Thermal Energy Management

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Thermal Systems

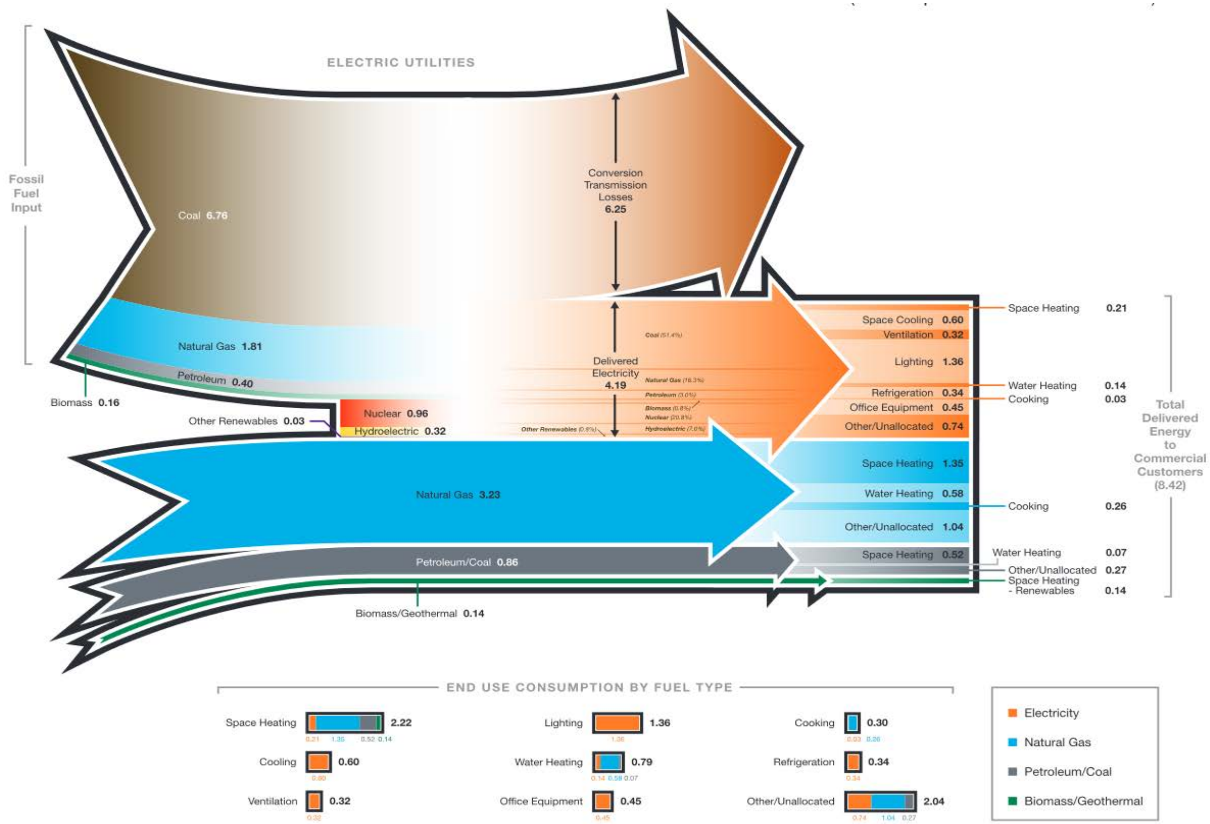
- Energy Flows.
- Heat Transfer.
- Heating, Ventilation, and Air Conditioning (HVAC) Systems.
- Boilers and Steam Systems.
- Waste Heat Recovery.
- Automation Systems.

Energy Flows

- The energy flows defines the energy conversion, transformation, and transfer through energy balance diagram.
- This energy balance “business as usual” starts with the primary energy till the final consumed energy in a certain activity.
- Accordingly, on starting with primary energy the final energies can be in form of lighting source, mechanical power, electrical energy, chemical energy, heating process, cooling process, ……etc.

Energy Flows

- Energy Flow in Building



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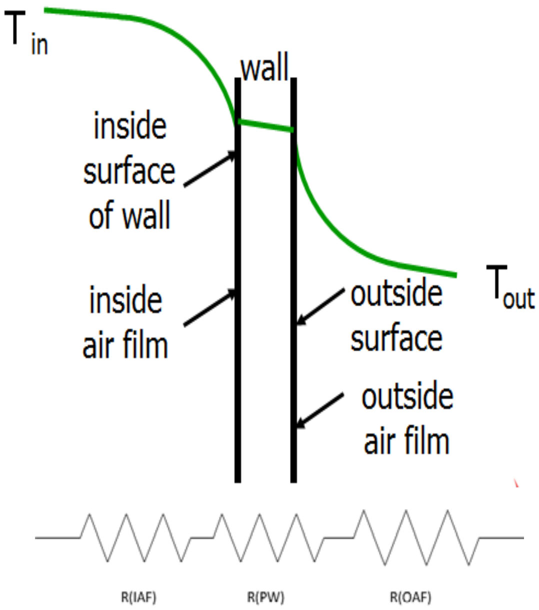
The Heat Flow

- The heat flow is processed through heat transfer that takes place by three modes;
  - Conduction (proportional to Δt)
  - Convection (approx. prop. to Δt^2)
  - Radiation (approx. prop. to Δt^4)



- Heat Transfer by Conduction;
  - Heat is lost and gained through the building shell.

Heat Flow Equation

- The heat flow equation is;

$$Q(Watt) = U\ X\ A\ X\ \Delta T$$

Where;

Q: Heat Flow in Watt

U: Overall thermal conductance (Watt/m^2. ^oC).

A: Area (m^2)

ΔT: Temperature Difference (^oC)

Heat Flow Equation

- For Water

$$Q(kW) = LPS\ X\ 4.2\ X\ \Delta T$$

- For Air

$$Q(Watt) = LPS\ X\ 1.2\ X\ \Delta T$$

LPS: Flow rate in Liter per Second.

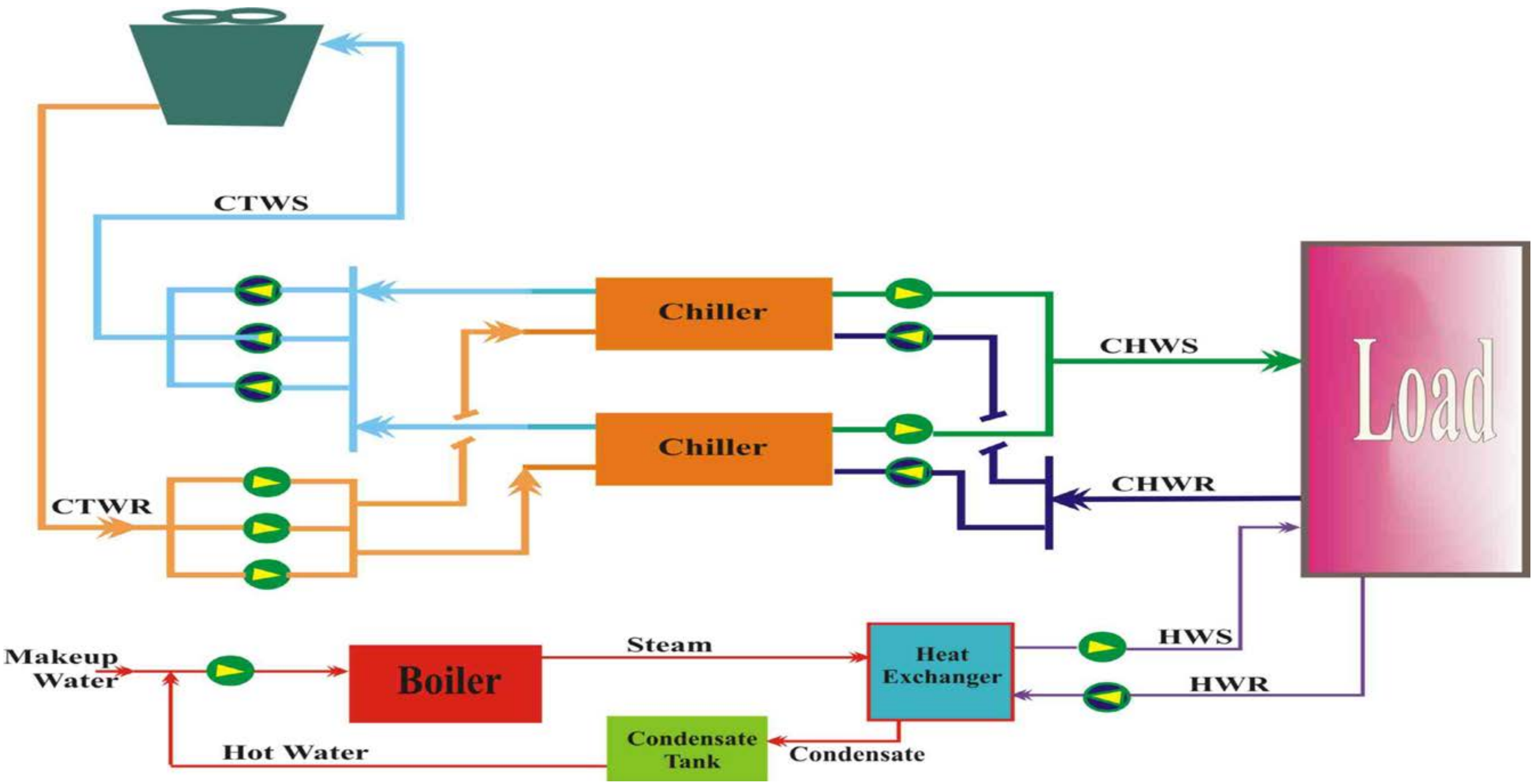
ΔT: Temperature Difference (^{o}C).

HVAC System

- HVAC is to provide and maintain a comfortable environment within a specific space for the occupants or for process through the control of the following parameters:
  - Temperature
  - Humidity
  - Air Quality
  - Air Distribution

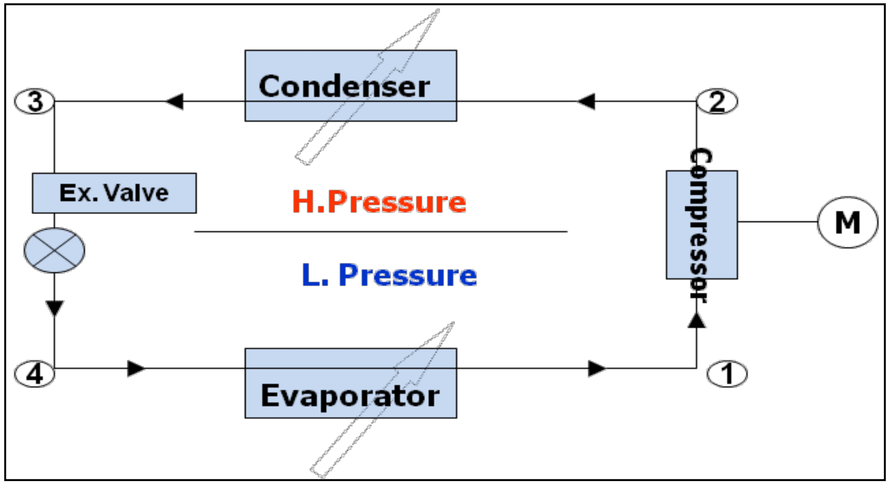
HVAC System Components

- Primary Equipment;
  - Chillers (Big)
  - Direct expansion (DX) systems (Rooftop, Pad Mount)
  - Boilers (Gas - Steam)
  - Cooling Towers
- Secondary Side (Air Side)
  - Fan coil system
  - Single duct, single zone system
  - Dual duct system
  - Single duct, variable air volume system

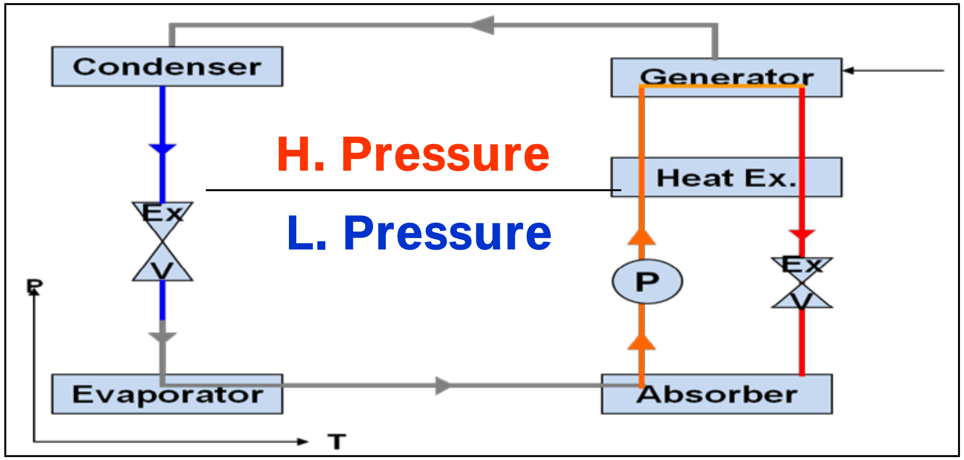

CTWS
Chiller
Chiller
CHWS
Load
CHWR
CTWR
Makeup Water
Boiler
Steam
Heat Exchanger
HWS
HWR
Condensate Tank
Condensate
Hot Water

HVAC Systems – Cooling Cycles

- Vapor Compression Cycle
  - Mechanically Driven.



- Absorption Cycle
  - Thermally Driven



Energy Balance of Cooling Cycle

$$Q_{input} + Qload - Qreje_{cted} = 0.0$$

Q_{input}: Input Energy to Cycle – Work input or thermal input

Q_{load}: Cooling Effect (Load) - Evaporator

$Q_{rejected}$: Energy rejected from cycle through condenser.

Power and Energy Terms in HVAC

- Cooling Capacity is expressed in Tons of Refrigeration (TOR). TOR is 12,000 Btu/hr.
- 1 TOR = 12,000 Btu/hr = 3.517 kW
- HVAC Performance Measures;

$$EER = \frac{BTU\ of\ Cooling\ output}{Wh\ of\ Electric\ input} \quad \frac{BTU}{Whr}$$

$$COP = \frac{EER}{3412}$$

$$COP = \frac{Energy\ Output}{Energy\ Input}$$

$$SEC = \frac{3.517}{COP} \quad \frac{KWe}{TOR}$$

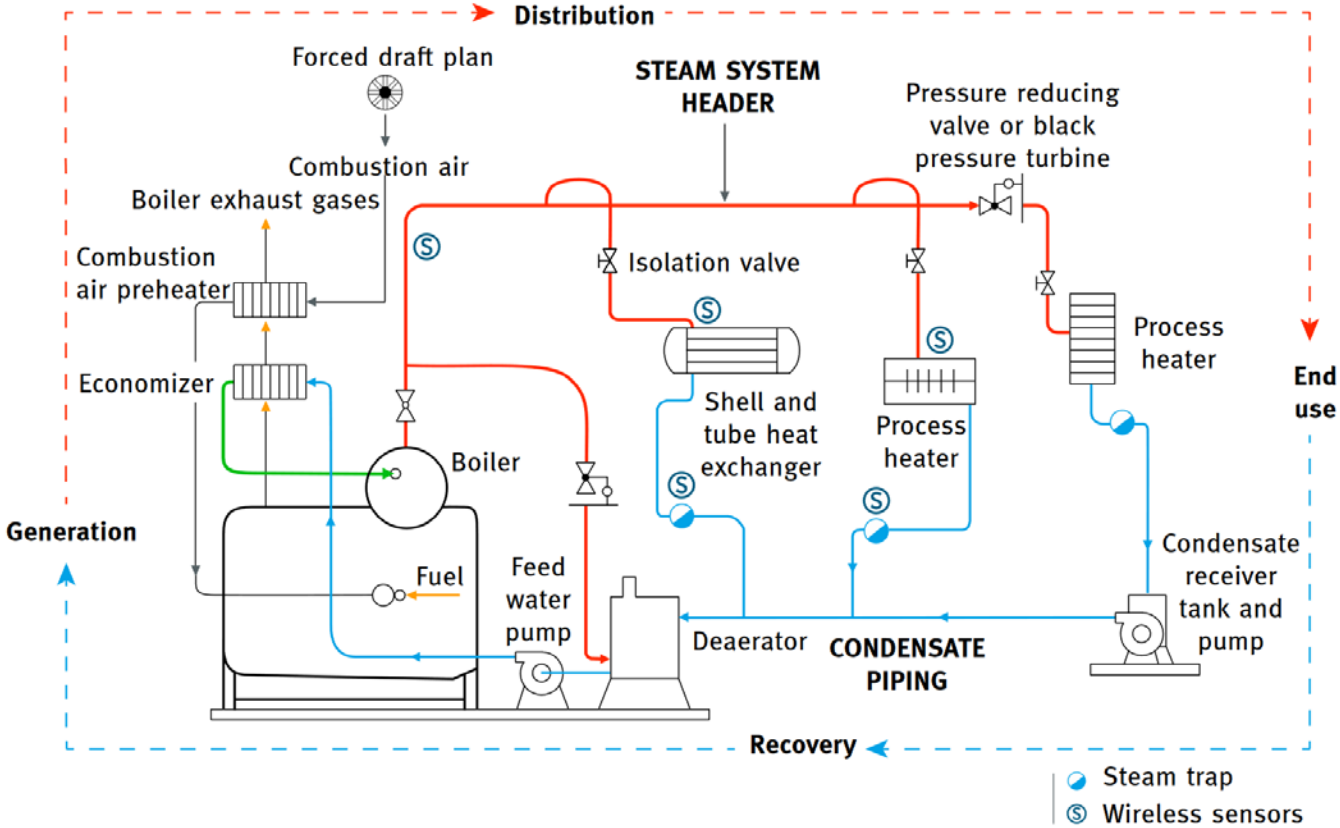
$$SEC = \frac{12000}{EER} \quad \frac{KWe}{TOR}$$

HVAC Systems – Opportunities to Save Energy

- Investigate the chiller performance (COP).
- Chiller operation versus served load.
- Chiller Set point adjustment.
- Energy Management Controllers to Primary Equipment.
- Energy Management Controllers to Secondary Equipment.

Boilers and Steam Systems

- System Components;



Boilers and Steam Systems – Energy Savings Opportunities

- Combustion system improvement and controls.
- Flue Gas Energy Recovery.
- Blowdown Process Automation.
- Heat Recovery for Blowdown.
- Steam Traps Repair and improvement.
- Heat Transfer Surfaces improvement.
- Steam pipes insulation.

Waste Heat Recovery Systems

Waste Heat Sources	Uses for Waste Heat
• Combustion Exhausts: Glass melting furnace Cement kiln Fume incinerator Aluminum reverberatory furnace Boiler • Process off-gases: Steel electric arc furnace Aluminum reverberatory furnace • Cooling water from: Furnaces Air compressors Internal combustion engines • Conductive, convective, and radiative losses from equipment: Hall-Hèroult cells [a] • Conductive, convective, and radiative losses from heated products: Hot cokes Blast furnace slags [a]	• Combustion air preheating • Boiler feedwater preheating • Load preheating • Power generation • Steam generation for use in: power generation mechanical power process steam • Space heating • Water preheating • Transfer to liquid or gaseous process streams

Waste Heat Resources and Recovery Potential

Temp Range	Example Sources	Temp (°F)	Temp (°C)	Advantages	Disadvantages/ Barriers	Typical Recovery Methods/ Technologies
High >1,200°F [> 650°C]	Nickel refining furnace Steel electric arc furnace Basic oxygen furnace Aluminum reverberatory furnace Copper refining furnace Steel heating furnace Copper reverberatory furnace Hydrogen plants Fume incinerators Glass melting furnace Coke oven Iron cupola	2,500-3,000 2,500-3,000 2,200 2,000-2,200 1,400-1,500 1,700-1,900 1,650-2,000 1,200-1,800 1,200-2,600 2,400-2,800 1,200-1,800 1,500-1,800	1,370-1,650 1,370-1,650 1,200 1,100-1,200 760-820 930-1,040 900-1,090 650-980 650-1,430 1,300-1,540 650-1,000 820-980	High-quality energy, available for a diverse range of end-uses with varying temperature requirements High-efficiency power generation High heat transfer rate per unit area	High temperature creates increased thermal stresses on heat exchange materials Increased chemical activity/corrosion	Combustion air preheat Steam generation for process heating or for mechanical/ electrical work Furnace load preheating Transfer to med-low temperature processes
Medium 450-1,200°F [230-650°C]	Steam boiler exhaust Gas turbine exhaust Reciprocating engine exhaust Heat treating furnace Drying & baking ovens Cement kiln	450-900 700-1,000 600-1,100 800-1,200 450-1,100 840-1,150	230-480 370-540 320-590 430-650 230-590 450-620	More compatible with heat exchanger materials Practical for power generation		Combustion air preheat Steam/ power generation Organic Rankine cycle for power generation Furnace load preheating, feedwater preheating Transfer to low-temperature processes
Low <450°F [<230°C]	Exhaust gases exiting recovery devices in gas-fired boilers, ethylene furnaces, etc. Process steam condensate Cooling water from: furnace doors annealing furnaces air compressors internal combustion engines air conditioning and refrigeration condensers Drying, baking, and curing ovens Hot processed liquids/solids	150-450 130-190 90-130 150-450 80-120 150-250 90-110 200-450 90-450	70-230 50-90 30-50 70-230 30-50 70-120 30-40 90-230 30-230	Large quantities of low-temperature heat contained in numerous product streams.	Few end uses for low temperature heat Low-efficiency power generation For combustion exhausts, low-temperature heat recovery is impractical due to acidic condensation and heat exchanger corrosion	Space heating Domestic water heating Upgrading via a heat pump to increase temp for end use Organic Rankine cycle

Control and Automation of Energy Systems

- Energy effective systems require energy effective controls (manual or automatic)
- Energy effective controls means that first we need to understand how the equipment SHOULD be operated and controlled, and then put such systems in place
- Requires that the system is properly installed, operational and commissioned.

Types of Control

- Manual Controls
  - Switches
  - Dimmers
- Basic Automatic Controls (Open Loop)
  - Timers
  - Photo-sensors (to detect external darkness)
- Basic Automatic Controls (Closed Loop)
  - Thermostat
  - Humidistat
  - Dimmable ballast with photo sensor

Control Technologies

- Pneumatic control - compressed air powered controls
  - 20 - 100 kPa air systems
  - Typical of older systems or hazardous areas
- Electric control - voltage or current powered
  - 0 - 5 V, 0 - 10 V, 4 - 20 mA continuous
  - Typical of discrete control systems and some very old BMS
- Direct Digital Control - electronic
  - pulses; 0s and 1s; pulse coded data, discrete
  - interfaces directly with PCs, and the Internet
  - Should have interface with BacNet, LonWorks, etc and TCP/IP

Control System Hierarchy

Data Processing and Control Algorithm (Controller)

Working Station

Input / Output Carrier Modules

Inputs (measured Values/feedback signals)

Field Devices (Sensors, Actuators, …etc.)

Outputs (Control Actions)

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