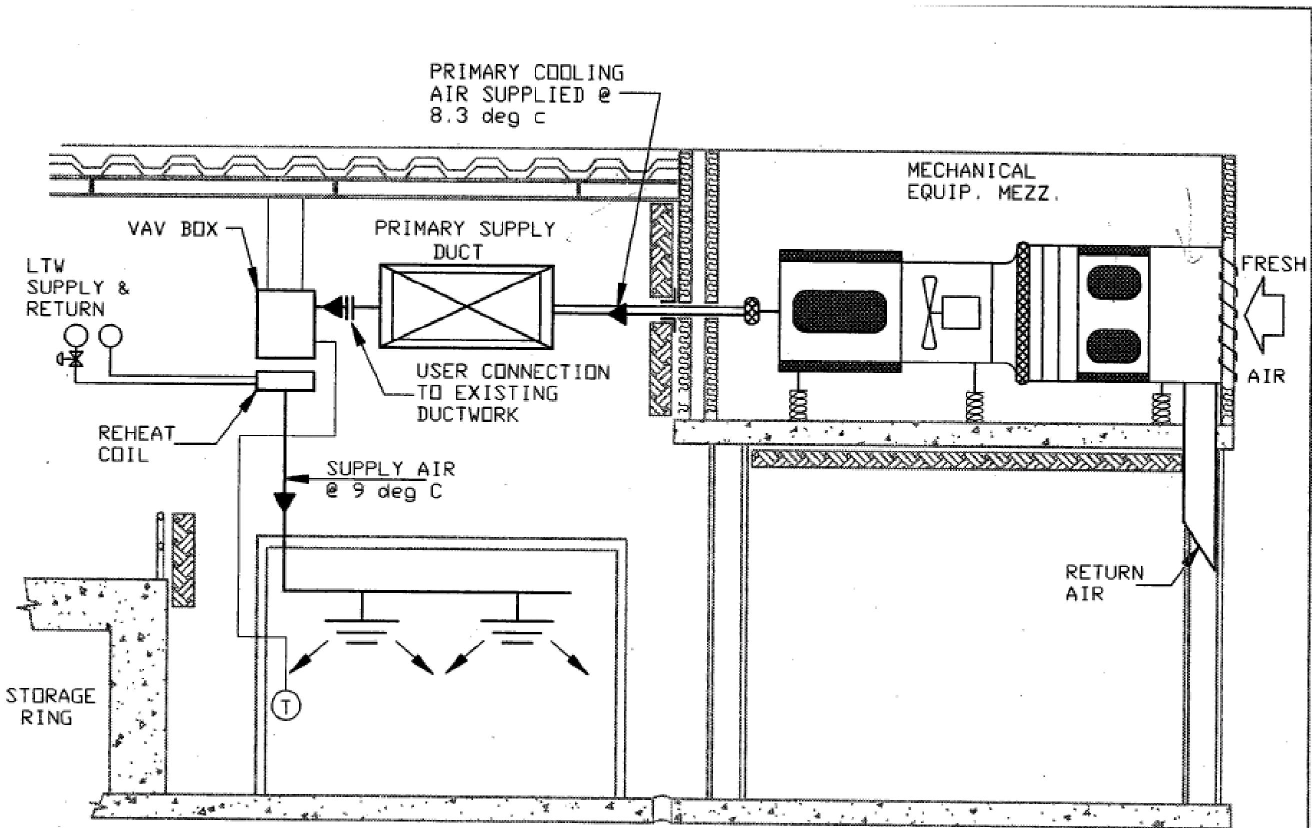
<u>**VAV unit with reheat coil**</u>

Experiment Hall Temperature Control



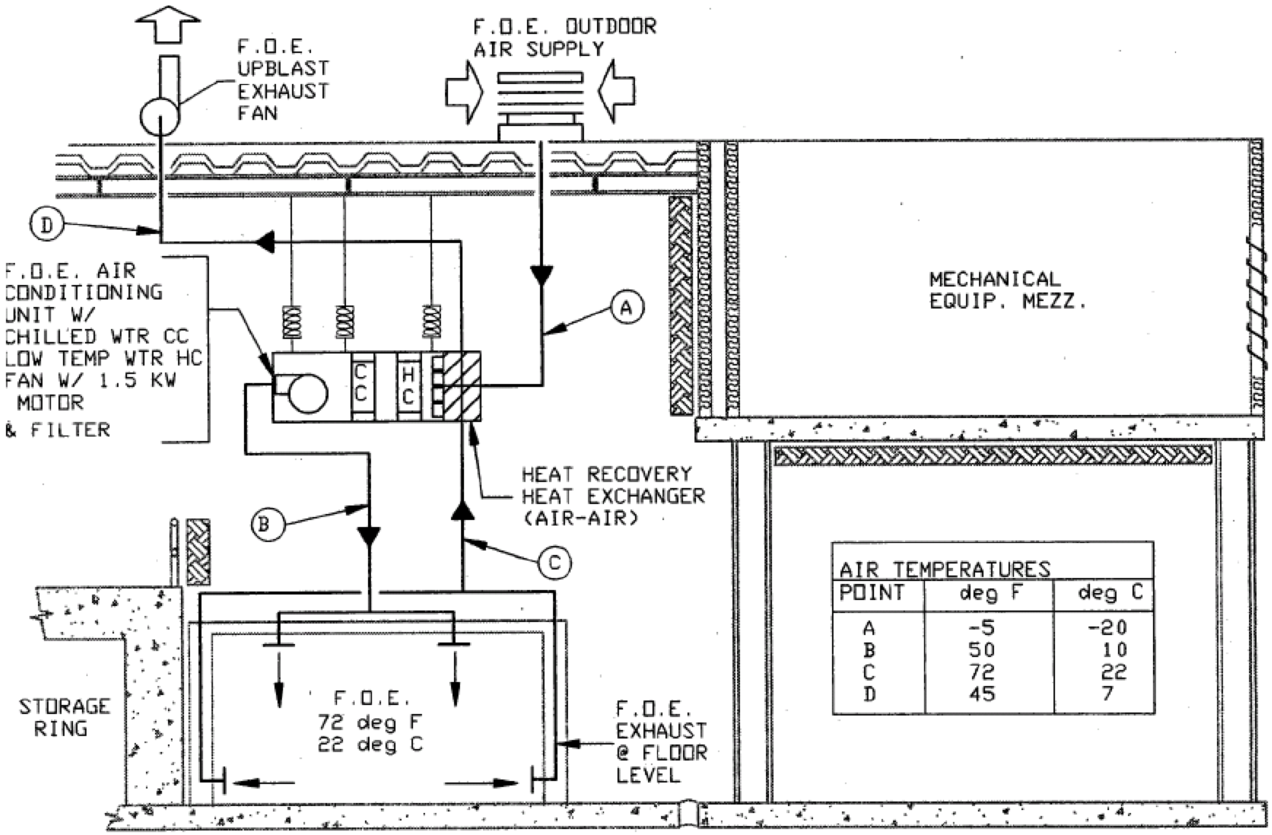
SCHEMATIC SECTION VIEW THRU EXPERIMENT HALL

Experiment Hall Temperature Control



TYPICAL APPLICATION OF
CHILLED AIR UTILIZATION

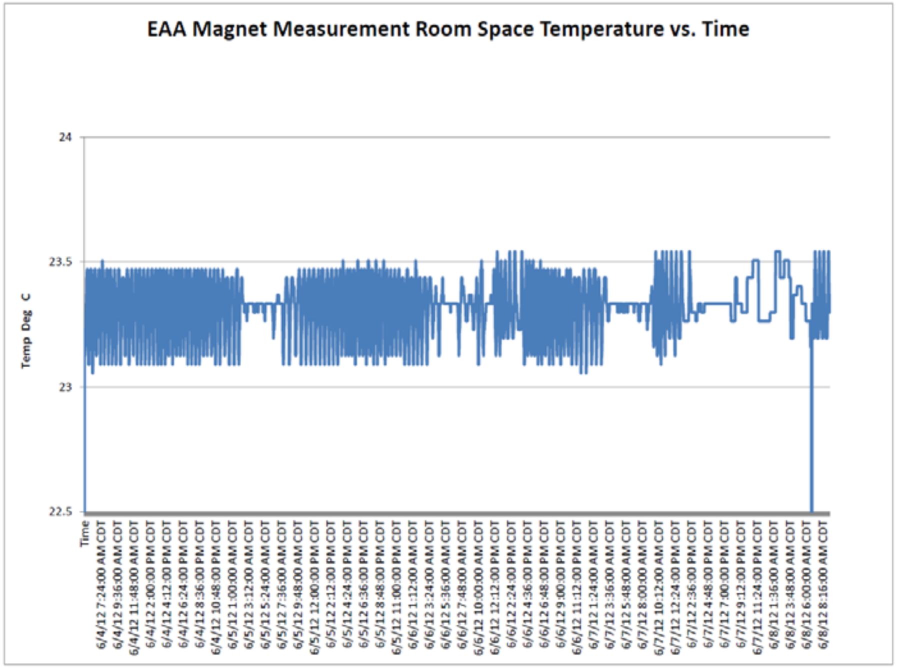
Experiment Hall Temperature Control



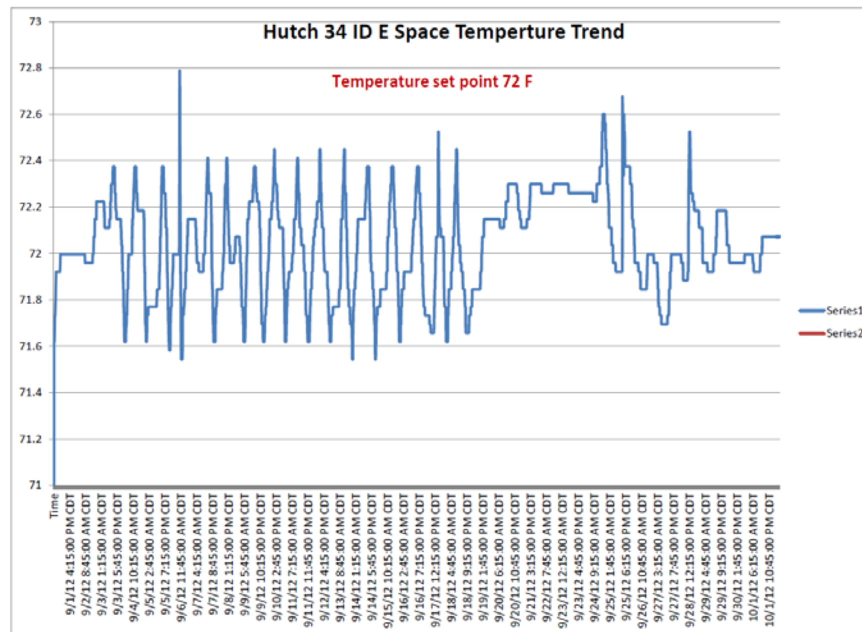
AIR TEMPERATURES		
POINT	deg F	deg C
A	-5	-20
B	50	10
C	72	22
D	45	7

FLOW DIAGRAM OF POSSIBLE F.O.E.
ENVIRONMENTAL CONTROL SYSTEM

Experiment Hall Temperature Control

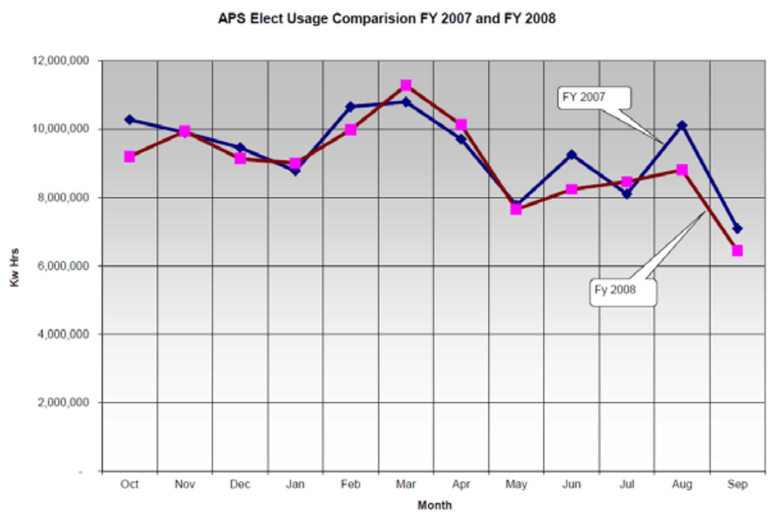


<u>Examples of space temperature control using induction fan terminal units.</u>



Sustainability - Environmental and Economic Considerations

- **APS has a large "carbon footprint" and incurs energy costs that reflect this.**
  - **Monthly electrical energy consumption averages 9 GW hours.**
  - **Electric Costs are on the order of $7,000,000 per year**



  - **Our laboratory spaces use large quantities of ventilation air for vapor dilution and removal.**
    - **APS uses approximately 18 GW hours of energy per year to heat this ventilation and supply the other building heating needs.**

Sustainability - Environmental and Economic Considerations

- **APS generates sufficient waste heat to heat all of the loads in the 400 area with sufficient heat leftover to heat most of the rest of the Argonne Site.**
  - **Recycling waste heat would result in a sustainable decrees in the APS and ANL carbon footprint.**
    - **Yielding substantial operating cost savings to the Laboratory**

Some ANL Heating Energy Facts

HEAT RECOVERY CAN CUT OUR HEATING COST IN HALF

AND DRAMITCLY REDUCE

ENERGY CONSUMPTION AND GREEN HOUSE GAS EMISSIONS

STEAM ENERGY COST	**$0.16**
HEAT PUMP EQUIVALENT ENERGY COST	**$0.08**

HOW?

ANL Winter steam peak demand is about:	**180,000 lbs per hour**
Equivalent to:	**46 Megawatts**
ANL Yearly heating consumption is about:	**726,000,000 lbs of steam per year**
Equivalent to:	**180,000 Megawatt hours**
Or:	**$7,000,000 per year steam cost**
Waste heat extraction with heat pumps Can produce over	**4 Kw of heat for 1 Kw of electric power**
Equivalent to:	**16 pounds of 200 psig steam**

Sustainability - Environmental and Economic Considerations

- Challenges to exploiting APS waste heat
  - Waste heat is generated at very low temperatures
    - Typically < 27 °C
  - The maximum Carnot efficiency using the winter outdoor air as a heat sink is less than 10%
  - That said; extracting even 5 % of the yearly APS waste energy would result in the recycling of:
    - Over 5 GW hours of energy
  - Using direct heat transfer techniques can yield nearly 100% of low grade heat transfer if the paths to sinks operating within certain low temperature regimes is strategically exploited.

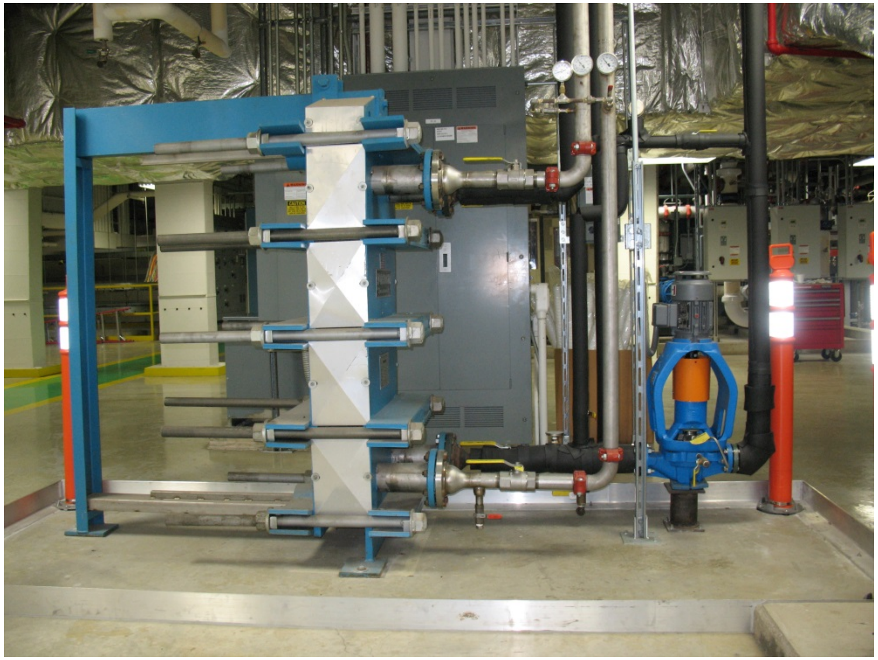
Sustainability - Environmental and Economic Considerations

The first heat recovery system was installed at APS for the Linac Ventilation in 2005 as a prototype to verify the efficacy of the concept.

Low grade waste heat from the APS Linac process water cooling system was recycled to provide the heating source for the autumn, winter, and spring season.

- **Sufficient heat was extracted to fully satisfy the heating demands except in the most extreme winter conditions.**

- **During the first year of operation over 400,000,000 BTU (118 Mw-Hrs) of energy was saved**



Sustainability - Environmental and Economic Considerations

- **A multi stage heat recovery system was designed and incorporated into the CNM.**

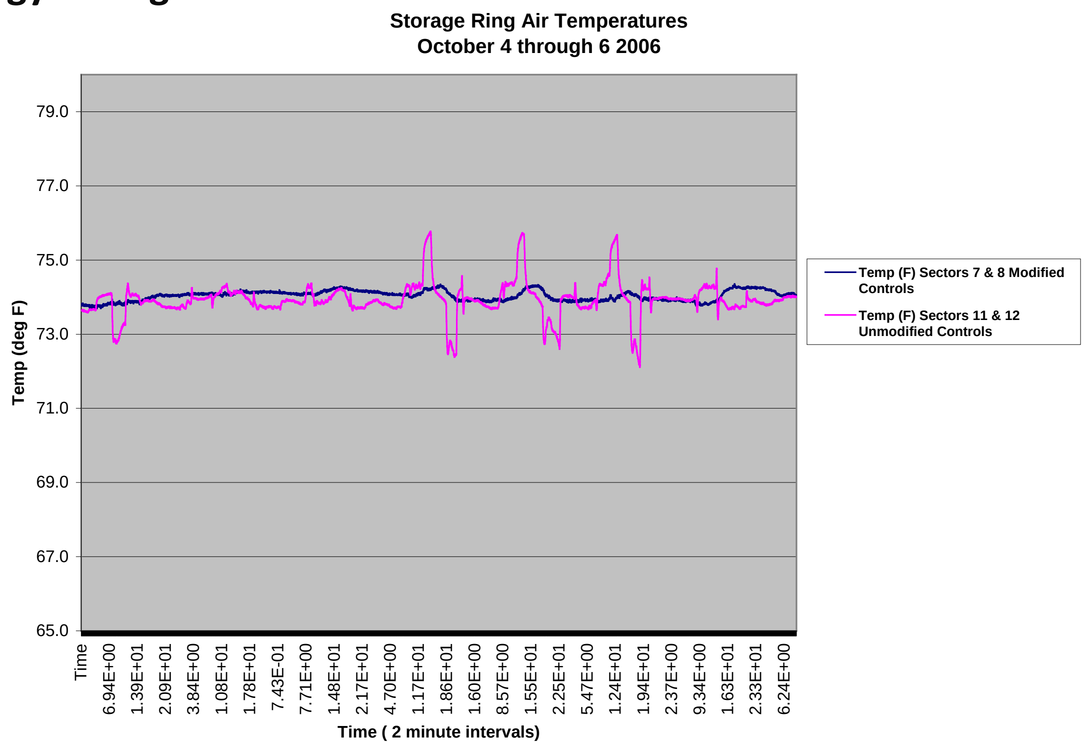
This system is based on three stages of waste heat reclamation:

This would account for an average yearly saving of over 3.5 billion Btu (1000 Mw hrs) of heat.

Over $ 25,000 of average yearly energy savings.

Sustainability - Environmental and Economic Considerations

- A single stage heat recovery system using process water waste heat was installed for the storage ring and with enhancements to the system controls improved the storage ring temperature stability with a substantial reduction in energy consumption.
- An order of magnitude improvement in space temperature stability
- A reduction in energy usage averaging 14 Billion Btu (4100 Mw hrs) of heat.
- Over $100,000 in annual energy savings.



Sustainability - Environmental and Economic Considerations

- Another heat recovery system was installed in each of the APS Lab Office Module Buildings resulting in:
- A yearly energy savings of over 7 Billion Btu (2000 Mw hrs)
- Over $ 32,000 in annual energy savings.

Our latest heat recovery system installed for LOM 438 provide virtually all the building heat with storage ring waste heat.

Sustainability - Environmental and Economic Considerations

- **A summary of Energy Conservation Measures implemented over the past 14 years**
  - **Yielding nearly $700,000 in yearly energy savings.**

Argonne HEMSF Energy Conservation Measure FY 2000-2008	Total Energy Saving per Year		Cost Savings per Year ($)
	10^6 Btu	Mw Hrs	
Linac Heat Recovery System Prototype	410	120	$ 4,100
CNM Building 440 Multi-Stage Heat Recovery	4,800	1,400	$ 48,000
Advanced Photon Source Storage Ring HVAC Modifications	7,268	2,130	$ 78,597
Advanced Photon Source Addition of Variable frequency drives to process water cooling system	6,830	2,002	$ 116,759
Total all ECM's FY 00-08	14,098	4,132	$ 247,456

Argonne HEMSF Energy Conservation Measure FY 2009-2010	Total Energy Saving per Year		Cost Savings per Year ($)
	10^6 Btu	Mw Hrs	
Advanced Photon Source Experiment Hall HVAC Modifications	16,839	4,935	$ 141,502
Advanced Photon Source Process Water Evaporative Cooling System Upgrade	7,984	2,340	$ 179,417
Advanced Photon Source LOM HVAC Heat Recovery	8,190	2,400	$ 68,194
Advanced Photon Source Lighting Upgrade	1,646	482	$ 36,995
Advanced Photon Source Lighting Controls Upgrade	1,677	492	$ 37,683
Total all ECM's FY 09-10	36,336	10,649	463,791

Sustainable Path Forward

- Building on our work to date the APS is developing designs for a large scale system that:
- Focus on synergies created within the APS improving integration of heat generating sources with systems that require large quantities of heating for temperature control and winter operation.
- Applies multiple technologies with the goal of redirecting waste energy to maximize its effective utilization. The ultimate goal is to:
  - Recover and effectively utilized sufficient waste heat to provide the total heating demand for the APS averaging
    - 63 Billion BTU or over 18 Gw Hrs of energy per year.

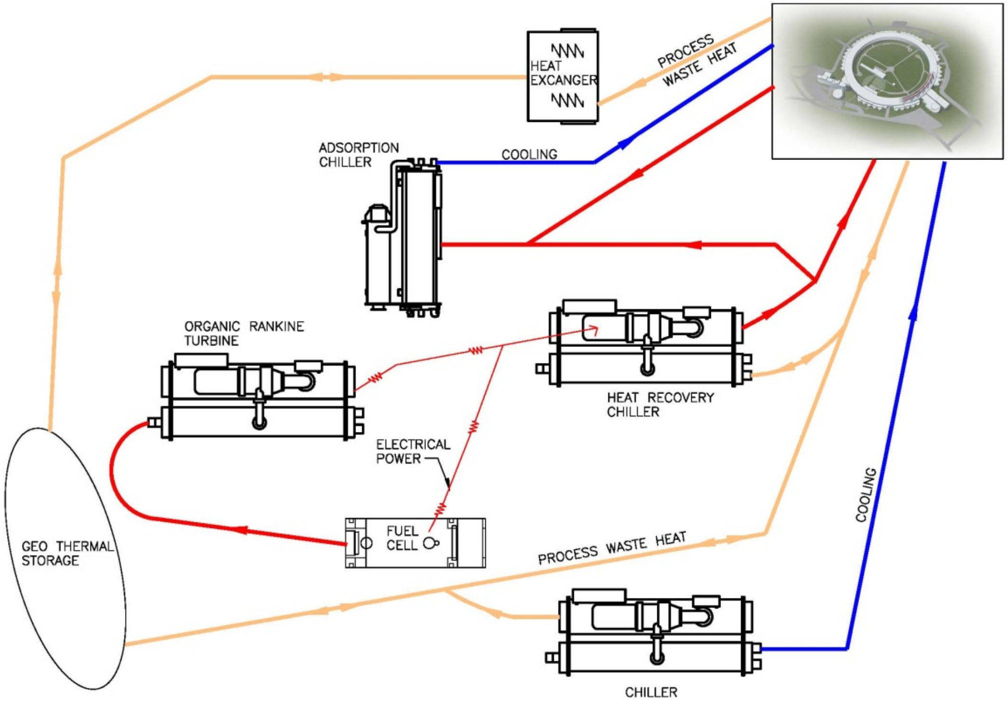
- The foundation of the these systems will be proven core technologies and strategies:
  - Direct heat transfer
  - High capacity heat recovery chillers
  - Performance based control algorithms

- Layered upon these core technologies will be systems employing state or the art and other cutting edge technologies a number of which are currently part of ongoing ANL research. Currently being considered are:
  - Aquifer Thermal Energy Storage
  - Fuel Cells
  - Combined Heat Power Units
  - Organic Rankine Cycle Turbines

Sustainable Path Forward

Final Phase

18 GW Hr APS Energy Recovery and Storage System Concept



Water and Air Handling Systems at the Advanced Photon Source

Environmental Control for Critical Applications

<u>Questions or Comments?</u>