Robert Bean, R.E.T.
Registered Engineering Technologist
Building Construction Engineering

Coast2Coast Comfort Report

Westside Report

Geoff McDonell, P.Eng., LEED AP
Senior Mechanical Engineer
OMICRON

Healthy HEATING

Comforting Your Mind, Body & *Soles*

Energy and Control Issues Related to Radiant Slab Systems

By Geoff McDonell P.Eng.

Radiant floor slab heating systems that have been used for a several decades in North American homes, are fairly well known, well documented, and by most radiant floor heating contractors and designers are considered almost mainstream in terms of design criteria and application techniques. One of the key mis-understandings is that concrete mass is "difficult" to control because of its' longer response time compared to conventional heating terminal devices (hot water baseboard, convectors, suspended radiant panels, etc.). Many folks still try to use night setback on a radiant heating slab to "save energy", as one would do for a conventional heating system, as well as trying to control the slab with two-way control valves. It just doesn't work. The concrete has a very heavy mass compared to conventional heating terminals (hot water baseboard, staple-up radiant in wood floor structures, etc.), and takes a long time to cool down, and conversely, a long time to heat up. This response time actually leads to lower energy use if the slab can be maintained at a steady state temperature that is "trickle charged" to maintain the desired space comfort conditions. The thermal mass of the concrete can be turned into a huge energy saver, and can provide increased comfort, provided the operational controls are set up properly, AND the building envelope is designed

The time it takes to raise a building or its components to its operating condition is called thermal lag.

Thermal lag is a function of building efficiency and the type of radiant panel, i.e.: low, medium or high mass.

Thermal lag should never be confused with thermal response. In fact many HVAC practitioners unintentional spread this misinformation when they say radiant takes forever to heat.

The thermal responsiveness of radiant is instant - it travels at light speed as soon as there is a temperature difference.

Btus's transferred by radiant don't have to think about moving - they do it when the 'see' anything with a different

properly.

The nice thing about radiant heating and cooling systems is that the radiant heat exchange process takes place at the speed of light, so in fact, radiant heating and cooling systems can be considered to have a very fast response time from an occupants' point of view. Considering that the high thermal mass of a thick concrete slab can stay at a steady state temperature with a small amount of "trickle charging", a radiant slab heating and cooling system can easily maintain a near constant space comfort condition, in spite of short term fluctuations in the thermal loads within the space. If there is nothing in the room that is at a different temperature than the surface of the radiant slab, there is no heat transfer. As soon as a warm object like a human being comes into the room, there is instantaneous heat exchange with the radiant slab. If a small amount of solar load enters the space and heats up furniture, floors and objects, they exchange this heat with the radiant slab constantly at the speed of light. It takes a very long time for the slab to change temperature even with steady heat exchange, so it can maintain a very stable indoor comfort condition provided the water loops are constantly circulating and removing/supplying the thermal loads absorbed/discharged by the slab.

A fairly crude rule of thumb is that a concrete slab has a thermal lag around 1 to 2 hours per inch of concrete for a change in temperature. This means that most residential radiant slab floors that consist of about 1.5" (38mm) to 2" (50mm) of topping on a sub-floor, have a lag time of around 2-4 hours, depending on the type of concrete mix. A suspended structural slab, with a thickness of six to eight inches, has an estimated lag of 10-16 hours, or more. So, why would anyone try to control a radiant slab loop with a room thermostat and an on/off control valve if there is more than a couple of inches of concrete used for the radiant slab?

Knowing this slow response time, it is then incumbent on the building design team to minimize the thermal fluctuations in a space served by a radiant slab, to work with the slow response time of the slab. The key, then, is a "whole building" design approach where the building envelope and internal heating and cooling loads are designed in such a way as to keep the heat losses and heat gain fluctuations to low levels, within the capability of the radiant slabs' operation. It's a bit of reverse engineering: the building envelope and internal loads have to be designed around the capabilities and thermal physics of the radiant slab. While the costs of high thermal performance glazing and exterior solar control may cause some concern, the point is that an integrated building design ought to be able to offset the added envelope costs with savings in the installed costs of the mechanical and electrical systems.

Another issue to consider is that floors are also covered with insulating materials - carpets, wood flooring, and other types of floor finishes that act as insulators that can slow down and reduce the floor surface heating temperature. Each radiant floor zone therefore has to be designed specifically for that particular room, it's heat losses and gains, and the types of floor finishes in order to maintain comfort conditions. This can be accomplished a couple of ways:

- individually pumped and controlled radiant zones,
- individual radiant loop modulating valves based on a steady supply water temperature (for thin slabs only, less than 2" thick)

The key is to use both an in-slab temperature sensor as well as a room temperature sensor so that the slab temperature can be controlled to a fine degree - you don't want the floor temperature to overshoot and overheat the room, and you don't want the slab to cool off too much, requiring excessive heat energy to warm it up again.

The maximum floor surface temperature that must be designed to for radiant floor heating is approximately 85F. The "do not exceed" temperature is 90F, beyond which physiological problems could occur as well as general discomfort. Remember, it's the radiant SURFACE temperature you are designing to - the actual surface temperature of the wood floor on top of the radiant slab (or carpet, or tile…) in order to achieve the "resultant" or "operative" temperature of the room being heated and cooled.

The other critical thing to pay attention to is the glazing/windows at the perimeter zones of the building - the windows must be selected to insure that the inner surface of the glass does not go below 63F (17C) or above 80F (27C), to avoid radiant temperature asymmetry at the perimeter zones. Designing the building envelope around the performance characteristics of the radiant slab system forces the building designers to use a very high performance skin and glass, which naturally leads to low on-going energy use and low maintenance requirements for a simple heating/cooling system.

"...the point is that an integrated building design ought to be able to offset the added envelope costs with savings in the installed costs of the mechanical and electrical systems."

Low mass systems like this bathroom floor using heat transfer plates have very short thermal lag and operate at a lower temperatures than other types of radiant floors.

Photo courtesy of Radiant Engineering

REFERENCES/RESOURCES:

1. PM Engineer Magazine Article: http://www.pmengineer.com/CDA/Article Information/features/BNP__Features__Item/0,2732,135227,00.html
2. Engineered Systems Magazine Article: http://www.esmagazine.com/CDA/Article Information/features/BNP__Features__Item/0,2503,101074,00.html
3. Canadian Architect Magazine Article, March 2003: http://www.canadianarchitect.com/issues/ISarticle.asp?id=79997&story_id=149504153624&issue=03012003&PC=&RType=
4. Reeves Journal Magazine Article: http://www.reevesjournal.com/CDA/ArticleInformation/features/BNP__Features__Item/0,3815,104871,00.html
5. Tekmar Controls Technical Essay 006 : http://www.tekmarcontrols.com/acrobat/e006.pdf
6. University of Arizona Carefree House Case Study : http://support.caed.asu.edu/radiant/02_caseStudies/carefree/latest/project_desc_01.html
7. Deep Creek Lake Residence On-line Case Study: http://www.ourcoolhouse.com/
8. United States Dept. of Energy - Energy Efficiency and Renewable Energy - Energy Savers Consumer Fact Sheet: http://www.eere.energy.gov/consumerinfo/factsheets/bc2.html