uponor

Industrial Buildings & Maintenance Facilities

Radiant Floor Heating and Cooling

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Radiant Heating and Cooling

Industrial Buildings & Maintenance Facilities

Radiant Heating and Cooling

- Heat Transfer Coefficients
  - Nominal

- Conduction
  - PEX Pipe in Concrete
  - ≈ 0.22 Btu/ft · hr · ºF
  - Spacing, Depth, Back Loss, R-value
- Radiation
  - 1.0 Btu/ft^2 · hr · ºF
- Convection (floors)
  - Heating 1.0 Btu/ft^2·hr·ºF
  - Cooling 0.2 Btu/ft^2·hr·ºF

Radiant Heating and Cooling

- Combined Floor HTC
  - Subject to AUST (Building Efficiency)
  - Building Architecture
  - Application ex.
  - Air Craft Hangars
  - Maintenance Bays

- Heating
  - 2.0 $Btu/ft^2 \cdot hr \cdot {}^oF$
- Cooling
  - 1.2 $Btu/ft^2 \cdot hr \cdot {}^oF$

Radiant Heating and Cooling

- Conditioning Surfaces
  - Industrial Comfort
    - Footwear
    - Clothing
    - Activity
- Heating Comfort (normal footware)
  - < 84°F +
- Cooling
  - > 66°F

Radiant / Convective Heat Transfer From A Radiant Floor , Btu/hr/sf						
Operative Temperature, °F	Floor Surface Temperature, °F					
	65	70	75	80	85	90
55	20	30	40	50	60	70
60	10	20	30	40	50	60
65	0	10	20	30	40	50
70		0	10	20	30	40
75			0	10	20	30
80				0	10	20

Radiant Heating and Cooling

Typical Fluid Temperatures

- Heating
  - 85ºF to 140ºF
- Cooling
  - 66ºF to 55ºF

Radiant Heating and Cooling

- Plant Temperatures
- Exergy Considerations
- Condensing Boilers
- Heat Pumps
- Solar
- Waste Heat
- Ground Source
- Evaporative Cooling

- Heating
  - 80ºF to 180ºF
- Cooling
  - 45ºF+/-

Radiant Heating and Cooling

Flow Rates

- Heat Capacity
- Water versus Air
    - Density
    - Specific Heat
- Δt's

$$\frac{\boldsymbol{Q_w}, \textbf{ Heat Transfer}_{\text{ liquid}}, \text{ Btu/hr}}{\textbf{60} \text{ min/hr} * p_w \text{ lbs/USgal} * C_p \text{ Btu/lb }^{o}\text{F} * \Delta \boldsymbol{t}\ ^{o}\text{F}} = \boldsymbol{q_w}, \text{ USgpm}$$

$$\frac{\boldsymbol{Q_w}, \textbf{ Sensible Heat Transfer}_{\text{ air}}, \text{ Btu/hr}}{\textbf{60} \text{ min/hr} * p_w \text{ lbs/ft}^3 * C_p \text{ Btu/lb }^{o}\text{F} * \Delta \boldsymbol{t}\ ^{o}\text{F}} = \boldsymbol{q_w}, \text{ cfm}$$

Radiant Heating and Cooling

Heat Capacity

- Water
  - 8.34 lbs/USgal * 1 Btu/lb °F
  - Btu/hr ÷ (500 x Δt)
- Air
  - 0.075 lbs/ft^3 * 0.24 Btu/lb °F
  - Btu/hr ÷ (1.08 x Δt)

Radiant Heating and Cooling

- Δt's
  - Room for Aggressive Designs
  - Thermal Mass
    - Slab Thickness
    - Tube Patterns
  - Building Use
    - Activity
    - Storage
    - Multi-Purpose

- Water Δt's
  - Plant
  - 10°F <40°F
  - Distribution/Injection
  - >20°F <100°F
  - Floor
  - >10°F <30°F, Heating
  - <10°F, Cooling
- Air Δt's
  - ≈60°F (heating)
  - ≈25°F (cooling)

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Example with Condensing Boiler

- @ Flux = 20 Btuh/sf ≈ 8000 sf.
- 162,000 Btu/hr
- Shop Floor
- Counterflow Tube Pattern
- Apply Exergy Principles
- Boiler, Distribution and Floor Design for 30°F Δt
- ≈ 11 gpm in 1.25” Pipe
- 2 Ft/100’ @ 2.36 fps

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Example with Air Based System

- 162,000 Btu/hr
- 60°F Δt
    - ex. 60°F$_{return}$, 120°F$_{supply}$
- ≈ 2500 cfm
- ≈ 24…28” Ø .06”w.c.$^{+/-}$ @ 900 fpm,

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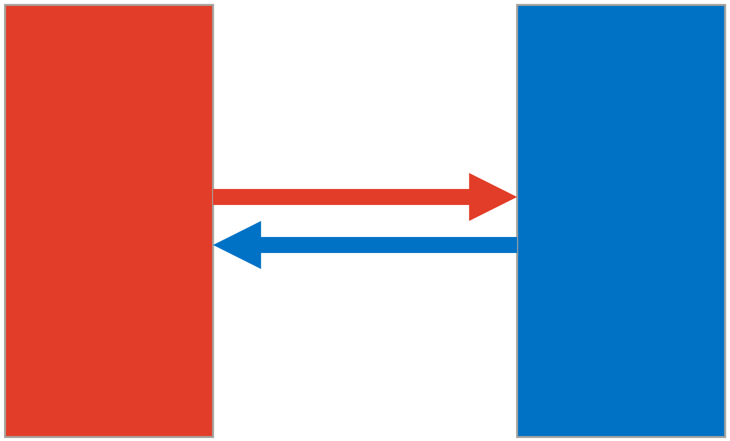
Example with District Energy System

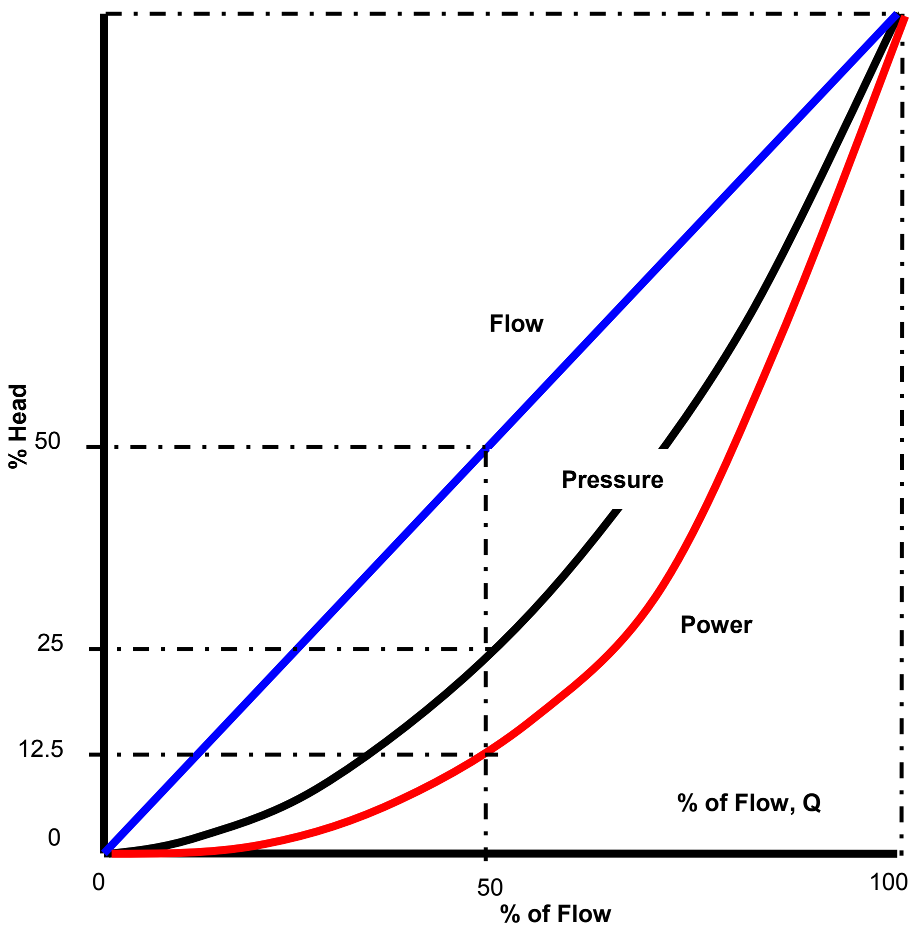
- **Plant Design** 30°F Δt
  - ≈ 11 gpm in 1.25″ Pipe
  - 2 Ft/100′ @ 2.36 fps
- **Injection Flow** 80°F Δt
  - ≈ 4 gpm in ¾″″ Pipe
  - 4.2 Ft/100′ @ 2.1 fps
- **Floor** 30°F Δt
  - ≈ 11 gpm in 1.25″ Pipe
  - 2 Ft/100′ @ 2.36 fps



Radiant Heating and Cooling

Benefits of Aggressive Δt

- Lower Flows
    - Infinity Laws
- Capital Costs
- PFV, Insulation, Hangars, Labor
- System Volume
    - Expansion Tanks
    - Chemicals, Glycol etc.



Radiant Heating and Cooling

- Horsepower Comparison, Injection System, Heating

System	Floor Heating	Injection Circ	Boiler Circ	Air Handler
	17 USgpm @14 ft of head	4 USgpm @ 5ft of head	17 USgpm @10 ft of head	2500 cfm @.6
Horsepower	.12	.04	.12	.75
	.25			

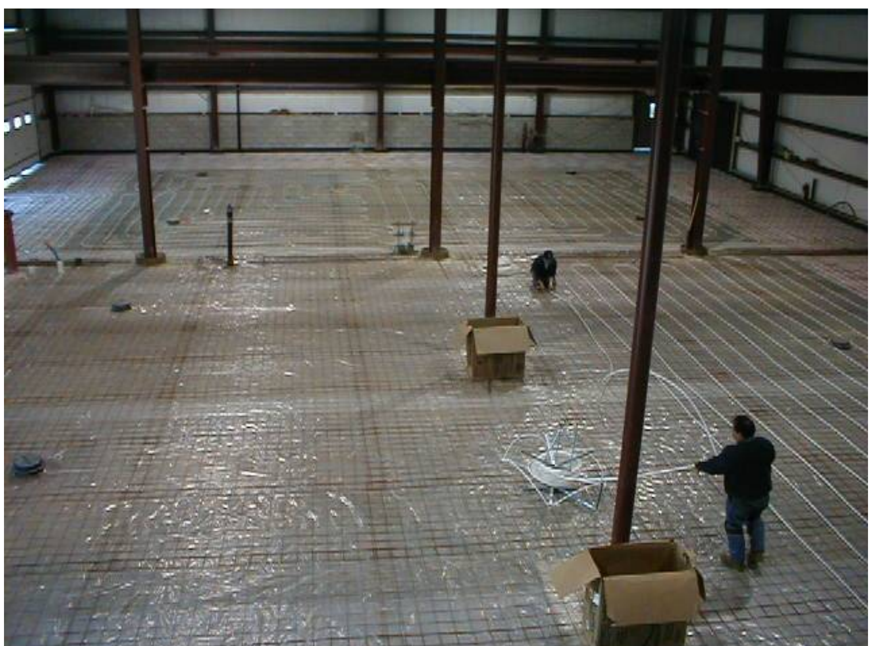
Radiant Heating and Cooling

- Power Comparison, Sensible Cooling
- q=341,180 Btu/h,
- t_{supply}=55.4°F, t_{return}=80.6°F, cp= 0.24 Btu/lb•°F, ρa =0.071 lb/ft3, total pressure drop air system Δp=0.247 psi, η_{air}=0.75,
- t_{supply}=55.4°F, t_{return}=62.6°F, cp= 1 Btu/lb•°F , ρa =8.34 lb/gal, total pressure drop air system Δp=11.63 psi, η_{water}=0.30

System	Floor Heating		Air Handler	
	gpm	95	cfm	13,250
Power	≈ 1600 W		≈ 14,000 W	

Radiant Heating and Cooling

- Measurable
- Heating Building Mass
- Heating Air in Building



- Quantitative Parameters
  - Plant Efficiencies
    - Exergy
    - Transportation Losses
  - Power Consumption
    - Water vs Air
    - 11 gpm vs 2500 cfm
- Human Element
  - IEQ
  - Operative Temp.
  - MRT & Dry Bulb

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Human Element

- ASHRAE Standard 55
- Energy Exchange
- See ASHRAE Tables
    - @ 1.0 Met, > 55% of Sensible is Radiant Transfer
- See ASHRAE Comfort Program
    - Centre for Built Environment, UC - Berkley

Radiant Heating and Cooling

- Energy Saving/Process Improvement Concept
    - Low Temp Systems Matched to Low Temp Plants or,
    - Low Temp Systems to High Temp Plants w/ Motive Temperatures for Lower Distribution Flows
    - Incorporate Thermal Storage
    - Apply District Energy Principles
    - Separate the IAQ from ICQ
    - Optimize Each System
    - Packaged Systems to Reduce CO_2 Emissions
    - Optimize Plants w/ Multi Fuel Sources

Radiant Heating and Cooling

- Energy Saving/Process Improvement Concept
  - Replace 100% air based heating systems with 100% water based radiant.
    - Condensing Boilers, Heat Pumps, Solar, District Energy
  - Replace 100% air based heating and cooling systems with water based radiant sensible heating and cooling plus air based systems for ventilation and latent cooling.
    - Ground Water, Off Peak, Heat Pumps,
    - Night Sky Radiation, Evaporative Cooling
    - Dedicated Outdoor Air Systems

Radiant Heating and Cooling

- Energy Saving/Process Improvement Concept
  - Less Volumetric 3D Restriction for Movement of Man and Machinery
  - Explosion Proof w/ External Remote Plants
  - Slabs Not Damaged by Natural Disasters Such As Tornado's, Flooding, (≈ earthquakes)
  - Can Be Connected to Trailer Mounted Mobile Emergency / Portable Plants Operated From Multiple Fuels.
  - Easier to Maintain Dry, Slip Free Surfaces in High Stress Activities (Mobilizations/Emergencies etc.)
  - Heated and Cooled Slabs Preferable in Emergency Medical Operations in a Non Healthcare Environment, Easier to Maintain Sterility and Offer Elements of Comfortable.

Pros & Cons Comparisons

System	100% Air	100% Radiant	Hybrid Air & Radiant
Load Analysis	Ignores building mass thermal capacitance	Considers building mass thermal capacitance	
Sensible (Gains and Loss), Conduction, Radiant, Infiltration	Infiltration pressure influenced	Infiltration pressure neutral	Infiltration pressure influenced (minimal)
	Slab Insulation as required by code	Slab Insulation as required by load analysis, geotechnical and conduction	Slab Insulation as required by load analysis, geotechnical and conduction
Latent (cooling)	Sensible & Latent	Sensible only	Sensible & Latent
Ventilation	Sensible, Latent & Ventilation	Sensible only	Sensible, Latent & Ventilation
Duct Sizing	Sensible, Latent & Ventilation	none	Latent and Ventilation
Design & Specifications	Standard Procedure	Specify experience in both radiant and hybrid systems	
Tendering Process	Standard Procedures		
Unique Installation Considerations	Mechanical chases	Tube installation and concrete pour	Mechanical chases, Tube installation and concrete pour, control integration
Commissioning	Standard Air Procedure	Standard Hydronic Procedure	Integrated Procedure
Operation	Standard Air	Standard Hydronic	Integrated
Maintenance	Typical for each type.		

Radiant Heating and Cooling

- Technology Installed Costs
  - Similar to most hydronic systems.
  - Prepackaged control panels reduce installations and commissioning times as much as 60%.
  - Reduced CO_2 Emission
- Level of Maturity
  - Forms of radiant system have been around since the Romans. It has been in the past 20 years where plastics and controls have evolved to provide robust systems.
  - Civil War Hospital 1864, History of Huts
- Experiences/Lessons learned
  - Impact on indoor air quality
  - Since radiant can only deal with sensible loads it requires a separate system for ventilation and latent cooling.

Radiant Heating and Cooling

- References:
- Energy Consumption Characteristics of Commercial Building HVAC Systems Volume III: Energy Savings Potential Prepared by Kurt W. Roth, Detlef, Westphalen, John Dieckmann ,Sephir D. Hamilton William Goetzler, TIAX LLC, 20 Acorn Park Cambridge, MA 02140-2390 TIAX Reference No. 68370-00 For Building Technologies Program Project Manager: Dr. James Brodrick (DOE) Contract No.: DE-AC01-96CE23798, July, 2002
- Analytical Tools For Dynamic Building Control Sponsored by ASHRAE Final Report for Research Project 985-RP Implementation of Thermal Storage in Building Mass HL 2000-15 Report #5031-1
- Hydronic Radiant Heating and Cooling of Buildings Using Pipes Embedded In The Building Structure, Bjarne W. Olesen, Ph.D.
- ASHRAE Transactions Using Radiant Cooled Floors to Condition Large Spaces and Maintain Comfort Conditions, Simmonds, Ph.D. , Holst, S , Reuss, S, Gaw, W

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- References Con't

- ASHRAE Journal, The ABC of DOAS, Dedicated Outdoor Air Systems, Wayne Morris, Associate Member, ASHRAE
- ASHRAE Journal, March 2003, Emerging Technologies, Dedicated Outdoor Air Systems, By John Dieckmann, P.E. Member ASHRAE, Kurt W. Roth, Associate Member ASHRAE, and James Brodrick, Ph.D., Member ASHRAE
- ASHRAE 2004 Handbook, HVAC Systems and Equipment, Chap. 11
- ASHRAE Journal, November 2001, Ceiling Panel Cooling Systems By Stanley A. Mumma, Ph.D., P.E. Fellow ASHRAE
- Vertically Integrated Systems in Stand-Alone Multistory Buildings (c) 2005 American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. www.ashrae.org. Robert Bean, R.E.T., Associate Member ASHRAE, Tim Doran, Member ASHRAE, Bjarne Olesen, Ph.D., Fellow ASHRAE, and Peter Simmonds, Ph.D, Fellow ASHRAE