Radiant Heating and Cooling
Thermal Mass Systems

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Objectives

- Maximize Life Cycle Value
- Reduce Energy Costs
  - ASHRAE 90.1 is the minimum standard
  - React to utility rates
- Reduce Maintenance Costs
  - Evaluate during design phase
  - Simplify equipment and system
U.S. Department of Energy - Building Life Cycle Costing

“Building Energy Technology” 1990

<table>
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<tr>
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<th>Design</th>
<th>Maintenance</th>
<th>Construction</th>
<th>Utilities</th>
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<td>0</td>
<td>5</td>
<td>10</td>
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All-Air HVAC Systems

- Unlimited application range
- Can be designed “anywhere, anytime” and made to work for any application
- Occupant “perception” of “fresh air” conditions due to high air movement rate
All-Air HVAC Systems

Comfort and IAQ:
- uneven space comfort
- high air velocities: typically $> 50-100$ fpm
- potentially high noise levels
- portion of contaminated air is mixed and re-circulated

Cost:
- large equipment capacities required
- moving large air volumes $\Rightarrow$ energy intensive operation
- large space requirements
- higher mechanical equipment and building space cost
Conventional HVAC Systems

Energy Use of a Typical All-Air HVAC System

33% for Space Heating & Cooling Plant
Up to 40% energy used for perimeter zones

67% for Energy Transport \( = \) Fan Energy ??

![Diagram showing energy use breakdown]
Air vs. Water

- Water can store 3,400 times more thermal energy per unit volume than air!
- A 1/2” water pipe can flow as much energy as a 24” X 24” air duct!
- More air volume to move = More Fan Energy Used
Human Comfort

- 20% humidity/perspiration
- 30% convection/air movement
- 50% radiation heat exchange

In a low velocity air environment at moderate humidity,
Passive Building Systems

- Hydronic radiant heating and cooling
- Daylighting
- Passive solar heating
- Thermal mass advantages
- Building envelope design
- Building orientation
- Natural ventilation

Passive building systems are climate adapted, have very low maintenance requirements, low energy use and high durability/very long life.
Hydronic Radiant Systems

CONCRETE CORE SYSTEM
Radiant Systems Design

- Radiant heating floors limited to 85°F-90°F
- Radiant heating ceilings, up to 200°F
- Radiant floor cooling max. output 25 BTUh/ft²
- Radiant cooling ceilings max. output 40 BTUh/ft²
- Radiant cooling is limited by ambient dew point

Radiant temperature control systems are controlling the Resultant Temperature in the space.

The key to energy efficiency is separating the temperature control function from the ventilation function.
Radiant Slabs

Typical features:

- Radiation is the dominant heat transfer mode
- Heat exchange occurs at the speed of light
- Strictly space temperature control function
- Distribution system imbedded in building structure
- Low temperature differences between the radiant surface and the space temperatures (5°- 10°F)
- Constant circulation/variable temperature
- Building mass energy storage self-regulating effect
- Track record of over 20 years throughout Western Europe
Radiant Slabs

- **Night time pre-cooling**
- **Thermal inertia**
- **Stable interior temperatures**
- **Requires high performance envelope**
- **Thermal mass heat pump effect**

ENERTIA®: Useful Energy from a Shift in Time
Radiant Slabs

- **Acts like a “Static Heat Pump”:**
  - Trims and Delays Effects of Transient Loads
    - **Heating Season:** Passive Solar Energy Absorption - Reduced Peak Heating Load
    - **Cooling Season:** Trims Peak Space Loads - Reduced Peak Cooling (or even eliminated!)
- Smaller Mechanical System Heat/Cool Capacity
- Improved System Operating Efficiency
- Reduced Capital & Operating Cost
- Stable Space Temperatures
- Simplified Controls
Radiant Slab Cooling

Design Considerations:

• Space loads must be controlled by:
  - High performance envelope
    - Glass U values and SC values
    - Exterior shading devices
    - Building orientation, shape, and size
    - Minimized lighting and equipment loads
    - Use of building mass
  • Integrated design approach
  • Coordination during Construction
Radiant Slab Cooling

Floors vs. Ceilings:

Floor cooling minimum temperature = 66°F
Floor cooling output limited to 12 Btuh/ft$^2$ to 15 Btuh/ft$^2$
Floor coverings are insulators

Ceiling cooling minimum temperature = 62°F
Ceiling cooling output limited to 25 Btuh/ft$^2$ to 30 Btuh/ft$^2$
Radiant Slab Cooling

- Maximum ambient dew point = 60°F
- Relative humidity controlled to be <60%
- Air handlers for ventilation only

Typically overhead/ceiling system for maximum efficiency
Radiant Slab Cooling

\[\text{Températures été}\]

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\text{date} & \text{12.07.94} & \text{13.07.94} & \text{14.07.94} \\
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\text{59°F} & \text{15} & \text{20} & \text{25} \\
\text{73°F} & \text{20} & \text{25} & \text{30} \\
\text{95°F} & \text{25} & \text{30} & \text{35} \\
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\text{SCHAUBLIN S.A Delémont, dalle active Ouest}

\text{CUEPE 15 - 9 - 94}
Radiant Slab Heating

Températures hiver

77°F

32°F
Radiant Slabs

Control systems: response time of concrete slabs is about 1.5 - 2 hours per inch of concrete
Radiant Slab Ceilings

Acoustic Considerations

- Room furnishings
- Floor finishes
- Ceiling Texture
- Suspended radiant panels using slab loops
Envelop Design

- Glazing solar performance
- Glazing thermal performance
- Thermal bridging
- Internal mass walls/floors
- Thermal load control first, then apply comfort systems designs.
Glazing Performance

Reduce or eliminate solar load transients

Radiant cooling design limit = +/-25 btuh/ft²
Glazing Performance

- Low-e coatings
- Gas fills – Argon, Krypton
- Multiple air spaces
- Frame construction
- Installation detailing

**Key Issue:**
Inside surface temperature of glass
- > 62°F in winter
- < 78°F summer
Total Comfort System

- Radiant system temperature control
- Ventilation system
  Dehumidification system

Design to de-couple the temperature control function from the ventilation function
Total Comfort System

Starts with the building envelope

- Reduce thermal loads to minimum
- Radiant temperature control system as primary
- Air system reduced to minimum ventilation
Ventilation System

- Filtered/treated 100% outdoor air
- Constant volume or VAV
- Energy Recovery
- Demand controlled
- Easy to verify and control
- Works in any climate
Ventilation System

- Some specialized computer modeling required for DV system
- Can be used for supplemental thermal control
- Variety of supply air schemes:
  - Conventional overhead supply
  - Low level displacement outlets
  - Underfloor displacement air supply
  - Cast into slab displacement system
Ventilation System

Displacement Ventilation
Displacement Ventilation

Low level, low velocity supply
High level exhaust
Very near room temperature
Cannot be used for heating
Can provide supplemental cooling

Displacement ventilation.
Energy Recovery Systems

Plate type air to air heat exchangers

Heat Wheels
Central Heat/Energy Recovery
Energy and Comfort

- System is simpler.
- Space temperature control only.
- Utilize the building mass energy storage.
- Passive control scheme.
- Radiant heat transfer is direct and draft-free
- Virtually no noise is associated with space conditioning
- Better efficiency and possibly smaller sizes of chillers and boilers
- Lower maintenance costs
Radiant Slabs

• Coordination during Construction:
Radiant Slabs

- Coordination during Construction:
Radiant Slabs

Coordination during Construction:

Cast-in-place inserts
Radiant Slabs

Coordination during Construction:
Tube Loops Pressurization - Air vs. Water
Radiant Slab Costs

Building Criteria:

- 3 Story Office Building
- Total Area = 90,000 sq. ft.
- Walls = R-20
- Roof = R-20
- Windows: 50% of total wall area
- Concrete Construction
Radiant Slab Costs

Envelope vs. Mechanical/ Electrical Costs:

Mechanical Cost for Conventional Building: 20.50$/Sq.Ft.

Electrical Cost for Thermoactive Slab Building 12.00$/Sq.Ft.
Mechanical Cost for Thermoactive Slab Building: 15.50$/Sq.Ft.

Savings for Mechanical/Electrical Systems 6.00$/Sq.Ft.

Premium for High Performance Glass 6.00$/Sq.Ft.

Canadian Cost Data provided by Geoff McDonell
Installations

Over 20 in North America
Countless in Europe