Technologies Driving the Exponential Demand for Net Zero Energy Buildings

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CEUs for this workshop

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Objectives

- Quantify the demand for Zero Net Energy (*ZNE) Buildings
- Define the science behind ZNE and low carbon footprint technologies
- Provide insight into high mass thermally conductive structures for heating and cooling
- Describe system configurations which double the rated performance of water-to-water heat pumps
- Understand how passive heating and cooling can provide 50x efficiencies over the state of the art
- Justify the need to separate heating and cooling from ventilation for ZNE performance
- Comprehend the importance of an integrated design team and systems architecture for ZNE results
- List 5 challenges contributing to the failure of NZE project teams or NZE building performance

* Zero Net Energy (ZNE) and Net Zero Energy (NZE) are synonymous
• NBI 42% Growth in ZNE Buildings in 2 Years: 700+ Projects > 62 Million SF
  • 700 in the U.S. and Canada, a growth of 42 percent between 2018 and 2020, according to the New Buildings Institute. Square footage rose by 38 percent in that same time period to 62 million.

• USGBC “LEED for ZNE Buildings” 100 Certifications > 23 Million SF
  • June 14, 2022 - The U.S. Green Building Council announced nearly 100 net zero certifications earned under the LEED Zero program, representing more than 23 million square feet of space.
The Future is Zero Net Energy, Low Carbon

- Denver Water Headquarters, Denver, Colorado – Completed 2021
- Center for Cyber Innovation, USAF Academy, Colorado (under construction)
- Polaris Hall, U.S. Air Force Academy - Completed 2015
- Anaheim Regional Transportation Intermodal Center, Anaheim, California - Completed 2014

Common Features:
- Natural Daylighting
- High Thermal Mass Structure
- Radiant Cooling and Heating
- Heat Pumps with Process Heat
- Precise Humidity Control
- Energy Recovery Ventilation
- BAS Predictive Controls
Overview

- Zero Net Energy (NZE) Building Fundamentals
  - Triple Bottom Line: Metrics for Comfort, IEQ, Energy Efficiency and Value
  - Hydronics versus Forced Air, High Mass versus Low Mass Structures
  - Separate Ventilation from Heating and Cooling, and Control Humidity

- Optimized Heating and Cooling System Configurations
  - Configure Heat Pumps to Optimize System Efficiency
  - Innovative Uses of Source Process Heat Exchangers for NZE Performance
  - Utilize Variable Speed Pumps and Factory-Built Modular Components

- Best Practices for Successful Implementations
  - Integrated Design/Build Team and Design Charrettes
  - Use a Proven Systems Architecture for Zero Net Energy Buildings
  - Understand U.S. Patents and Licensing related to NZE Technologies

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Performance and Indoor Environmental Quality (IEQ) Metrics

**Comfort**
- Uniform Temperature
- Ideal Indoor Humidity 40-50%
- Well Insulated – High R-Value*
- Tight Building Envelope

**Indoor Climate**
- Fresh Air Ventilation (CO²)
- Lower Allergens – MERV11
- No Indoor Combustion
- Dew Point Control*

**Environment**
- Lowest Total Energy Use
- Lower Peak Demand Energy
- Zero Carbon Emissions
- Minimize GHG Emissions*

**Value**
- Highest Energy Efficiency
- Reduced Maintenance Costs
- Healthy IEQ for Productivity
- Maximize Triple Bottom Line*

*R-Value - the capacity of an insulating material to resist heat flow. A higher value is more efficient at resisting heat flow through a material.

*U-value – the capacity of a building material (such as a window) to transmit heat ~ 1/R-value

*Dew Point - the temperature below which the water vapor in a volume of humid air at a given constant barometric pressure will condense into liquid water at the same rate at which it evaporates. Dew point control is critical with radiant cooling but not forced air cooling.

*GreenHouse Gas Emissions - The largest source of greenhouse gas emissions from human activities in the United States is from burning fossil fuels for electricity, heat, and transportation. www.epa.gov

*Triple bottom line is a business concept measuring social and environmental impact—in addition to financial performance. It can be broken down into “three Ps”: profit, people, and the planet.
British Thermal Unit (BTU) is a way to measure energy. One BTU is the amount of energy it takes to raise the temperature of one pound of water by one degree Fahrenheit at sea level.

Watts are also a measure of energy where 1 kilowatt = 1,000 watts 1 watt = 3.412 BTU/hour.

These metrics are used later to describe the capacity of fossil fuel heaters and heat pumps.

43% Transport Energy Savings with Radiant Cooling vs VAV

1 ½ inch Diameter Pipe

20 GPM x 10 deg ΔT x 500

100,000 BTU/hr

24 inch Diameter Air Duct

3541 CFM ÷ 425 CFM/Ton x 12,000 BTU/ton

100,000 BTU/hr
High Mass Thermally Conductive Structures Advantages over Traditional Forced Air Shell & Structure

Thermally Conductive Structure
- High Mass Structural Concrete Slabs
- Embedded Piping to Heat and Cool
- Minimal Ductwork for Ventilation
- Simplified Hydronic Zoning
- Small Temperature Variations in Spaces

Traditional Commercial Structure
- Steel Frame with Light Weight Infill
- Large Air Ducts for Forced Air HVAC
- Heating and Cooling tied to Ventilation: Complex Zoning
- Greater Temperature Variations

A High Performance Building Envelope is a Prerequisite to Attaining Net Zero Energy Performance
13th CAB Barracks - 440,000 SF creates over 10,000 gallons of circulating fluid
Direct Solar Load Affects Cooling Performance

• **Short wave radiation** is heat from sunlight and electrical lighting which is absorbed by the structure through reflected long wave radiation.

• **When heat gain load exceeds peak radiant floor cooling (RFC®)** capacity, supplemental air cooling is required.

• **Energy absorbed depends on radiant floor R-Value & IR Exposure**
  - Without direct solar heat gain, RFC® capacity = **8-12 Btu/h/ft²**
  - In spaces with high solar gain, RFC® capacity = **25-32 Btu/h/ft²**

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The Los Angeles Federal Building, California uses Radiant Floor Cooling in this Lobby
Comfort Issues: Low Mass Forced Air Cooling with Solar Heat Gain

Air Temp
53 to 108° F
10” Inside Glass

Rel Humidity
12% to 54%

Dew Point
28 to 52° F

24 Hour Temps
High Mass Radiant Cooling Systems with Solar Heat Gain

Prior Building Upgraded with High Performance Building Envelope and Radiant Floor Cooling

Air Temp
73 to 75° F

Rel Humidity
43% to 53%

Dew Point
51 to 57° F

24 Hour Temps

24 Hour Temps


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Radiant Floor Cooling Requires Precise Dew Point Control

50% Indoor Relative Humidity
68 deg F Floor Temperature
56.5 deg F Dew Point at Sea Level

66.5º F Highest Air Dew Point
56.5º F Dew Point at Floor
50% RH

Condensation Occurs Below Dew Point

68º F Floor Temp In Slab
80º F Ceiling Temp Chilled Beam

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Separate Heating and Cooling with Ventilation using Energy Recovery

Hydronic Fan Coils Provide Humidity Control, Supplemental Heating and Cooling

DEHUMIDIFICATION
- Hydronic Fan Coil
- ERV/DOAS/DCVS with Coil

Conditioned Space

Hydronic Fan Coil

Conditioned Supply Air

Condensation Occurs Below Dew Point

Fan Coil Supply Water Below Dew Point For Dehumidification

Optional Secondary Coil For Reheating

Energy Recovery Ventilation

Stale Exhaust Air

Fresh Intake Air

Fresh Outside Air

VENTILATION
- Fresh Air Fan/VAV
- Heat or Energy Recovery Ventilator
- Dedicated Outdoor Air System (DOAS)
Traditional Hydronic Heating System

Radiant Supply Temperature is the Control Parameter

- Radiant Supply
- Radiant Return
- Boiler Pump
- Boiler (Gas-Fired)
- Return
- Supply

*Radiant Supply Temperature

BOILER EFFICIENCY
Coefficient of Performance (COP) for generating hot water:

\[
\text{Power Out (kWh)} = \frac{0.85 \text{ to } 1.0}{\text{Power In (kWh)}}
\]

95% Boiler = 85% Energy Efficiency at high altitude (Denver, Colorado)

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High Mass Hydronic Cooling System

**Radiant Floor Temperature** and **Space Temperature and Humidity** are the Control Parameters

**HEAT PUMP EFFICIENCY**

Coefficient of Performance (COP) for generating chilled water:

\[
\text{Power Out (kWh)} = 1.0 \text{ to } 3.0 \\
\text{Power In (kWh)}
\]

* Radiant Floor Temperature

* Space Temperature

* Space Humidity

Radiant Floor Cooling - RFC®

Hydronic Fan Coil

Optional Chilled Beam (Ceiling Mounted)
Geothermal Heat Pumps with Ground Heat Exchangers (GHEX)

**LOAD SIDE (3.5 Units for Useful Heating or Cooling)**

- Cold Thermal Storage
- Hot Thermal Storage
- Geothermal Heat Pump
- Load Pump
- 3-Way Valve directs water to cold side or hot side

**SOURCE SIDE GROUND HEAT EXCHANGER**

- 3.5 Units Rejected TO or FROM Source

**Coefficient of Performance (COP)**

\[
\text{Power Out (kWh)} = \frac{3.5 \text{ Units (kWh)}}{1 \text{ Unit (kWh)}} = 3.5
\]

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Heat Pumps with Optimized Process Heat Exchanger

SOURCE SIDE (3.5+ Units Heating or Cooling)
Heat Pump is more efficient with hot source in heating or cold source in cooling

LOAD SIDE
(3.5+ Units for Heating OR Cooling)

SOURCE PROCESS HEAT EXCHANGERS
INCREASE THE HEAT PUMP EFFICIENCY

Coefficient of Performance (COP) for chilled water:

$$\text{Power Out (kWh)} \div \text{Power In (kWh)} = 3.5+$$

Power Out (kWh) = 3.5+
Doubling System Efficiency with “Dual Process” Configurations

Coefficient of Performance (COP)

\[
\text{Power Out (kWh)} = \frac{3.5 \text{ Hot} + 3.5 \text{ Cold}}{1 \text{ Unit (kWh)}} = 7.0
\]

Water Source Heat Pump Application

Air Source Heat Pump Application

Heat Pump Application

Water Source Heat Pump Application

Air Source Heat Pump Application
Direct Use of Fluids from Process HEX = Highest Efficiency

Direct Use **GHEX Radiant Floor Cooling** = 12x Conventional Air Conditioning Efficiency

*Direct Use of Solar Thermal Fluids in Radiant Heating has Similar Efficiency*

**Coefficient of Performance (COP)**

\[
\frac{\text{Power Out (kWh)}}{\text{Power In (kWh)}} = \frac{21.3 \text{ kWh}}{0.4 \text{ kWh}} = 53.3
\]

\[\text{Power In} = 0.4 \text{ kWh}\]

2 x 200 watt Variable Speed (VS) Pumps = 400 watts/hour = **0.4 kWh**

\[\text{Power Out (Cooling)} = 21.3 \text{ kWh}\]

BTU/hr = Flow Rate x Temp Diff x Constant (485 for Antifreeze)

15 GPM x 10 Deg Temp Diff x 485 = **72,750 BTU/hr**

Conversion - 1 kWh = 3,412 BTU/hr (Also used for EER Conversion)

72,750 BTU/hr / 3,412 BTU/h/\text{w} = **21.3 kWh**

**Slide 21**

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Variable Speed Pumping and Controls for NZE Performance

40 Ton GHEX, Circa 2012
- 3200 Watts Pumping Energy
- 14 Fixed Speed or 3 Speed Pumps
- Constant Source Flow Across GHEX
- Constant Flow through heat pumps
- Complex Manifolds and Controls
- High Capital and Operating Costs
- Site-Built

GHEX Pumps Upgrade – Circa 2023
- 1200 Watts Pumping Energy
- 4 Variable Speed ECM Pumps
- GHEX Flow Rate: Delta Temp across GHEX
- GHP Flow Rate: Delta Temp or Pressure
- Simplified Manifolds and Controls
- Reasonable Capital Costs, Low Operating Costs
- Factory-Built Modular Components
Factory-Built Radiant Panels with VS Pumps Reduce Cost and Risk

- Radiant Supply Injection Pump
- VS Mixed Radiant Circulator
- Zone Thermostats
- Zone Control Relay Panel
- Temperature Gauge
- Primary Radiant Loop
- Supply Piping in Rear
- Return Piping in Front
- Mixed Radiant Fluid - Supply
- Mixed Radiant Fluid - Return
- 3-Way Mixing Valve
- Hot or Cold Water Supply
- 10,000 SF Coverage

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ZNE Requires Integrated Design Build Team

Traditional Design/Build Methodology
Most Common Factor in ZNE Failures

Integrated Design Build Team
CASE STUDIES: 10 Common Challenges Relating to NZE Projects

#1 – Using Traditional Design/Build Methodology for NZE Implementations
#2 – Overestimating the Cooling Capacity of Radiant Floor/Ceiling Cooling (RFC®)
#3 – Failure to Install Supplemental Cooling (this applies regardless of Climate Zone)
#4 – Removing GHEX and Relying on ASHPs for Campus Hot and Cold Water
#5 – Using Evaporative Cooling Technologies for Supplemental Cooling
#6 – Installing Operable Windows in High Humidity Environments with RFC®
#7 – Using Low Thermal Mass (Air) Metrics for Designing High Mass (Hydronic) Systems
#8 – Relying on Historical HVAC Controls Methods for NZE Building Operations
#9 – Custom Build versus using COTS Methods and Modular Components
#10 – Failure to Acknowledge the Intellectual Property associated with RFC®
NZE Requires Integrated Systems Architecture and Controls
Efficiently Moves or Rejects Heat from the Any Source to Any Need
The Patent Specifications disclose the technology and implementation details discussed in this presentation.
Thank You For Attending – Questions?

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Energy Environmental
The Standard for Net Zero™