LEARNING OBJECTIVES OF THIS COURSE
BY THE END OF THIS COURSE, PARTICIPANTS SHOULD BE ABLE TO:

1. Explain the basic principles of radiant cooling systems and the factors that affect the output capacities
2. Define the meaning of a “hybrid” HVAC system and how it can be optimized to address the concern of condensation
3. Discuss how a hybrid HVAC system using radiant cooling leads to an improved building environment
4. Describe how a hybrid HVAC system using radiant cooling can reduce initial investment costs
5. Explain how a hybrid HVAC system using radiant cooling can reduce operating costs through reduced energy consumption and maintenance
6. Summarize the advantages of having a radiant system from a specifier’s perspective
PROLOGUE: RADIANT COOLING SYSTEMS

CORE COMPONENTS USED IN RADIANT HEATING AND COOLING INSTALLATIONS

- Crosslinked polyethylene (PEX) pipes
- Distribution manifolds

CROSSLINKED POLYETHYLENE (PEX) PIPES

INTRODUCTION

History
- Development work started in Germany in 1968 for the first PEX pipes
- Series production began in 1972 for PEX pipes for radiant heating applications
- PEX pipes are now used for multiple fluid-based applications around the globe

Capabilities of PEX pipes
- Toughness to withstand jobsite conditions
- High pressure and thermal capabilities
- High flexibility for making tight bends
- Wide range of diameters and coil lengths
- Proven long life with more than 40 years experience
CROSSLINKED POLYETHYLENE (PEX) PIPES

AVAILABLE SIZES

- Sizes 3/8, 1/2, 5/8 and 3/4 in. are most commonly used as radiant heating and cooling pipes within floors, walls or ceilings
- Larger sizes 1, 1 1/4, 1 1/2 and 2 in. are used to supply heated or cooled fluid to distribution manifolds and other hydronic components

DISTRIBUTION MANIFOLDS

REQUIRED IN ALL RADIANT SYSTEMS FOR CONTROL OF DISTRIBUTION PIPING

- A typical circuit of radiant pipe covers 150 to 250 ft² (14 to 23 m²); typical project uses many circuits of pipe
- Circuits are connected to factory-assembled distribution manifolds to control flow
- Examples:
1. PRINCIPLES OF RADIANT COOLING

Whenever there is a temperature difference between two objects, both objects will attempt to equalize the temperature. The energy transfer required to approach equivalent temperatures occurs through radiation.

Radiant energy travels from “hot” to “cold” through a space, without heating the space itself.

PRINCIPLES OF RADIANT COOLING

BASIC PHYSICAL PHENOMENA

MODES OF HEAT TRANSFER FROM OUR BODIES

Conduction – Direct contact
- Ex: Hand on a hot plate, feet on a cool floor

Evaporation – Energy transfers with the vapor associated from perspiration and breathing
- Ex: Moisture lost through sweating in warm conditions

Convection – A fluid transfers the energy (air is a fluid)
- Ex: Air being heated by a warm floor becomes buoyant; warm air gently rises while cold air falls

Radiation – Warm objects radiate heat waves to cooler objects in line of sight
- Ex: Sun heating the earth or people warmed near a bonfire; no air is involved
PRINCIPLES OF RADIANT COOLING

BASIC PHYSICAL PHENOMENA

HUMAN COMFORT

- Heat emission from the human body occurs through four modes of transfer:
  - Conduction (~5%)
  - Evaporation (~20%)
  - Convection (~30%)
  - Radiation (~45%)

- Our bodies radiate heat to any surface in line of sight which is cooler than our bodies’ surface temperature of 85° to 90°F (29 to 32°C)
  - Reducing surrounding surface temperatures draws more heat from our bodies via radiation

- Humans feel most comfortable when they can regulate at least 45% of their heat emission through radiation

OVERVIEW OF RADIANT COOLING SYSTEMS

HEAT TRANSFER

In a radiant heating system, warm fluid circulates through PEX pipes which are integrated in the floor structure
  - Heat radiates up from the warmed floor, providing a comfortable environment by warming people and objects
  - Warm air also rises due to natural convection

A radiant cooling system works with the reverse energy transfer process, providing a comfortable environment by absorbing heat from the space
  - Heat transferred through the floor is removed from the space via the circulating fluid
  - In cooling mode, the same network of pipes is used as in the heating mode
  - In some applications pipes can be embedded into the ceiling or even the wall

Image courtesy of RPA
PRINCIPLES OF RADIANT COOLING

OVERVIEW OF RADIANT COOLING SYSTEMS

INSTALLATION TYPES

Radiant Floor Cooling and Floor Heating (FC/FH)
- With insulation underneath to condition the space above and below
- Heated/cooled floor
- Uni-directional

Thermally Activated Slab (TAS)
- Without insulation underneath to condition the space above and below
- Heated/cooled floor and ceiling
- Bi-directional

THERMALLY ACTIVATED SLAB EXAMPLE WITH EXPOSED DUCTWORK AND CEILINGS

WOODBRIDGE, ONTARIO
From years of adjusting thermostats, we have been conditioned to believe that air temperature alone translates to comfort, but this is not necessarily true.

We have to consider:
1. **Air temperature**
   - Space’s air temperature, monitored by thermostat as "set point temperature"

2. **Mean radiant temperature (MRT)**
   - Average temperature of surrounding surfaces

3. **Operative room temperature**
   - Weighted average of mean radiant temperature and the conditioned space’s air temperature

The *operative temperature* is what we perceive on our skin in a room and what is most important to consider when specifying a radiant system.

Higher air temperature set points during the cooling season and lower set points during the heating season are possible with radiant systems.

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**PRINCIPLES OF RADIANT COOLING**
**TEMPERATURE SET POINTS**

---

**PRINCIPLES OF RADIANT COOLING**
**TEMPERATURE SET POINTS**
**THE EFFECTS OF MEAN RADIANT TEMPERATURE ON COMFORT**

![MRT comfort graph](image)

MRT comfort graph originally published in *Architectural Forum*, January 1939
PRINCIPLES OF RADIANT COOLING
TEMPERATURE SET POINTS

Spaces with 100% forced-air systems have higher mean radiant temperatures due to solar gains and office equipment
- Occupant turns down the air set point, trying to counter radiant loads using cooler air
- This requires more air movement, inefficiently countering MRT

With an air-based system in combination with a radiant cooling system, surface temperatures are lower
- This increases the heat emitted from the occupant to surrounding surfaces via radiation
- Occupant feels comfortable within the space, which removes the need for a lower air temperature and/or increased air flow
- Most efficiently counters heat loads

PRINCIPLES OF RADIANT COOLING
RADIANT COOLING CAPACITIES
THEORY

\[ q = \text{HTC} \left( T_{\text{SURFACE}} - T_{\text{AIR}} \right) \]

Specific heating/cooling capacity in W/m² or Btu/(h·ft²)
Heat transfer coefficient
Average surface temperature
Air temperature

Heat transfer coefficient (HTC) values can be approximated based on values from DIN EN 1264 and 15377

- ~60% greater potential to absorb heat from ceiling cooling system vs. floor cooling system based solely on HTC
- Reverse for delivering heat in heating mode
PRINCIPLES OF RADIANT COOLING

RADIANT COOLING CAPACITIES
PERFORMANCE OF RADIANT FLOORS

For comfort ASHRAE Standard 55 limits floor temperature range to:
- Greater than 66°F (19°C) in cooling mode
- Less than 84°F (29°C) in heating mode

Typical capacities based on setpoints adjusted for radiant systems:

<table>
<thead>
<tr>
<th></th>
<th>OUTPUT</th>
<th>T_SURFACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating</td>
<td>78-84°F</td>
<td>19-31 Btu/(h·ft²)</td>
</tr>
<tr>
<td>Cooling</td>
<td>66-70°F</td>
<td>8-12 Btu/(h·ft²)</td>
</tr>
<tr>
<td>Ceiling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating</td>
<td>78-84°F</td>
<td>11-17 Btu/(h·ft²)</td>
</tr>
<tr>
<td>Cooling</td>
<td>66-70°F</td>
<td>15-24 Btu/(h·ft²)</td>
</tr>
</tbody>
</table>

Obtaining a designed surface temperature from a radiant floor system depends on factors such as average fluid temperature, pipe spacing, pipe placement, floor covering, room set point temperature

Ceilings not limited by ASHRAE 55 floor range, used only to show capacity comparison

2. ADDRESSING CONCERN OF CONDENSATION

DESIGN CONSIDERATIONS
HUMIDITY AND CONDENSATION

Understanding the basic principles of radiant systems starts to reveal where their many benefits can be found. Many are convinced that radiant heating systems contribute to sustainable building, but still have reservations about radiant cooling.

Radiant cooling needs a slightly more sophisticated design approach compared to radiant heating due to solar gains, occupant loads and resulting moisture management issues, which for most climates of North America pose concerns for specifiers.

When a surface temperature is lower than the dew point, condensation can form.
Cooling projects located outside arid climates demonstrate that results are driven by successful design, not climate - Controls are available to avoid uncomfortable and dangerous condensation


Also noteworthy, usage of radiant cooling in “very cold” regions - Where specifiers have chosen radiant heating, they can easily take advantage of the cooling potential in the existing PEX network - Addition of radiant cooling minimally increases the initial cost and has many advantages during operation

Successful radiant cooling projects center around understanding the correct balance of an air handling unit (AHU) working in conjunction with a radiant system. These are referred to as “hybrid HVAC systems.”

Note: “AHU” is used to indicate any forced-air system used to condition a space (e.g., fan coil, packaged rooftop unit, DOAS).

The radiant system and the AHU work together as a hybrid HVAC system, optimizing system design and performance by decoupling the following portions of the system:
1. Hydronic and air-based
2. MRT and air temperature
3. Sensible (dry) and latent (humid) cooling
ADDRESSING CONCERN OF CONDENSATION

DESIGN CONSIDERATIONS

HYBRID SYSTEMS

Although hydronic conditioning systems have many benefits, they usually cannot work alone in commercial applications.

Hybrid HVAC systems must have an air-based component for several reasons:

1. AHU is required to meet the building’s fresh air requirements, staying consistent with increased building environment standards (e.g., ASHRAE 62.1, LEED)

2. Downsized forced-air components must exist to counter humidity from outside air and from occupants within a building (latent cooling)

3. For some applications it is desirable to have a fast acting system to handle quick shifts in occupancy and transient loads

DESIGN CONSIDERATIONS

HYBRID SYSTEMS

The key to preventing condensation lies in three specific areas:

1. Infiltration
   - First and foremost, use a tight building envelope to reduce loads associated with non-mechanical infiltration

2. Surface Temperature
   - Control surface temperatures by designing cooled surfaces to operate at specific supply temperatures to prevent the surface from reaching dew point, which might lead to surface condensation

3. Relative Humidity
   - Control the level of humidity in a building with the AHU to keep the dew point lower than the cooling slab’s operating temperatures
   - Spaces are typically designed for about 50% maximum relative humidity during peak cooling periods
ADDRESSING CONCERN OF CONDENSATION

- Outdoor temperature sensor on the northern side of the building, not exposed to direct sunlight
- Humidity and temperature sensor(s) in each zone to monitor dew points and set points
- Floor temperature sensor in the upper level of the thermal mass
- Supply and return fluid temperature sensors in the piping network

DESIGN CONSIDERATIONS

BUILDING CONTROL STRATEGY

3. HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT

THERMAL COMFORT

Radiant cooling and heating systems are integral in creating hybrid systems that reach higher levels of thermal comfort than their 100% forced-air system counterparts.

- This finding is supported in detail through a research study
- Survey - Concrete Core Temperature Control Systems, 2008 by the University of Nuremberg, Germany
- Study evaluates seven common and uncommon heating and cooling systems under North American conditions for a fully simulated commercial building
The study compared several types of commercial heating/cooling systems on the following attributes:

- Thermal comfort (learning objective 3)
- Initial investment cost (learning objective 4)
- Operating costs: energy demand + maintenance costs (learning objective 5)

The study considers the following conditions:

- North American and local building codes and standards (e.g., ASHRAE Title 24 California Standards and Energy Code)
- North American construction techniques
- North American energy and investment costs including material and labor
- North American climate

**BASIS OF STUDY**

- **Project type:** Four-story poured commercial construction
- **Location:** Sacramento, California
- **Outside design temperatures:** $100^\circ F / 31.5^\circ F$ (0.4% / 99.6%)
- **Effective area:** Approximately 14,500 ft² total area on four floors
- **Heaviness of construction:** 160 lb/ft², cast-in-place construction
HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT

BASIS OF STUDY
THE REFERENCE OFFICE ROOM

The study focused on a typical occupied office

Office dimensions: 17.7 ft x 18.5 ft x 9.8 ft
Floor Area: 328 ft²
Volume: 3,210 ft³
Occupancy: 2 persons
Heat emission per person: 450 Btu/h (seated, office work)
Electrical equipment: 3.5 Btu/(h·ft²)
Lighting: 3.8 Btu/(h·ft²)
Normal office hours: 7:30 am to 6:00 pm on weekdays
Operating hours of heating and cooling systems: 6:00 am to 6:00 pm on weekdays

HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT

COMPARED SYSTEMS - OVERVIEW

100% Forced Air System (AHU)  Floor Radiant System (FCH) + downsized AHU  Ceiling Radiant System (CHC) + downsized AHU  Thermally Activated Slab (TAS) + downsized AHU

The University of Nuremberg's study compares seven systems, three of which are not very common in North America so they are excluded from this presentation.

Focusing on the above four HVAC system options, the three on the right are hybrid HVAC systems shown above include a downsized air handling unit (AHU) to decouple and optimize the space's cooling requirements.
## HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT

### COMPARED SYSTEMS - OVERVIEW

<table>
<thead>
<tr>
<th>System</th>
<th>Floor Radiant System (FCH)</th>
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<tr>
<td>100% Forced Air System (AHU)</td>
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- VAV’s positioned in corridor plenum feed the space with conditioned air
- Fresh air supply requirements are met by the air handling unit (AHU)
- Supply air is conditioned to ensure required temperature and humidity

<table>
<thead>
<tr>
<th>Zone Loads:</th>
<th>External Wall:</th>
<th>Window:</th>
<th>Frame:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 persons at 450 Btu/h</td>
<td>U=0.16 Btu/(h·ft²)</td>
<td>U=0.46 Btu/(h·ft²)</td>
<td>U=0.55 Btu/(h·ft²)</td>
</tr>
<tr>
<td>Electrical Equipment:</td>
<td>U=0.08 Btu/(h·ft²)</td>
<td>U=0.10 Btu/(h·ft²)</td>
<td>U=0.06 Btu/(h·ft²)</td>
</tr>
<tr>
<td>Lighting: 3.8 Btu/h·ft²</td>
<td>U=0.45 Btu/(h·ft²)</td>
<td>g=0.75</td>
<td>p=0.35</td>
</tr>
<tr>
<td></td>
<td>Glazing:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p=0.75</td>
<td></td>
<td></td>
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### HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT

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<td>p=0.35</td>
</tr>
<tr>
<td></td>
<td>Glazing:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p=0.75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT
COMPARED SYSTEMS - OVERVIEW

<table>
<thead>
<tr>
<th>100% Forced Air System (AHU)</th>
<th>Floor Radiant System (FCH) + downsized AHU</th>
<th>Ceiling Radiant System (CHC) + downsized AHU</th>
<th>Thermally Activated Slab (TAS) + downsized AHU</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall: ( U = 0.16 ) BTU/(h·ft²)</td>
<td>Window: ( U = 0.46 ) BTU/(h·ft²)</td>
<td>Frame: ( U = 0.55 ) BTU/(h·ft²)</td>
<td>Percentage Frame: 10%</td>
</tr>
<tr>
<td>Lighting: 3.8 BTU/h·ft²</td>
<td>Glazing: ( U = 0.45 ) BTU/(h·ft²)</td>
<td>( g = 0.36 )</td>
<td>Blinds: ( z = 0.75 )</td>
</tr>
</tbody>
</table>

Zone Load:
- 2 persons at 450 BTU/h
- Electrical Equipment: 3.5 BTU/h·ft²
- Lighting: 3.8 BTU/h·ft²

Floor Radiant System (FCH)
+ downsized AHU

Ceiling Radiant System (CHC)
+ downsized AHU

Thermally Activated Slab (TAS)
+ downsized AHU

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HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT

THERMAL COMFORT

Thermal comfort has a special standing concerning productivity in a work environment.

ASHRAE Standard 55 *Thermal Environmental Conditions for Human Occupancy*

- “Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment.”

The following factors must be considered when thermal comfort is defined:

- Clothing insulation
- Metabolic rate
- Air temperature
- Air speed / draft
- Humidity
- Radiant temperature

THERMAL COMFORT

Creates a broad range of perceived “comfort”

---

**Boundaries for thermal comfort according to Standard 55**

- Operative temperature:
  - Summer period @ 50% RH: 75-80°F
  - Winter period @ 30% RH: 70-77°F
  - Range of the floor temperature: 66-84°F

- This is the so called comfort area, where the percentage of people who are comfortable is optimized. Less than 10% dissatisfied.
HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT

BASIS OF STUDY

DESIGN TEMPERATURES

The study used:
- Cooling period: 75°F
- Heating period: 68°F
- Minimum floor temperature: 66°F
- Maximum floor temperature: 84°F

| Sample week of outdoor summer weather conditions used to simulate cooling mode for systems |
|---------------------------------|---------------------------------|---------------------------------|
| Ambient Temperature and Solar Gains During Cooling Period |
| Temperature (°F) | Solar Radiation (Btu/h·ft²) | Ambient Temperature |
| 0°C | 0 | 0 |
| 10°C | 0 | 0 |
| 20°C | 0 | 0 |
| 30°C | 0 | 0 |
| 40°C | 0 | 0 |
| 50°C | 0 | 0 |
| 60°C | 0 | 0 |
| 70°C | 0 | 0 |
| 80°C | 0 | 0 |
| 90°C | 0 | 0 |
| 100°C | 0 | 0 |
HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT
RESULTS OF STUDY
OPERATIVE ROOM TEMPERATURES DURING SIMULATED SUMMER WEEK

Indoor operative temperature felt by office occupants during simulated week in summer

HYBRID HVAC SYSTEMS FOR IMPROVED BUILDING ENVIRONMENT
RESULTS OF STUDY
THERMAL COMFORT COMPARISON FOR VARIOUS METRICS

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4. REDUCED INVESTMENT COSTS

OVERVIEW

A radiant cooling system has significant benefits when used in a hybrid HVAC system to increase economic efficiency for a building.

The study compared the following cost components:

- Initial investment costs
- Operating costs including energy demand and maintenance (learning objective 5)

REDUCED INITIAL INVESTMENT COSTS

THEORETICAL OFFICE SPACE

COOLING LOAD CALCULATION FOR SIZING EQUIPMENT

- Calculated using comprehensive DOE software Energy Plus
- Specific cooling load of 23.6 Btu/(h ft²) for the office space
- Air change rate of 7.5 was needed for handling 100% of the calculated cooling load
- Radiant cooling systems cover part of the cooling load and allow for a significant reduction on the air handling side
  - 45% reduction

<table>
<thead>
<tr>
<th>Type of Heating/Cooling System</th>
<th>Required Air Change Rate Per Hour</th>
<th>Equivalent cfm for 327 ft² Office</th>
<th>Equivalent cfm for Office Building</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Forced Air (AHU)</td>
<td>7.5 ACH</td>
<td>400 cfm</td>
<td>16,850 cfm</td>
</tr>
<tr>
<td>Radiant Floor + AHU</td>
<td>5.0 ACH</td>
<td>268 cfm</td>
<td>11,230 cfm</td>
</tr>
<tr>
<td>Radiant Ceiling + AHU</td>
<td>4.0 ACH</td>
<td>214 cfm</td>
<td>8,990 cfm</td>
</tr>
<tr>
<td>Therm. Act. Slab + AHU</td>
<td>4.0 ACH</td>
<td>214 cfm</td>
<td>8,990 cfm</td>
</tr>
</tbody>
</table>
REDUCED INVESTMENT COSTS

RESULTS OF THE STUDY

INITIAL MATERIAL INVESTMENT COSTS

- Specific unit pricing for the geographic region of Sacramento, CA was considered
- A survey of engineers and contractors yielded the following unit pricing

### RESULTS OF THE STUDY

#### INITIAL INVESTMENT COSTS

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Price</th>
<th>Unit</th>
<th>Machine Life</th>
<th>Service and Maintenance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat generation (gas-fired boiler incl. main manifold; pipes incl. insulation, pumps, control system, exhaust system, valves)</td>
<td>$0.15</td>
<td>Btu/h</td>
<td>20</td>
<td>3.5</td>
</tr>
<tr>
<td>Cooling production (steam water set; recirculating pump, pipes incl. insulation, control system, pumps, valves, etc.)</td>
<td>$0.38</td>
<td>Btu/h</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>AHU as mixed air system incl. AC device with four thermodynamic air treatment functions, duct system with insulation, outlets, built-in parts such as fire protection valves, etc., control systems</td>
<td>$0.8</td>
<td>Btu/h</td>
<td>15</td>
<td>3.5</td>
</tr>
<tr>
<td>Under floor heating/under floor cooling incl. connection</td>
<td>$5</td>
<td>$/ft²</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Sub-distribution FH/FC incl. control system, pipes incl. insulation, pumps, sub-distribution manifold, valves</td>
<td>$4.5</td>
<td>$/ft²</td>
<td>20</td>
<td>1.5</td>
</tr>
<tr>
<td>Concrete core temperature control incl. connection</td>
<td>$3.5</td>
<td>$/ft²</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Sub-distribution concrete core temperature control incl. control system, pipes incl. insulation, pumps, sub-distribution manifold, valves</td>
<td>$5.5</td>
<td>$/ft²</td>
<td>20</td>
<td>1.5</td>
</tr>
<tr>
<td>Chilled ceiling incl. connection</td>
<td>$25</td>
<td>$/ft²</td>
<td>20</td>
<td>1.5</td>
</tr>
<tr>
<td>Sub-distribution chilled ceiling incl. control system, pipes incl. insulation, pumps, sub-distribution manifold, valves</td>
<td>$5</td>
<td>$/ft²</td>
<td>20</td>
<td>1.5</td>
</tr>
</tbody>
</table>

REDUCED INVESTMENT COSTS

RESULTS OF STUDY

INITIAL INVESTMENT COST COMPARISON

- Radiant Sub-distribution
  - PEX pipes, manifolds, valves, pumps, sensors, control units, etc.
- Radiant System
  - Ceiling panels, connections, insulation, installation, etc.
- AHU
  - All air equipment, ducting, controls, humidification
- Cooling Production
  - Chilled fluid generation, control unit, connections
- Heat Production
  - Boiler, pumps, control unit, valves, etc.
5. REDUCED OPERATING COSTS

OVERVIEW

Hybrid HVAC systems incorporating a radiant system can aid in reducing energy consumption

- The study compared the following categories of energy demand:
  - Heat generation
  - Cooling production
  - Auxiliary air handling components (i.e., fans for air distribution)
  - Auxiliary radiant components (i.e., circulator pumps for fluid distribution)

REDUCED OPERATING COSTS

RESULTS OF STUDY

FINAL ENERGY DEMAND COMPARISON

Final energy demand correlates directly with building owner’s operating costs.
REDUCED OPERATING COSTS
RESULTS OF STUDY
MAINTENANCE COSTS

Maintenance costs are incurred to support and ensure continued availability of an asset or system, such as scheduled and unscheduled repairs and support staff.

- These costs are calculated with a fixed percentage for service and maintenance.

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Price</th>
<th>Unit</th>
<th>Machine Life</th>
<th>Service and Maintenance [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat generation, gas-fired boiler incl. main manifold, pipes incl. insulation, pumps, control system, exhaust system, valves</td>
<td>0.15</td>
<td>$/(Btu/h)</td>
<td>20</td>
<td>3.5</td>
</tr>
<tr>
<td>Cooling production (steam water net, recoupling plant, pipes incl. insulation, control system, pumps, valves)</td>
<td>0.58</td>
<td>$/(Btu/h)</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>AHU as mixed air system inclusive AC device with four thermodynamic air treatment functions, duct system with insulation, outlets, built-in parts such as the protection valves etc., control system</td>
<td>0.8</td>
<td>$/(cfm)</td>
<td>15</td>
<td>3.5</td>
</tr>
<tr>
<td>Under floor heating / under floor cooling incl. connection</td>
<td>5</td>
<td>$/ft²</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Sub-distribution FH/FC incl. control system, pipes incl. insulation, pumps, sub-distribution manifold, valves</td>
<td>4.5</td>
<td>$/ft²</td>
<td>20</td>
<td>1.5</td>
</tr>
<tr>
<td>Concrete core temperature control incl. connection</td>
<td>3.5</td>
<td>$/ft²</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Sub-distribution concrete core temperature control incl. control system, pipes incl. insulation, pumps, sub-distribution manifold, valves</td>
<td>5.5</td>
<td>$/ft²</td>
<td>20</td>
<td>1.5</td>
</tr>
<tr>
<td>Chilled ceiling incl. connection</td>
<td>25</td>
<td>$/ft²</td>
<td>20</td>
<td>1.5</td>
</tr>
<tr>
<td>Sub-distribution chilled ceiling incl. control system, pipes incl. insulation, pumps, sub-distribution manifold, valves</td>
<td>5</td>
<td>$/ft²</td>
<td>20</td>
<td>1.5</td>
</tr>
</tbody>
</table>

REDUCED OPERATING COSTS
RESULTS OF STUDY
MAINTENANCE COST COMPARISON

- Radiant Sub-distribution
  - Pumps, miscellaneous

- Radiant System
  - Miscellaneous servicing

- AHU
  - Filter replacement, blower fan motors, miscellaneous servicing

- Cooling Production
  - Pumps, chiller maintenance

- Heat Production
  - Pumps, boiler maintenance

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The study compared the following parameters for the four systems:
1. Thermal comfort
2. Initial costs
3. Energy demand
4. Maintenance costs

The comparison lead to an overall score based on the following weighted values:

<table>
<thead>
<tr>
<th>Category</th>
<th>Weighted Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal comfort</td>
<td>30%</td>
</tr>
<tr>
<td>Initial costs</td>
<td>20%</td>
</tr>
<tr>
<td>Energy demand</td>
<td>40%</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>10%</td>
</tr>
<tr>
<td>Total:</td>
<td>100%</td>
</tr>
</tbody>
</table>
ADVANTAGES TO ARCHITECTURAL SPECIFIERS
FROM EXPERIENCE

The study and also the experience from hundreds of radiant cooling projects realized throughout the world prove the advantages of these systems.

Increased Thermal Comfort
- Radiant cooling optimizes the surface temperatures of the occupants’ surroundings, providing a even and comfortable environment
- The human body feels most comfortable when it can regulate at least 45% of its heat emission via radiation achieved through a radiant system
- Comfortable cooling is provided with reduced ventilation air and little to no flow noises

Reduced Investment Costs
- Radiant cooling can lead to a reduction in costly forced air components of an HVAC system
- Higher setpoints reduce building’s required cooling load, which results in less cooling capacity from total HVAC equipment
- Often additional ducting becomes unnecessary and air systems can be downsized to only serve the fresh air requirements
ADVANTAGES TO ARCHITECTURAL SPECIFIERS
FROM EXPERIENCE

The study and also the experience from hundreds of radiant cooling projects realized throughout the world prove the advantages of these systems.

Reduced Operating Costs
- Radiant cooling allows a higher space set-point temperature, while still maintaining the same level of cooling comfort compared to a traditional AHU
- Operating with moderate supply water temperatures allows the integration of renewable systems such as geothermal heat pumps at maximum efficiencies
- Superior heat transfer properties of water compared to air allows hydronic portion of the system to efficiently distribute energy to conditioned spaces
  - A 1 in. water pipe carries same thermal energy as 10 in. x 18 in. rectangular duct
  - A 60 watt circulator can deliver the same energy as a 1,500 watt air distribution fan
- Reduction in required maintenance of the radiant system compared to the 100% air system helps to augment operating incentives
- Lower energy usage may aid in LEED certification

ADVANTAGES TO ARCHITECTURAL SPECIFIERS
FROM EXPERIENCE

The study and also the experience from hundreds of radiant cooling projects realized throughout the world prove the advantages of these systems.

Architectural Flexibility
- Reduced mechanical equipment foot print yields more usable square footage
- Intrusive ductwork may be reduced
- Conditioning brought to space without the need for large ceiling plenum, leading to increased ceiling height, reduced building height or potential for additional levels
- Thermal storage of the slab may allow off-peak cooling to augment a building’s efficiency
- Flexible zoning through manifolds, actuators, and controls integrate perfectly with commercial building automation systems
ADVANTAGES TO ARCHITECTURAL SPECIFIERS

SUMMARY

Architects, engineers and other specifiers note the following advice from experience:

- Radiant cooling is suitable for most commercial, industrial and institutional applications with careful engineering design of total HVAC solution.
- Radiant cooling is not practical for most residential applications mainly due humidity control issues.

Scenario where radiant cooling is most advantageous:
- Atriums with large glass exposures; counter solar gains directly with cooled floor.
- Areas where reduced noise from ventilation is desired.
- Buildings already being designed with radiant heating systems.
- Buildings where peak electrical rates are favorable toward thermal storage.

Coordination between all people involved in the building design and construction is mandatory for the success of the integration of radiant systems!
- Taking an integrated design process (IDP) approach has proven successful and is advocated by ASHRAE and AIA.

SUMMARY

RADIANT COOLING SYSTEMS

RADIANT FLOOR EXAMPLE APPLIED IN SHOWROOM
LIBERAL, KANSAS

- Project received award from the Radiant Professionals Alliance (RPA).
- Radiant system was combined with air system to meet customer’s need for:
  - Optimum thermal comfort.
  - Reduced energy consumption.
RADIANT COOLING SYSTEMS
THERMALLY ACTIVATED SLAB APPLIED IN A DORMITORY
TORONTO, ONTARIO

RADIANT COOLING SYSTEMS
RADIANT CEILING EXAMPLE APPLIED IN A UNIVERSITY LIBRARY
CHICAGO, ILLINOIS
CONCLUSION

REVIEW LEARNING OBJECTIVES

1. Explain the basic principles of radiant cooling systems and the factors that affect the output capacities
2. Define the meaning of a “hybrid” HVAC system and how it can be optimized to address the concern of condensation
3. Discuss how a hybrid HVAC system using radiant cooling leads to improved building environment
4. Describe how a hybrid HVAC system using radiant cooling can reduce initial investment costs
5. Explain how a hybrid HVAC system using radiant cooling can reduce operating costs through reduced energy consumption and maintenance
6. Summarize the advantages of having a radiant system from a specifier’s perspective

QUESTIONS

Feel free to ask any questions related to today’s topics

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THANK YOU FOR YOUR TIME

SUSTAINABLE BUILDING TECHNOLOGY
ACHIEVING HIGH EFFICIENCY WITH INTEGRATED SYSTEMS