RADIANT HEATING AND COOLING + DEDICATED OUTDOOR AIR SYSTEMS

TECHNOLOGY SNAPSHOT

- Cool or warm water is piped through panels, ceilings or floors to provide radiant thermal comfort to occupants.
- 100% of ventilation air is provided by a Dedicated Outside Air System (DOAS) which can include energy recovery.
- Pumping water is significantly more efficient than using fans to push air, so fan energy is significantly reduced with this system.
- Radiant system design avoids some common operational performance issues that plague standard forced-air systems such as simultaneous heating and cooling.
- Compatible with other lower energy cooling systems such as indirect evaporative cooling, ground or water source heat pumps, and high efficiency chillers.

Water Resource Center in Watsonville, CA. Radiant heating/cooling and decoupled ventilation systems. (Source: *GreenSource*)

Zero Net Energy[1] (ZNE) is the future and, in a growing number of places, the present of building design and energy policy. In California alone there are almost 50 documented commercial buildings that have been verified or are targeting ZNE.[2] A growing strategy to get to ZNE is to separate the building's heating/cooling from the ventilation/dehumidification.

Design firms and owners are striving to meet heating, ventilation and air-conditioning (HVAC) loads with optimum comfort and minimal energy. Radiant systems provide heating and cooling through pipes, most commonly filled with water, while ventilation and any humidity control requirements are efficiently met by a Dedicated Outdoor Air System (DOAS).

With space conditioning and ventilation responsible for 41-51% of the total energy load in conventional California offices,[3] leading design teams are turning to radiant systems that can cut this energy use in half. These savings come in large part because using water to move and remove heat in a building is inherently more efficient than using air. Water transfers thermal energy about 7 times more effectively than air.[4]

This ZNE Technology Application (TA) Guide provides an overview of Radiant Heating and Cooling + DOAS systems. It focuses on office applications, but other sectors such as retail, healthcare, museums and industrial applications are also good opportunities for radiant systems and DOAS.

> Quite simply, most of the conventional mechanical systems in wide use today are not efficient enough for a net zero energy building approach.
>
> Tom Hootman, Net Zero Energy Design

1 Zero net energy buildings have greatly reduced energy loads that, averaged over a year, can be 100% met with onsite renewable energy.
2 California has 47 ZNE buildings listed in this 2014 report, and more have been identified since publication. Summary of California's statewide policy for all new commercial buildings to be ZNE by 2030.
3 41% for small office and 51% for large office, CEUS Itron 2006.
4 Center for the Built Environment (CBE) at the University of California Berkeley Brower Case Study.

Technology Overview

SYSTEM SELECTION

Matching the distribution approach with the application is key to the success of the system. Some 'rules of thumb' that can help guide this process are:

- Floor and ceiling slabs work well in spaces with standard ventilation rates that don't experience rapid changes in occupant density.
- Ceiling slabs are more effective than floor slabs for cooling the space.
- Panels (ceiling and wall) have a faster thermal response than slabs, making them more effective in spaces with frequently changing thermal demands.
- Panels are better suited than slabs for cooling-dominated applications and work well as a retrofit application.
- Chilled beams work well in spaces that have high ventilation rates and high ceilings and can be combined with radiant slabs to meet large sensible cooling loads[5].

Radiant distribution systems utilize piping, distribution pumps and control valves to deliver heated or chilled water to the space, typically via two methods which may be singular or combined in a building application: 1) radiant slabs and 2) radiant panels.

Radiant Slabs. Radiant slabs have imbedded tubing (typically flex) in large mass areas of the building — most commonly concrete floors but also via ceiling slabs. This approach was historically used for heating but is now more widely applied to include cooling. Radiant slabs are usually configured as two-pipe systems, meaning they can only be in heating or cooling mode, and valves regulate the amount of heated or chilled water delivered to the zone. Using radiant slabs for both heating and cooling requires design and attention to the changeover method between the two modes of operation.

Figure 1: Radiant Floor Piping Installed in a new Office Space (Source: PAE Consulting Engineers)

Radiant Panels. Radiant panels are ceiling or wall-mounted panels that affix water tubing (typically copper) to an insulated tile. Water is supplied to this tubing by piping located above the ceiling. Valves regulate the flow of water to the panels based on the temperature needs of the space. An advantage of radiant panel systems is that they can be used to supply both heating and cooling through the use of a four-pipe system. This configuration can condition the perimeter and interior zones differently which, in larger buildings, often have varying space condition requirements.

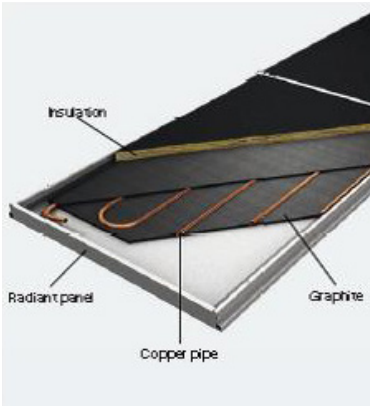


Figure 2: Diagram of Radiant Ceiling Panels. (Source: Zehnder Carboline product brochure)

5 See Trends Section

The Dedicated Outside Air System

CHARACTERISTICS OF DOAS SYSTEMS

- 100% Outside Air (OA) delivered to each zone by its own ductwork
- Flow rates typically exceed ASHRAE Standard 62.1
- All of the latent load capability is handled by the DOAS system
- Uses a high induction diffuser
- May include a) an indirect evaporative cooler to efficiently temper ventilation air and/or b) total energy recovery (TER) from the building exhaust air to reduce the load on the radiant system

The DOAS gains its name from being 'dedicated' to bringing in outside air for ventilation and can be designed to meet 100% of the code ventilation requirements for all spaces.

There are various DOAS configurations available as manufactured packaged units or built-up onsite, depending on the application. The DOAS configuration and features are driven largely by the latent and sensible loads of the application. Dehumidification, the use of pre-cooling (which may allow some downsizing of the radiant system), and heat recovery are all system options to be considered based on the climate and building characteristics.

Most DOAS systems bring outside air across a filter and then through a tempering coil to supply cool dehumidified air directly to the space. Exhaust air is then sent back through the DOAS and may include heat recovery, depending on the climate, before being exhausted to the outside.

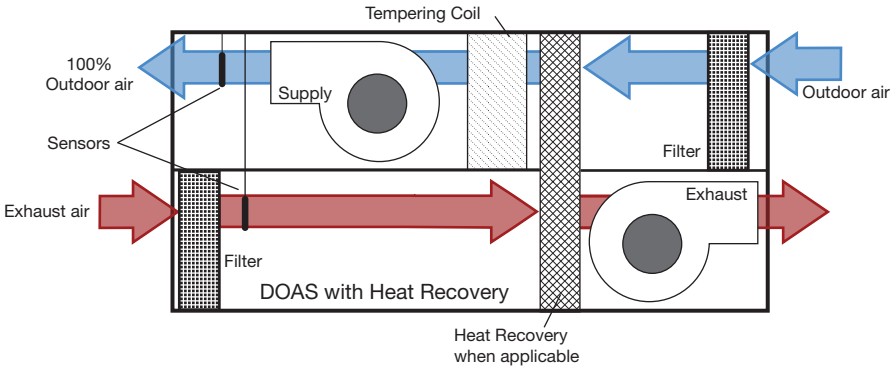


Figure 3: Components of a Dedicated Outside Air System with Energy Recovery (Source: NBI)

The David Brower Center, Berkeley, CA, uses in-slab ceiling radiant heating and cooling with chilled water supplied by a cooling tower. An underfloor air distribution system supplies ventilation from a dedicated outside air system. (Source: Center for the Built Environment, University of California, Berkeley)

Design and System Considerations

RADIANT HVAC SYSTEMS ANALYZED AS A PATH BEYOND THE NEW TITLE 24-2013

Based on California code compliance for a new commercial construction project with a floor-slab hydronic radiant system, the following were conservative estimated savings over Title 24[10]:

- Option 1 – Modeled as Four-Pipe Fan Coil: Compliance margin at 12% better than code and **cooling 14% less energy than standard design**
- Option 2 – Modeled as Induction Unit: Compliance margin at 16% better than code and **cooling 28% less energy than standard design**

Low and zero net energy building designs begin with greatly reduced thermal loads. To correctly size the Radiant + DOAS system to meet these loads the analysis must consider the interaction of the two systems to ensure opportunities for pre-cooling and energy recovery are taken and that control strategies will work in concert.

It is especially important that proper mechanisms be put in place to eliminate the risk of condensation buildup on radiant surfaces. This can include monitoring of space dew-point temperature and system shutdown or lock-out capability if the building includes natural ventilation. For radiant floors, ASHRAE specifies that surface temperatures be maintained at or above 66°F to eliminate the risk of condensation (see *Application Examples* for some approaches used on a project in India).

Energy Modeling for Code

In California the 2013 Title 24 Nonresidential Buildings Energy Standards (Title 24) requires minimum HVAC system efficiency. Radiant-based systems, however, do not fit the traditional Energy Efficiency Ratio (EER) rating used for compressor-based systems but are documented as meeting or exceeding code EER requirements.[6]

Under a Prescriptive approach there is currently no radiant heating or cooling system efficiency requirement in Title 24. Under a Performance approach the radiant system can be modeled using other systems as proxies such as a) built-up single zone with cooling coil but no fan, b) four-pipe fan coil with adjustments to fan energy, and c) induction cooling with adjustments to fan energy.[7]

Radiant systems can allow for the use of a wider comfort temperature band, however energy saving calculations take no credit for this since the temperature schedules between the code base case and proposed case are identical. Thus modeled energy use may be higher than actual for an effectively operated system.

EnergyPlus modeling software, the most common software for Title 24, does not fully model radiant systems. Manufacturer and custom software can, and should, be used to establish sizing loads. U.S. Department of Energy (DOE) based EnergyPro software has just been approved on an interim basis in California for Title 24 modeling. The gaps in modeling software capabilities for radiant systems are a barrier for broader adoption of this technology. Establishing accurate modeling methods and tools to estimate performance within EnergyPlus[8] and extend the capabilities of ASHRAE toolkits is being pursued.[9]

The gaps in modeling software capabilities for radiant systems are a barrier for broader adoption of this technology.

6 PNNL identifies radiant cooling as a strategy to meet 50% better than code performance relative to ASHRAE 90.1-2004

7 HMG 2010, Radiant Cooling: *Non-residential Stakeholder Meeting for California Codes and Standards* presentation based on modeling with DOE 2.1E

8 Although EnergyPlus has built-in modules for high and low temperature hydronic and electric radiant systems, greater modeling capabilities, and refinement of energy estimates, would support the inclusion of these systems in new buildings.

9 ASHRAE *Radiant System Module for the Simulation and Analysis of Spaces* Research Project (RP) 1383

10 HMG 2010, IBID

Radiant System Optimization

First, reduce thermal gain through such strategies as exterior shading, high efficiency glazing, and carefully designed window-to-wall ratios and placement. (Source: Infosys, Peter Rumsey - Point Energy Innovations/ Article in *Ashrae Journal* May 2014)

- Rules of thumb for heat exchange rate from radiant slab to space.[11]
  - 15-16 Btu/sf in best conditions
  - 8-12 Btu/sf is typical
  - 4-5 Btu/sf worst-case scenario
- Factor in, and apply in operations, the expanded range of temperature set points to the space compared to a standard forced-air system.
- All pumps included in the distribution system should be selected to include either variable-speed drives or electronically commutated motors (ECMs) and be controlled to eliminate continuous pumping.
- Minimize pumping energy by reducing pressure drops across the distribution system. Use larger piping, shorter distances and smooth transitions.
- When using both radiant heating and cooling in a slab, include a significant deadband in the control sequence to avoid rapid changeover.
- Radiant systems are best for spaces with predictable schedules and load characteristics as radiant systems typically have longer warm-up and cool-down periods.
- Scheduling can use less energy than running the slab at lower loads in high cooling climates. Turn the slab off one to two hours prior to unoccupied hours, and turn it back on one to two hours before occupancy.[12]

DOAS Optimization

- Ensure the system is equipped with a highly rated filtration system.
- Utilize passive methods (natural ventilation) and indirect evaporative pre-cooling first.
- Identify candidate areas (e.g., conference room) for localized demand control ventilation to reduce ventilation air when not occupied.
- If energy recovery strategies are included, ensure there is no significant pressure drop from the intake to the exhaust side as this can result in cross-contamination of the air streams.
- In colder climates the design of energy recovery strategies needs to account for frost protection.

11 HMG 2010, IBID
12 P. Rumsey, *ASHRAE Journal* May 2014

Energy, Comfort and Performance Gains

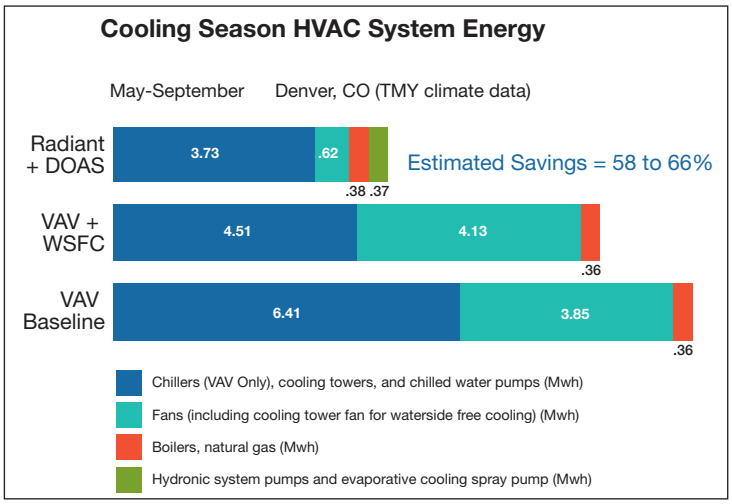


Figure 4: Comparison of simulated cooling-season HVAC system energy consumption by component (Source: Moore, T. Center for the Built Environment [CBE] at the University of California Berkeley)

Radiant heating and cooling systems provide gains in three main areas discussed below: 1) energy savings, 2) delivering comfort for occupants, and 3) offsetting some performance issues typical of standard systems.

1) Energy Savings

Combining radiant space conditioning with a DOAS significantly reduces the amount of HVAC energy, **often by 50% when compared to a similar building using a standard forced-air system.**

Figure 4 shows the results of modeled radiant strategies against baselines using traditional HVAC approaches. A 33,637 sf office building in Denver was compared to three systems: 1) Variable Air Volume (VAV) Baseline — an all-air variable air volume system with terminal re-heat and outside-air economizer, 2) VAV Waterside Free Cooling (WSFC) economizer — a similar VAV system with an hydronic-based heating and cooling system, and 3) Radiant + DOAS system that includes indirect evaporative cooling and energy recovery. **The Radiant + DOAS reduced the HVAC cooling load from 10.6 mWh to 5 mWh, and energy savings was 58-66% over these commonly applied HVAC systems.**

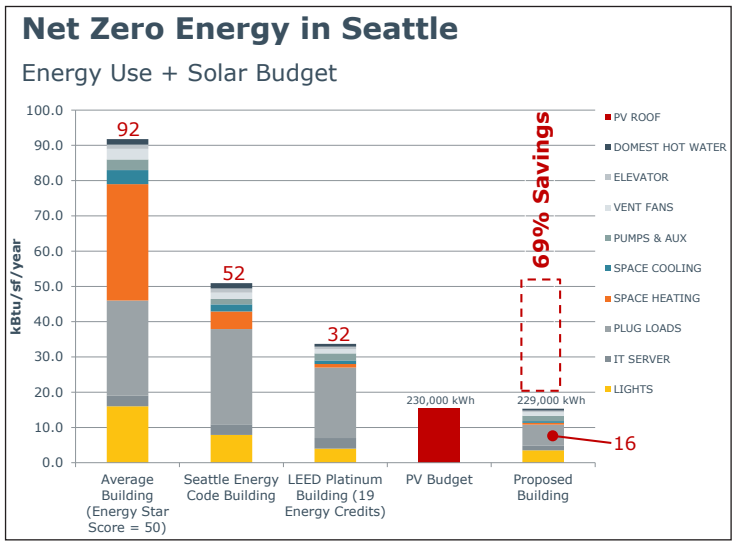


Figure 5: Comparison of a Typical Seattle Office and the Bullitt Foundation (Source: PAE Consulting Engineers)

The Pacific Northwest National Laboratory (PNNL) conducted energy simulation studies for new construction, medium-sized office buildings to achieve 50% energy savings relative to a building that just meets ASHRAE Standard 90.1-2004. PNNL concluded that **meeting the 50% target would not be feasible even with a high-efficiency VAV system.** Instead, the PNNL report recommends the use of **hydronic radiant floors for heating/cooling combined with a DOAS system for ventilation to achieve the 50% savings threshold.**

The Bullitt Foundation in Seattle used radiant heating and cooling slabs with a DOAS system and natural ventilation to help target ZNE in its new headquarters building. The final design has a modeled Energy Use Intensity (EUI) of just 16 kBtus/gsf/yr versus a comparable Seattle Energy Code compliant office building with an EUI of 52 kBtus/gsf/yr (Figure 5).

For new office buildings striving for low or zero net energy setting **a total energy use target of 25 kBtu/gsf/yr is reasonable** based on findings from measured energy use of ZNE buildings.[13]

13 NBI 2014 *Getting to Zero* Status Update

2) Delivering Comfort

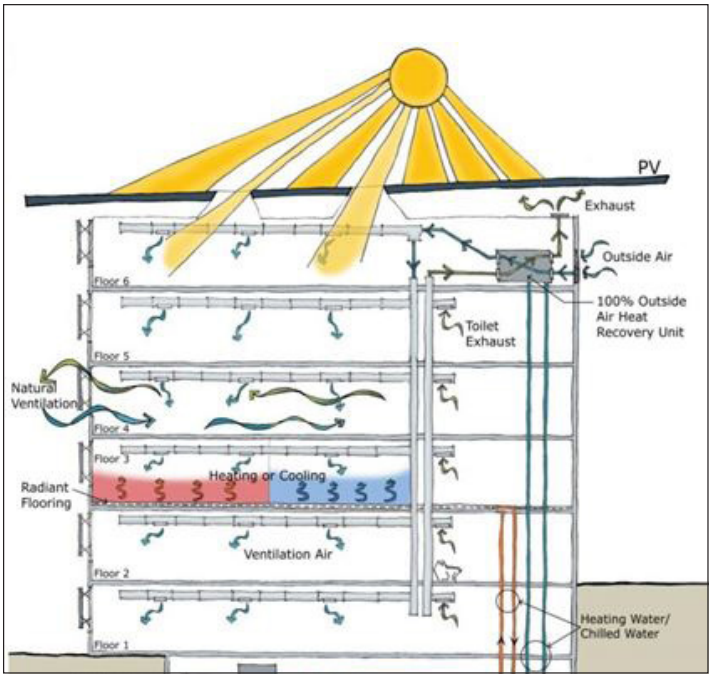


Figure 6: DOAS Integration with a Radiant Slab. The Bullitt Center, Seattle, WA (Source: PAE Consulting Engineers)

All-air systems directly control only air temperature, but radiant systems with a separate ventilation system control two parameters — air and mean radiant temperatures. Our body's sense of thermal comfort responds to both of these factors. Just think of feeling cold when sitting beside an older window in winter, despite the room air temperature being 'comfortable' – the colder surface temperature of the window has a greater affect than the ambient air temperature.

Radiant systems warm or cool surfaces (slabs or panels), and this translates to thermal comfort in the space provided in a more even and steady manner. Because of the way our bodies respond thermally, radiant systems can meet the same comfort levels with lower set temperatures in heating mode and higher set temperatures in cooling mode. These wider temperature margins (+/- 2°F) mean less energy is required to meet the occupant thermal needs.

In two different studies office occupants with radiant systems reported an improved sense of comfort. In the Brower Center (California) and the Infosys Building (India) survey responses indicated an extremely positive response regarding space comfort compared with a larger dataset of responses to other types of HVAC systems.[14]

There can also be indoor air quality (IAQ) benefits since DOAS systems deliver dedicated ventilation air at a higher volume and can be combined with natural ventilation approaches. The Bullitt Center in Seattle applied this integrated approach of DOAS with operable and automated windows to meet its ZNE design target and provide higher levels of fresh air (Figure 6).

"By separating the ventilation and dehumidification from the temperature control water, we can actually control these better throughout the facility, reaping energy, thermal comfort, and air quality benefits."

Tom Hootman
Net Zero Energy Design

3) Offsetting Performance Issues

Decoupling space conditioning from space ventilation requirements effectively eliminates a common occurrence in buildings with Variable Air Volume (VAV) Systems – simultaneous heating and cooling.[15] This inefficiency occurs when a zone with high cooling loads drives the supply air temperature down, causing most zones to receive air that has been cooled to a low temperature, then reheated. Simultaneous heating and cooling is not only one of the "Top Five" energy problems in standard systems, it also creates additional wear on contactors, hot-water pumps, chilled-water pumps, boilers, chillers and auxiliaries.[16]

14 Bauman. 2011, Center for the Built Environment (CBE) at the University of California Berkeley and Sastry/ Rumsey 2014

15 Variable Air Volume (VAV) with Reheat, Constant Volume with Reheat, Dual Duct, Multi-zone Fan, Central AC with perimeter heating. Common Opportunities (in Building Operations), Northwest Energy Efficiency Alliance (NEEA).

16 Common Opportunities (in Building Operations), NEEA.

Application Examples

Lab space in the Tahoe CES Building (Source: Center for the Built Environment, University of California Berkeley)

Tahoe Environmental Center

- Built in 2006
- 45,000 sf
- Energy Use (estimated): 60% less than ASHRAE 90.1-2001

It is expected that the radiant nature of the space conditioning will allow for the use of a wider comfort temperature band.

(Source: Rumsey Engineers, Case Study of the Tahoe Center for Environmental Sciences)

The Tahoe Center for Environmental Studies, UC Davis Incline Village, NV

The 45,000 square foot Tahoe Center for Environmental Studies (CES) is one of only five science laboratories in the world to receive a Platinum LEED Certification from the U.S. Green Building Council – with the radiant heating and cooling system playing a key part in its measured energy success story.

The CES is located in a very dry climate which has a mild cooling season. Heating and cooling are delivered by radiant panels and some floor slabs. The very dry climate allowed for direct evaporative cooling to temper the summer ventilation air to 66°F using the same airless atomizing humidifiers employed during the winter season. The dedicated ventilation air is supplied via a displacement configuration that is constant volume/ low velocity at floor level and provides neutral/cool air at 25 cfm/person. CO_2 sensors are located in high-occupancy areas so ventilation rates respond to demand. In this application the DOAS provides a significant amount of cooling to these areas, reducing the radiant system load.

For cooling, chilled water is provided to the radiant system zones from 50,000 gallons of thermal storage charged at night, when climate conditions allow for the production of 55°F or lower temperature chilled water by a cooling tower with a waterside free-cooling economizer.

In this climate, heating loads are far more significant than cooling. The baseline heating load is served by waste heat from a 24 kW (altitude de-rated capacity) cogeneration turbine. The peak heating load is supplied to the radiant systems by condensing boilers operating at a minimum of 94% efficiency.

Significant modeling and architectural coordination of shading, window placement, glass type and space configuration combined with appropriate mechanical zoning eliminated the need for any reheat.

Measured results show the Tahoe CES uses 50-60% less energy than a code baseline building (ASHRAE 90.1-2001). The radiant and ventilation system, modeled to reduce heating, cooling and ventilation by about 38%, was a major contributor to the low energy results.

The Exploratorium (Source: Devin A. Abellon, P.E., Upnor)

Exploratorium Museum

- Renovated in 2012
- 330,000 sf
- Energy Use (estimated): 38 kBtu/gsf/yr

"This project combines an effort to both innovate and think critically about the impact science can have on the world," "Our net-zero goal is, in part, a way to reduce our global footprint and help improve the community we've been a part of for more than 40 years. Net zero is a process — and an opportunity for the public to learn with us."

Dennis Bartels, Ph.D
Exploratorium Executive Director

Table 1: Exploratorium: Projected Energy Use Breakdown - Annual Electricity Usage (kWh)

"We did not wish to sacrifice comfort for energy savings on this project, and radiant is a premium comfort system."

Joseph Wenisch, Integral Group

Exploratorium Museum, San Francisco, CA

The Exploratorium, a 330,000 sf structure built in 1931 and renovated in late 2012, is a model of innovative sustainable design and possibly the largest ZNE museum in the U.S. The building uses a radiant-slab heating and cooling system to meet comfort demands. Water from San Francisco Bay feeds into eight 50-ton, water-to-water heat pumps. The electric-chilled heaters feed a four-pipe system that carries either hot or chilled water to a 200,000-foot network of tubing in concrete slabs on two levels that cover 90% of the floor space and serve 82 different zones.

Heating and cooling, along with lighting and pumps, are expected to make the biggest contributions to energy savings: a 55% savings in yearly electrical consumption for heating; and 94% for cooling (Table 1). Which is why radiant-slab heating and cooling was a critical part of the Exploratorium plan from the outset, according to Joseph Wenisch, project manager for Integral Group, the lead engineering and systems design company for the project.

The supply of outside air for ventilation exceeds ASHRAE requirements by 30% through the use of a dedicated outdoor-air system. By creating separate systems—radiant for heating and cooling and a dedicated system for OA natural ventilation— the project was able to specify ductwork half the size that would have been necessary in an all-air variable air volume system.

Item	ASHRAE 90.1-2010 Baseline (VAV)	Exploratorium	% Difference
Lights – Interior	853,143	375,300	**-56%**
Lights – Exterior	49,100	70,500	44%
Space Heating	**782,934**	**352,800**	**-55%**
Space Cooling	**422,555**	**25,000**	**-94%**
Pumps	292,687	77,500	**-74%**
Ventilation Fans	**287,374**	**155,800**	**-46%**
Domestic Hot Water	112,154	105,600	**-6%**
Process Exhaust Fans	59,439	59,439	0%
Plug Load	53,997	53,997	0%

Infosys Building in Hyderabad, India – designed with VAV for one side and Radiant Cooling for the other. (Source: Infosys, Peter Rumsey - Point Energy Innovations/ Article in *Ashrae Journal* May 2014.)

InfoSys Building

- Built in 2011
- 250,000 sf
  - 125,000 sf VAV Cooling
  - 125,000 sf Radiant Cooling
- Energy Use (actual): Radiant side uses 34-42% less than the VAV side

Over a one-year study period the Radiant + DOAS system used 34% less energy than the best-in-class VAV system and received higher occupant satisfaction scores (Table 2).

Infosys Building, Hyderabad, India

Infosys, one of India's top software companies, wanted to compare a variable-air-volume system to a radiant system with a dedicated outdoor air system. The 250,000 sf building, fully occupied in 2011, runs east-west and is uniquely comprised of two symmetrical office blocks with exact features that allowed comparisons of cost, energy and occupant comfort.

The climate is challenging - either hot and humid or hot and dry with a 2013 high of 115°F and a peak dew point of 77°F; there is no heating season. The design team minimized thermal loads with a well-detailed envelope, sophisticated daylighting that limits direct sunlight and a window-to-wall ratio at 30%.

The VAV system is supplied by a 275-ton high efficiency chiller with variable speed drives (VSD) on all pumps and air handling units (AHU). The AHU's also include an energy recovery wheel, evaporative cooling and a free cooling option when ambient conditions are appropriate.

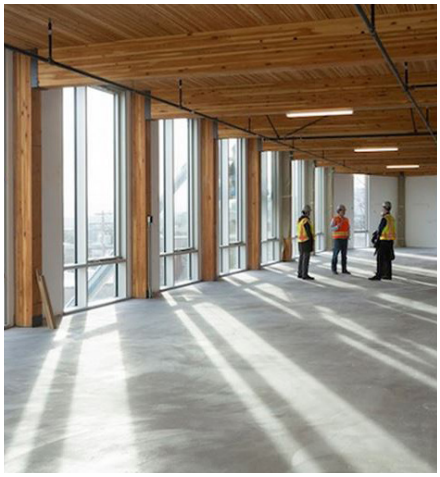
The radiant system is also supplied by a 275-ton high efficiency chiller with VSD's on all pumps and AHU's for the DOAS system. The primary radiant distribution is through floor and ceiling slabs, but the conference rooms also include passive-chilled beams due to higher loads and a need for faster response. Most spaces on the radiant-cooled side of the building also have ceiling fans to assist with air movement.

Properly controlling the radiant cooling + DOAS was critical in ensuring optimized performance. One approach was to stop cooling two hours before unoccupied hours and start cooling two hours before occupancy, rather than running the slab at a slightly warmer temperature throughout the day. Controlling the migration of moisture through the slab was addressed by keeping the space dew point below the chilled-water supply temperature, not the slab surface temperature.

Table 2: System Comparison Results at Infosys Building – April 2011 to March 2012 (Source: NBI – derived from P. Rumsey *ASHRAE Journal* May 2014)

System Type	First Year Energy Use		% of Occupants responding satisfied or very satisfied to thermal comfort[1]
VAV	12.3 kBtu/gsf		45%
Radiant + DOAS	8.1 kBtu/gsf		65%
Radiant + DOAS Energy Savings compared to VAV	Year 1	Years 2-3[2]	Radiant received higher scores from occupants
	34%	42%	

[1] Question: On average, how satisfied are you with your thermal comfort in your workspace in warm/hot weather? Part of the Occupant Comfort survey: Center for the Built Environment, University of California Berkeley.



Bullitt Center cement floors and daylight (Source: © John Stamets). Right: The Bullitt Center exterior (Source: Miller Hull Partnership).

Bullitt Center

- Built in 2013
- 50,000 sf
- Energy Use (estimated): 16 kBtu/gsf/yr
- Energy Use (actual): 9 kBtu/gsf/yr *Transition to full occupancy*

The Bullitt Center's heating and cooling is just 2-3% of the building load compared with a typical office building at 40%.

[2] See ASHRAE Article for details of year two efficiency modifications to dehumidification

The Bullitt Center, Seattle, WA

The HVAC system in the Bullitt Center, recently named the world's most sustainable building by World Architecture News, relies partly on natural ventilation and automated windows. When needed, a heat-recovery ventilator kicks in as part of a dedicated outside-air system. This combination of ventilation strategies, combined with a highly efficient shell and glazing, greatly reduces thermal loads.

A radiant-floor system with flex tubing is buried in the concrete slab of each floor. A mix of water and glycol runs through the tubes, warming or cooling the slab, which efficiently radiates into the occupied spaces. A ground-source heat pump and 26 geo-thermal wells provide the thermal capacity for the radiant system.

The Bullitt Center is projected to use almost 70% less energy than a new building that meets Seattle's rigorous energy code and is predicted to be an energy-use intensity (EUI) of just 16 kBtu/gsf/yr (4.7 kWh/gsf/yr). Initial metering shows an actual EUI of less than 10.

The Bullitt Center's heating and cooling is just 2-3% of the building load compared with a typical office building at 40%. The ground-source heat pump is the key factor in the heating and cooling energy efficiency. But the absence of fan energy within the distribution system, thanks to the hydronic radiant-slab system, is also a major contributor to the overall system efficiency and highlights the integrated nature of low and zero net energy buildings.

The Bullitt Foundation plans to meet the International Living Future Institute's Living Building Challenge, which includes Zero Carbon. **The energy reduction is estimated to save 122 metric tons of carbon/yr.**[17] Carbon is becoming a key metric in today's market and in codes and policies.

More at Bullitt Center features page.

17 Optimizing Urban Ecosystem Services: The Bullitt Center Case Study

Radiant Tubing in pre-configured roll out mats can save installation time (Source: Viega)

Cost Characterization

Advancements in radiant heating and cooling are reducing system and installation costs, and some projects today are at equal or less cost than equivalent VAV systems. For example, flex piping is now pre-fabricated into roll-out mats which reduce installation costs. A case study on a Wal-Mart Super Center in Las Vegas that applied radiant cooling with pre-fab mats cites: "The mats contributed to a 60+% reduction in radiant first costs."[18]

Higher first cost is typically seen when a new type of system is compared as an alternate to the traditional system. The new system is not optimized like the base system, and lack of familiarity can lead to conservatively high estimates. As optimized configurations for the new system evolve, price premiums typically drop. They can even flip to a cost savings as evidenced by the Radiant + DOAS case study information in Table 3.

In a series of interviews with design firms, manufacturers and contractors for the California Title 24 nonresidential energy code in 2010, incremental system costs for radiant systems were characterized as:[19]

- Material Costs
  - $1-$2/sf for pipes, fittings, valves
- Installed Costs
  - Pipes, fittings, valves: RS Means: $4-$5.25/sf without controls (conservative estimate)
  - $2-$30/sf additional for controls
- Entire system including dedicated outdoor air systems and Plant
  - $9-30/sf incremental cost over VAV

Table 3: Cost comparison of a VAV and Radiant + DOAS System (Courtesy: Infosys, Peter Rumsey - Point Energy Innovations/ Article in *Ashrae Journal* May 2014)

HVAC System Components	VAV	Radiant
Chiller	$69,754	$69,754
Cooling Tower	$28,973	$28,973
HVAC Low Side Works	$506,520	$339,543
AHUS, DOAS, HRW	$113,511	$63,848
Radiant Piping, Accessories, Installation, etc	$0	$201,282
Building Automation System	$137,148	$146,019
Total cost USD $	$855,906	$849,419
Building Area (per system) in gsf	124,861	124,861
$/gsf (converted Rupees to $)	$6.85	$6.80
$/gsf HVAC System Cost	5.15/gsf	5.11/gsf

18 Value Engineer Radiant Cooling, Wal-Mart Las Vegas, NV

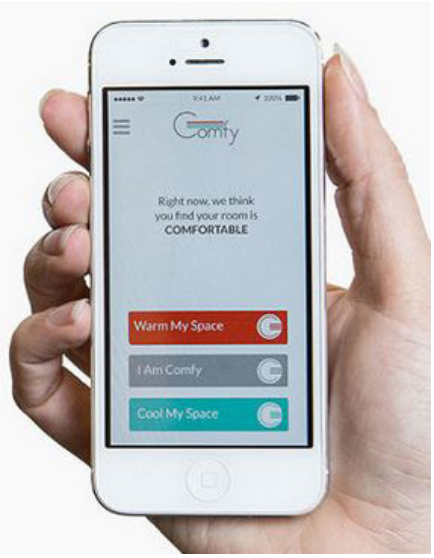
19 HMG 2010, IBID Radiant Cooling: Non-residential Stakeholder Meeting for CA Codes and Standards presentation

Another source of cost data on radiant systems comes from a radiant-based system installed in a six-story, 31,000 sf office building in Philadelphia built to ASHRAE 90.1-2004 standard which was compared to a typical VAV system. This example resulted in a net savings of $2/sf. Other recent examples show that this technology can be implemented for comparable (and sometime even less) cost than a standard code-compliant VAV system.

The Infosys Building in India provided data on the cost of a best-in-class VAV system and a Radiant + DOAS system as seen in Table 3. Reductions in air-handling units in this table spotlights one of the cost trade-offs that helps Radiant + DOAS. In this case the VAV system needed six air handlers, while the Radiant + DOAS system needed just one. This reduced not only cost but also space needed for equipment in the building.

Trends

Occupant-Based Thermal Comfort Strategies



Trends are toward personal control of thermal comfort (Source: *FastCompany Magazine*)

Common approaches to HVAC focus almost exclusively on control of ambient air temperature to provide thermal comfort. Radiant heating and cooling is one of the trends that is reducing energy use and improving thermal comfort through increased focus on occupant needs. Other innovations more directly address thermal comfort by providing local heating and cooling with low-energy personal comfort systems or by controlling HVAC based on occupant polling. Provision of air movement for cooling—through low-energy ceiling or desk fans, or through natural ventilation—is a traditional occupant-based approach making a comeback in zero net and other ultra-low energy buildings.

Low-energy personal comfort system options will soon include ergonomic chairs equipped with highly efficient heating and cooling capabilities. This approach can reduce overall energy use by allowing the ambient temperature deadband to be widened while maintaining occupant satisfaction. Low-energy personal comfort systems may also be useful in mitigating thermal problems from architectural or HVAC design issues without significantly increasing energy use and in some cases may eliminate the need for ambient heating or cooling entirely.

Control of HVAC based on occupant polling can reduce energy use caused by over-cooling or over-heating while addressing varying occupant needs based on differences in clothing and/or metabolism. In addition, cold or hot "calls" can often be addressed with less ongoing impact on overall system control and the associated increases in energy use.

There may be potential synergies between the occupant-based strategies, resulting in various combinations of the strategies being implemented together. At this writing, occupant polling-based HVAC control and innovative low-energy personal comfort systems are too new to allow predictions regarding market adoption alone or in combination with each other or Radiant + DOAS systems.

Chilled Beams

The use of chilled beams, also in combination with DOAS, is becoming increasingly popular following the general trend of decoupling thermal distribution from ventilation. Like Radiant + DOAS, chilled beam/DOAS uses water to distribute cooling with low energy use and greatly reduces the potential for energy waste from simultaneous heating and cooling. However, chilled beams employ primarily convective rather than radiant heat transfer in the conditioned space, with less potential for expanding the ambient temperature deadband. Chilled beams can often handle higher cooling loads, especially active versions including higher air flows for increased convective effect.

Indirect Evaporative Cooling

Evaporative methods were a cooling technique long before the advent of mechanically based cooling and can be found in traditional architecture in hot and dry climates around the globe. This historical passive cooling technique is a technology trend thanks to 'indirect' evaporative systems that separate the supply air to the space from the 'working air' that passes over a wetted medium. This design of **Indirect Evaporative Cooling** (IEC) systems offers a highly efficient way to cool or pre-cool air *without raising the humidity* in the indoor space. By eliminating the moisture issues traditionally associated with direct evaporative systems the new IEC systems become an attractive option that can be used in combination with most forms of HVAC including Radiant + DOAS (or chilled beam/DOAS).

The David Brower Center (pictured right) makes use of an in-slab radiant heating and cooling system and indirect evaporative cooling (IEC) tied to the cooling tower to temper the ventilation air. This design highlights the inherent efficiencies associated with decoupling space conditioning from space ventilation. The combination enhances the performance of the cooling tower (used for conditioning the water used in the radiant system) by using the IEC to precool the building ventilation air. (Source: Center for the Built Environment, University of California Berkeley)

Resources

Western Cooling Efficiency Center (WCEC)

California Public Utilities Commission (CPUC) Energy Efficiency Strategic Plan

CPUC ZNE Buildings Site http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/Zero+Net+Energy+Buildings.htm

New Buildings Institute (NBI) ZNE Resource Site http://newbuildings.org/zero-energy

Center for the Built Environment (CBE), University of California, Berkeley, CA

ASHRAE *Advanced Energy Design Guide* for Small to Medium Office Buildings

Net Zero Energy Design; Hootman, T. 2013

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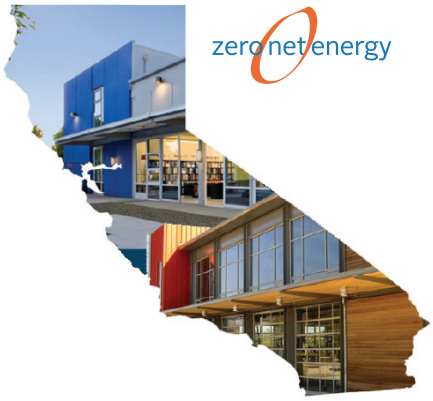
Zehnder Carboline product brochure

The ZNE Technology Application Guides bring information on readily available leading-edge technologies found in today's ZNE buildings to California design firms and owners. Low and zero net energy buildings may be eligible for federal tax credits. In addition, California utility companies offer energy efficiency programs such as Savings by Design for new construction commercial buildings.



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