Radiant Ceiling Cooling

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This is the 15th article covering one of several energy-saving technologies evaluated in a recent U.S. Department of Energy report. The complete report is at www.eren.doe.gov/buildings/documents.

Buildings with radiant ceiling cooling systems, also known as "chilled beam" systems, incorporate pipes in the ceilings through which chilled water flows. The pipes lie close to the ceiling surfaces or in panels, and they cool the room via natural convection and radiation heat transfer (*Figure 1*).

Although the technology has existed for more than 50 years, it has had problems in the past. Condensation of moisture on the cooled surfaces sometimes damaged ceiling materials (e.g., plaster) and created conditions favorable to biological growth.

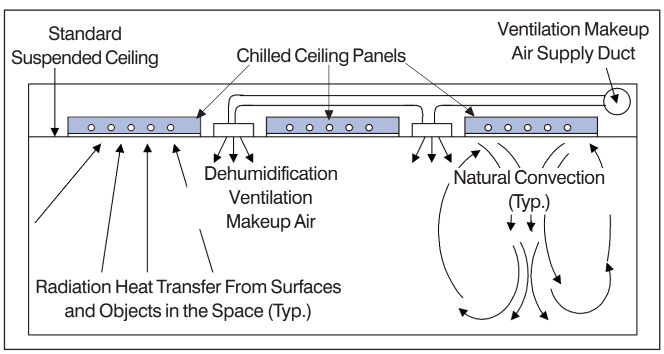

Figure 1:

As noted by Mumma,[1] current systems usually require dedicated outdoor air systems (DOAS) and tight building envelopes to manage humidity. Most commercial buildings avoid condensation on the chilled panels by using a separate system to maintain the dew point of the indoor air below the panel temperature. Ventilation makeup air is the predominant source of peak humidity load in most buildings. Consequently, humidity loads can be handled separately from the chilled ceiling by dehumidifying the makeup air before it enters the space (with enough extra humidity removal to address internal moisture sources). Mumma[2] reports that with a good base dewpoint control, the chilled panels can manage temporary increases in local moisture loads without condensation formation.

A radiant ceiling cooling system delivers sensible cooling directly to spaces, which de-couples maximum air delivery from the cooling load. Radiation and natural-convection heat transfer each account for about half of the approximately 50 Btu/ft^2 (150 W/m^2) cooling capacity of passive radiant ceiling panels.[3,4] At these heat transfer rates, radiant ceiling panels can meet peak sensible loads with about one-third of the ceiling area covered by cooled panels (for a cooling load of 16 Btu/h · ft^2 [50 W/m^2]). Active chilled beam units that use recirculated room airflow induced by the ventilation makeup air supply can supply up to 79 Btu/h · ft^2 (250 W/m^2). Each unit can be controlled separately, which simplifies zoning.[5]

Energy Savings Potential

Radiant ceiling cooling reduces HVAC energy consumption in several ways. In space cooling mode, energy savings accrue from delivering higher chilled water temperatures (T_{cw}) to the radiant ceiling panels to meet sensible loads, e.g., from T_{cw}=50°F[6] to 61°F[7] (10°C to 16°C) compared to 40°F to 45°F (4°C to 7°C) for conventional systems. This, in turn, allows the chiller evaporator temperature to rise and improves cycle efficiency. Radiant ceilings also reduce the heat dissipated by ventilation fans within the conditioned space (discussed later) and the outdoor air (OA) volumes that require cooling.

Radiation heat transfer directly cools the occupants, which may allow slightly higher building air temperatures, decreasing building cooling loads. Radiant ceilings used with a DOAS, however, generally preclude economizer operation, as most of these systems do not include additional ventilation capacity. Overall, radiant ceilings reduce cooling energy by 15% to 20%.[8]

The combination of radiant ceiling with a DOAS also reduces air moving power by moving only the air required for ventilation (typically 25% to 30% of the airflow rate required for peak cooling loads in an all-air system). If the ducts of this DOAS design are matched to this reduced, but constant, flow requirement, blower power does not decrease at periods of low load, as in the case with VAV. However, a DOAS can meet ANSI/ASHRAE Standard 62 ventilation requirements with less ventilation airflow due to its inherent precision in delivering required ventilation flows in the aggregate and to individual zones in the building. An analysis comparing the energy consumption of a conventional VAV system with a radiant ceiling with DOAS found that, for a small office building in a Mid-Atlantic state, the radiant ceiling with DOAS could realize annual blower-power savings on the order of 25%, with greater savings in warmer climates.[8]

In space heating mode, the DOAS saves energy by reducing the ventilation airflow due to its inherent precision in delivering required ventilation flows. Simulations show that OA typically accounts for 50% to 60% of the space heating load. The DOAS enables approximately a 20% reduction in OA volume, which decreases space-heating energy consumption by roughly 10%.[8]

Taken together, these results generally agree with the building simulations by Stetiu,[4] who estimated HVAC savings in cold, moist areas to be 17% to 42%, and an average savings of 30% in warm, dry areas. Mumma[1] reported similar energy savings (a 23% decrease in HVAC energy expenses) for an office building in Philadelphia. On a national basis, radiant ceilings, used in combination with a DOAS, could reduce commercial building HVAC energy consumption by about 0.6 quads relative to VAV systems. Relative to a DOAS with a sensible-only VAV system, radiant ceilings realize more modest savings of about 0.2 quads.

Market Factors

In new construction, the installed costs of radiant ceiling with a DOAS with enthalpy recovery appear to be similar to conventional VAV systems. However, this depends on using other system components: if the system requires separate radiant heating systems, the radiant ceiling costs substantially more than an all-air system. For new buildings, Mumma[1] posits that a radiant ceiling with a DOAS (with sensible and enthalpy transfer devices) costs less to construct than a VAV-based system. One chilled-beam manufacturer quoted a system price of 2% more than a VAV system, with large cost reductions for ducts and fan equipment.[9] This parallels the findings of Springer.[6] It is not completely clear, however, if cooling panels would cost less than a sensible-only VAV plus DOAS (as advocated by Coad[10]). The reduced space required by radiant ceilings (for mechanical equipment and ductwork) translates into an effective cost reduction by increasing the amount of usable space.[11]

Other issues besides first cost appear to impede greater use of radiant ceilings. Many HVAC system designers and contractors are unfamiliar with the radiant ceiling approach and often believe it costs more than other systems. The installation of a radiant ceiling also has architectural implications, necessitating early communication on a project between architects and HVAC system designers. Past problems involving condensation (and resulting moisture) due to higher infiltration levels in older buildings and untreated OA also inhibit present use of radiant ceiling cooling.

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