Research on Radiant Systems Technology

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

Background

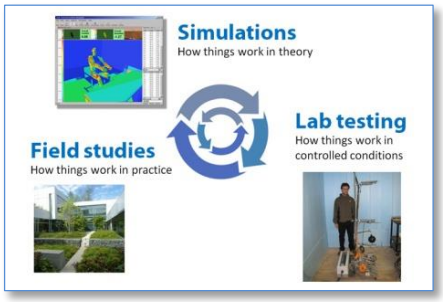
The Center for the Built Environment is an Industry/University Collaborative Research Center that was founded with oversight from National Science Foundation. The center's work is supported and guided by a consortium of building industry leaders that represent the diversity of the commercial building sector. Our research team uses a multidisciplinary approach, based in the belief that the development and application of new commercial building technologies must address energy, design, and technical considerations, while also taking into account human factors concerns including occupant comfort, health, and productivity.

Project Objective

The overarching goal of this project is to contribute to improved understanding of applications, design, and optimization of radiant cooling, and to develop guidelines, tools and resources for system designers and operators. This research area is currently underway as a multi-project research topic, as outlined below.

Research Approach

The research staff at CBE have developed an approach for evaluating new building technologies in order to understand the benefits and opportunities offered by these technologies, the limitations and barriers to adoption (both real and perceived), and to create valuable resources for industry professionals.



Our research approach includes three related research efforts: (1) *simulation studies*; (2) *laboratory studies*; and (3) *field studies* of advanced buildings with radiant cooling systems. These three approaches are closely interlinked, with each informing the development and findings of others. The table below provides a current overview of research topics related to radiant cooling systems. This research is jointly funded by CBE Industry Partners, and the California Energy Commission PIER Program. The work is also described on CBE's website at http://www.cbe.berkeley.edu/research/radiant-systems.htm.

Table of Radiant Cooling Research Projects (Updated March 2014)

Radiant System Performance in Near-ZNE Buildings *Status:* Ongoing (Spring 2014)	The goal of this work is to provide to the professional design community with new and improved information, guidance, and tools for designing and operating near zero-net-energy (ZNE) buildings using radiant cooling and heating systems. This is being accomplished by conducting two thorough case studies of existing near-ZNE buildings that employ slab integrated radiant systems: (1) SMUD East Campus Operations Center, Sacramento, CA, and (2) the David Brower Center, Berkeley, CA. We have also conducted laboratory experiments, which are described below under Comparison of Cooling Loads for Radiant and Air Systems. The case studies and laboratory testing will also be supplemented with whole-building energy simulations, allowing a sensitivity analysis of climate and control strategies. Additional information is available at: http://www.cbe.berkeley.edu/research/radiant-near-zne-buildings.htm

Online Map of Buildings Using Radiant Technologies *Status:* Ongoing (Spring 2014)	CBE has created a publicly available online map (http://bit.ly/RadiantBuildingsCBE) of radiant system projects, with a database of building data and features. Ninety buildings are in the database, including offices, university buildings, multi-purpose buildings, laboratories, museum/exhibitions spaces, and schools. The database currently includes 46 embedded surface systems (ESS), 38 thermally activated building systems (TABS) and 6 radiant panel systems. Information is classified into 12 categories available for each building. *References:* Karmann, C., S. Schiavon, and F. Bauman. 2014. Online Map of Buildings Using Radiant Technologies. Proceedings of the 13th International Conference Indoor Air 2014, Hong Kong, July 7-12. (In press)
Review of Radiant Cooling System Design Methods *Status:* Completed (2014)	CBE staff conducted a literature review, twelve surveys and eight interviews with leading practitioners to assess the state of the industry and identify potential gaps and limitations in current design practice. The findings show that; (1) design guidelines provide a wide range of approaches for cooling load calculation and system sizing; (2) most practitioners calculate cooling load for radiant systems as they would for air systems; and (3) that 46% of the respondents reported that steady state analysis methods and tools were used for radiant system sizing. *References:* Feng, J., F. Bauman, and S. Schiavon. 2014. Critical Review of Water Based Radiant Cooling System Design Methods. Proceedings of the 13th International Conference Indoor Air 2014, Hong Kong, July 7-12. (In press)
Comparison of Cooling Loads for Radiant and Air Systems *Status:* Ongoing (Spring 2014)	Unlike air distribution systems where the cooling load is primarily convective, the cooling load for radiant systems is comprised of both convective and radiant components. However, in current practice most design engineers are using the same cooling load calculations that they use for convection based air systems. CBE's research team compared simulated zone-level sensible cooling loads in both radiant and air systems. Results showed that cooling loads are different due to the importance of radiant heat exchange in radiant systems. All radiant systems are quick to respond to changes in zone heat gains, but thermally massive systems are slow to respond to control signals. Peak cooling loads for radiant systems may be higher or lower than those for air systems, depending on how the systems are configured and operated. In 2013 we conducted laboratory experiments comparing cooling loads between radiant chilled ceiling and overhead air distribution systems to verify the differences observed during the simulation studies. *References:* J. Feng, S. Schiavon, and F. Bauman, 2013. "Cooling load differences between radiant and air systems," *Energy and Buildings*, 65, 310-321. http://escholarship.org/uc/item/7jh6m9sx Bauman, F., J. Feng, and S. Schiavon, 2013. "Cooling load calculations for radiant systems: Are they the same as traditional methods?" ASHRAE Journal 55(12), pp. 20-27, December. https://escholarship.org/uc/item/6px642bj Feng J., F. Bauman, and S. Schiavon. In press. "Experimental comparison of zone cooling load between radiant and air systems," Accepted by *Energy and Buildings*. http://escholarship.org/uc/item/9dq6p2j7
Using In-Slab Radiant Systems With Cooling Towers in U.S. Climates *Status:* Completed (2013)	EnergyPlus was used to evaluate the cooling performance of thermally activated building systems (TABS) with evaporative cooling source for typical United States climates. Various design options for air system sizing and comfort zone expansion (for example, using personal comfort systems) were investigated to extend the range of application, and documented in the final report. *Reference:* Feng, J., and F. Bauman, 2013. Evaluation of cooling performance of thermally activated building system with evaporative cooling source for typical United States climates. http://escholarship.org/uc/item/5wk0c4d5

Impact of Solar Heat Gain on Radiant Floor Cooling System Design *Status:* Completed 2013	Radiant floor cooling systems are increasingly being used in large glazed transition spaces such as atria, airports, and perimeter areas. However, current design standards and test methods provide limited guidance on sizing such systems and their associated air systems with incident solar radiation. This study reviewed radiant cooling capacity estimation approaches, evaluated the impact of solar heat gain on radiant floor cooling capacity, and improved the predictability of design methods for cases with incident solar radiation. *Reference:* Feng J.,S. Schiavon, and F. Bauman, 2013. "Impact of solar heat gain on radiant floor cooling system design," *Proceedings of the 11th REHVA World Congress-CLIMA 2013* http://escholarship.org/uc/item/2913930b
Simulation of a Hybrid UFAD and Radiant Hydronic Slab HVAC system *Status:* Completed 2011	We used an EnergyPlus simulation model to simulate the operation of a novel integrated HVAC system that offers ultra-low energy performance when applied in some climates. This system combines an underfloor air distribution (UFAD) system with a cooled radiant ceiling slab. A cooling tower supplies water to pre-cool the structural slabs during the night and early morning. The paper compares the performance of this system to both an overhead system and an underfloor air distribution system in the cooling season for the Sacramento, California climate. The UFAD/radiant hybrid system shows an energy reduction of between 21-25% during the peak cooling months, an electricity demand reduction of 27% during the peak hour, and improved occupant thermal comfort. *Reference:* Raftery, P., K.H. Lee, T. Webster, and F. Bauman, 2012. "Analysis of a hybrid UFAD and radiant hydronic slab system." *Applied Energy,* Volume 90, Issue 1, 250-257, February. http://www.escholarship.org/uc/item/2966x4kw
Laboratory Study of Room Air Stratification in Combined Chilled Ceiling and Displacement Ventilation Systems Status: Completed 2010	Radiant chilled ceilings with displacement ventilation (DV) represent a promising integrated system design that combines the energy efficiency of both sub-systems with the opportunity for strong ventilation performance. The purpose of this study was to conduct laboratory experiments for a typical interior zone office to investigate how room air stratification is affected by the ratio of cooling load removed by a chilled ceiling to the total cooling load for two configurations of varying ceiling coverage by chilled radiant panels. The study provides improved design guidance and has already been implemented in manufacturer's design literature. *Reference:* Schiavon S., F. Bauman, B. Tully, and J. Rimmer, 2010. "Room air stratification in combined chilled ceiling and displacement ventilation systems," *HVAC&R Research Journal*. http://escholarship.org/uc/item/6xp8p3sx
Thermal Comfort with Radiant Floors and Ceilings *Status:* Completed 2009	The surface temperatures of radiant floor and ceiling systems should depend on the ambient air temperature, yet the surface temperature limits specified by current standards do not vary with air temperature. In addition, the standard limits for ceiling temperature are specified in terms of radiant temperature asymmetry, which is difficult to convert into surface temperatures. This paper provides graphs that allow designers to directly determine the acceptable range of floor and ceiling surface temperatures as a function of air temperatures. This work provides system designers and operators with greater flexibility for optimizing energy performance, while improving thermal comfort for occupants. *Reference:* Wang, Z., H. Zhang, D. Lehrer, E. Arens, C. Huizenga., T. Yu, S. Hoffmann, 2009. "Evaluating thermal comfort of radiant floors and ceilings," 4th International Building Physics Conference, Istanbul, June. http://escholarship.org/uc/item/5764d997

Simulation and Evaluation of Radiant Cooling Performance with Evaporative Cooling Sources *Status:* Completed 2008	We conducted whole-building simulations of slab-integrated hydronic radiant cooling with mechanical ventilation, compared to a conventional all-air cooling system. Cooling-season performance was evaluated in terms of thermal comfort, peak loads, and energy consumption in three climates. Simulation results suggest energy-saving potential for radiant cooling systems in both Denver (71% savings) and Sacramento (59% savings) climates. The report also describes three essential control strategies to utilize slab thermal mass and to extend nighttime cooling-tower capacity. *References:* Moore, T. 2008. "Simulation of radiant cooling performance with evaporative cooling sources," Summary Report, October. https://escholarship.org/uc/item/9qm3670s Moore, T., and F. Bauman, 2008. "Performance evaluation of radiant cooling systems in warm climates," Internal Report, Center for the Built Environment (CBE), UC Berkeley, April.
Radiant Cooling Research Scoping Study *Status:* Completed 2006	This early study identified the opportunities and limitations of radiant cooling strategies for North America, and research needs that CBE might most effectively address. Based on literature, case studies, and interviews with experienced designers, this work provided a roadmap for radiant cooling research to address shortcomings of industry resources, in order to provide the greatest benefit to CBE partners and the building industry at large. *References:* Moore, T., F. Bauman and C. Huizenga, 2006. "Radiant cooling research scoping study," CBE Internal Report, April. https://escholarship.org/uc/item/3j52t8vz