The benefits of radiant floor heating systems have been known for centuries, as first used by the Roman Empire since 25 BC, known as “hypocaust”. Many remains of hypocausts have survived among Roman architectural ruins throughout Europe, western Asia, and northern Africa. The hypocaust is generally regarded as a major Roman invention which improved the hygiene and living conditions of citizens, and was a forerunner of modern central heating.

A hypocaust was composed of a raised floor (typically about two feet), supported by columns or pedestals of stone every few feet, with the space below left open. A furnace, composed of a continuously burning fire, created heat, which was then allowed to flow through the space below the raised floor, thus heating the floor and rest of the room. Once cooled, the air escaped through flues in the wall and out of vents in the roof. The furnace takes up a fair amount of space, so it was usually located in a separate room. The flues were built directly into the walls so they did not take up useful space.
In contrast to the eventual disappearance of the Roman under-floor hypocausts, under-floor heating has remained in use for millennia in Korea, where it is known as ondol. It is thought that the ondol system dates back to the Koguryo or Three Kingdoms (37 BC-AD 668) period when excess heat from stoves were used to warm homes.

In the early 1900s, when the American architect Frank Lloyd Wright was building the Imperial Hotel in Japan, he was invited to the home of a Japanese nobleman. There Wright found a room that was different from typical Japanese rooms, with a warm floor covered with yellow paper—a Korean ondol room. The Japanese gentleman had experienced ondol in Korea and, once back in Japan, had an ondol room built in his house. "The indescribable comfort of being warmed from below" impressed Wright. The original Imperial Hotel in Tokyo was built in 1890. To replace the original wooden structure, the owners commissioned a design by Wright, which was completed in 1923.

Wright decided then and there that ondol was the ideal heating system and began incorporating it in his buildings. Wright invented radiant floor heating, using hot water running through pipes instead of hot air through flues, which is now referred to as a “Hydronic” Heating System. In Korea, ondol has likewise been adapted to modern technologies and changes in fuel. Modern Korean homes and apartments are built with heating pipes embedded in floors that are typically concrete covered with vinyl or oiled papers. Heated water circulating through the pipes, warmed by a gas or oil boiler, has replaced heated air, minimizing the danger of carbon monoxide poisoning or burns.

Conventional forced-air systems use moving air to deliver heat, creating drafts and temperature swings.

With radiant heat, the distribution of warmth is even between the floor and ceiling to maintain an ideal temperature. Like sunshine, radiant heat warms people and objects first, even before air temperatures rise.
Hydronic Heating Systems

**HYDRONIC RADIANT SYSTEM - Slab on Grade**

Radiant tubing is embedded in cement. The tubing is typically attached to metal mesh with plastic ties. A four inch slab is most typical. The tubing is best placed in the middle of the slab. Full under-slab insulation is recommended for most residential application. Slabs have a very large thermal mass, which stabilizes temperature swings but slows response. This method is recommended whenever a slab is poured. Estimated Assembly R-value: R-0.69 - R-1.0.

**HYDRONIC RADIANT SYSTEM - Thin Slab on Subfloor**

Radiant tubing is attached on top of sub-floor with approved staples or plastic clips. A thin Slab of gypsum-based cement or cent is poured over the tubing. Typical slabs are 1.5 inch thick when using 1/2 inch tubing, but may be as thin as 1.25 inch thick when using 3/8 inch tubing. Gypsum cement is lighter than cement, but a little less conductive. Estimated Assembly R-value: R-0.69 - R-1.0.

**HYDRONIC RADIANT SYSTEM - Hanging or attached below Subfloor**

Radiant tubing is hung or attached to the underside of the joists in an airspace with insulation below. This requires higher water temperatures and has more limited heat output than other systems. It is often used for retrofitting when access from below is possible. Hanging systems have more even joist cavity temperatures than when pipe is attached in contact with subfloor joists. Estimated Assembly R-value: R-1.7 - R-2.2 (pipe + 3/4 inch plywood only).

**HYDRONIC RADIANT SYSTEM - With Plates below Subfloor**

Radiant tubing is attached to the underside of the joists with metal plates to diffuse the heat. Insulation is recommended below the plates. This has higher water temperatures and more limited heat output than above subfloor systems, but plates make it more effective than hanging pipe from under joists. It is often used for retrofitting when access to joist space is available. Estimated Assembly R-value: R-1.3 - R-1.8 (pipe + 3/4 inch plywood only).
Hydronic Heating Systems

HYDRONIC RADIANT SYSTEM - Structural Radiant Subfloor with Aluminum & Grooves

Pre-manufactured 1.125inch thick panels have grooves for tubing and an aluminum sheet bonded to the board. In this case, the pre-manufactured panels serve both as the structural subfloor and as the channel into which the tubing is installed. The aluminum sheet makes the system accelerate rapidly and spreads out the heat. Tubing is installed 12inch on center in the grooves. Estimated Assembly R-value: R-0.6

HYDRONIC RADIANT SYSTEM - Boards with Grooves and Metal which are attached to top of Subfloor

Several varieties currently exist. One board has metal on the bottom and another on the top. Both serve to spread the heat laterally. Normally they are glued and screwed or stapled to the top of a wooden subfloor. Under some conditions the may be attached on top of existing slabs. These are modular systems with straights and end pieces that are assembled to make a channel for pipe. Different products use different pipe sizes. Estimated Assembly R-value: R-0.75 - R-1.1 depending on product.

HYDRONIC RADIANT SYSTEM - Sandwich Method with or without Plates on Top of Subfloor

Typically, 1inch x 4inch x 3/4inch sleepers are attached to the top of the subfloor and pipe is placed in between the sleepers with or without the addition of the metal plates. The metal plates typically cover about 80% of the pipe, adding significantly to the even dispersion of the heat. Estimated Assembly R-value: R-1.1 - R-1.5 depending on product and plates.

Valve Assembly
Hydronic Heating Systems

Dry sand is an excellent thermal mass. In this application, a layer of sand is poured into the sleeper bays, then OSB (oriented strand board), or plywood is fastened to the sleepers. The final floor can be carpet, tile, laminate flooring, or any material requiring a solid surface.
**Electric Radiant System:**

Another variation of this type of heating system that has become increasingly popular is the Electric Radiant Floor Heating system, which utilizes wiring to dispense heat throughout a flooring assembly. Electric Radiant heating systems come in many formats such as single cable type, coil type and cable/mesh type and are designed for interior and exterior use in concrete, asphalt, synthetic coatings, under sub-floor, under tile or stone, carpet and laminate flooring. Exterior applied systems are traditionally used to prevent icing and snow pack build-up on driveways, decks, highways etc. These systems can also be powered utilizing traditional power grid as well as “alternative” energy sources such as solar power and wind turbine power sources.

---

**Radiant Heated Baseboards**

Contains one length each of front and back panels, damper, support brackets, slide cradles, and 1/2" heating element.
Electric Radiant Systems:

The heat cable is an ideal way to protect your home’s roof from structural damage due to ice and snow buildup.

Heat small, select areas such as a heated driveway with a pair of 2-foot-wide tire tracks, a wheelchair ramp, outdoor stairways, pathways, dog runs or kennels, etc. Radiant heated driveway, walkway and snowmelt applications can be tailor made for virtually any of your snow and ice melting needs.

The electric roof heating system is discreetly installed under roof shingles.

A “Roof heat” radiant heating cable installed inside a roof gutter. The heat cable is an ideal way to protect your home’s roof from structural damage due to ice and snow buildup.

A Radiant heated roof being installed on large roof cavity.
Some electric radiant systems manufactures strongly recommend using a continuity test unit during the installation process as to ensure there are no damaged cables installed. If the mat cabling is cut, ripped or breached the test unit will sound an alarm notifying the installer that damage has occurred allowing for repairs prior to embedment of the system.
Electric Radiant Systems:

**ELECTRIC RADIANT SYSTEM - Embedded Cable or Mat**

The electric cable, mesh or mat is encapsulated by embedding it in a 1/8inch to 2inch mud bed or in thin set mortar on top of the sub-floor as required by the National Electric Code. It is available as a low or line voltage for warming or heating. Higher output systems utilize wider spacing and require a thicker embedding layer. When only floor warming is desired, the system is controlled by a floor temperature sensor. Heating systems are usually controlled with a thermostat, often in combination with a floor sensor. Different systems and embedding thicknesses allow for a variety of floor coverings. Check with manufacturer for limitations and recommendations regarding flooring goods. Estimated Assembly R-value: R-0.3 - R-1 depending on embedding layer.

**ELECTRIC RADIANT SYSTEM- Self regulating Mat or Cable**

This type is formulated so that as the temperature of the mat or cable goes up, the resistance increases, which limits the heating output to a fixed temperature. Some may be embedded in a mortar layer or used directly (as recommended by the manufacturer) under a wide variety of floor coverings. Estimated Assembly R-value: R-0.3 - R-1.0 depending on layer.

**ELECTRIC RADIANT SYSTEM - Film Type installed from Below**

With the film type product, elements are printed with a conductive ink and embedded in a film of plastic. Current products are line voltage. These systems have higher resistance to heat transfer than embedded systems since the heat must travel through an airspace and the subfloor. They must be installed with an airspace. Estimated Assembly R-value: R-1.7 - R-2.2 (pipe and 3/4inch plywood only) The listed Assembly R-values are illustrative estimates only and do not include the R-values of the floor coverings, which must be added to determine total system R-value. Note: Insulation is usually required under radiant heating systems. The Radiant Heating System Design should be designed and installed by qualified professionals.
Electric Radiant Systems;

“OTHER” AREAS OF USE

DECORATIVE TOPPINGS AND/OR CONCRETE

SHOWER FLOORS

RADIANT HEATED FURNITURE

SHOWER SEATS

TOWEL RACKS

SWIMMING POOL DECKS

LANDSCAPED PAVER DECKS
Electric Radiant Systems:

When and if Failures Occur in an Electric Radiant Heating System

Inevitably, for one reason or another, the floor and interior finishes are completed and the floor will not pass the continuity test, or will trip the GFCI, rendering the mat useless. To avoid excavating the complete floor surface and creating major construction interruptions, the use of infrared thermography has been incorporated into failure investigations. Infrared allows for a quick, precise, and easy to understand pictorial report that documents the precise area of failure points along the heating wire. The trick is to get the area of failure, or fault, to heat up and display itself.

With infrared assessment, this process can be quick, definitive, and cost effective. Additionally, the use of infrared produces an easy to understand pictorial report so all parties involved can see the problem at hand.
As you have seen in this report there are many options to choose from that will suit almost any type of need and construction method available, so this is the place to stress the importance of consulting with the radiant system manufacture as well as the adhesive companies and sub-panel system manufactures regarding appropriate system specification and compatibility to ensure a successful installation as well as long term performance.
The MIA’s [Marble Institute of America] “Dimensional Stone Design Manual” also addresses the installation of radiant heating with and without crack isolation membranes. Referring to the RPA’s [Radiant Panel Association]‘Standard Guide for the Design & Installation of Residential Radiant Panel heating Systems’ recommendation, “Ceramic, Quarry Tile & Marble…..installed over suspended radiant floor panels shall have a crack isolation membrane placed between the tile & the thermal mass.” It is also noted that, “some electric radiant panel systems” do not require a crack isolation membrane.

Reference Details:

TCNA / Tile Council of North America

Concrete Floors

1. Radiant heat on concrete [ Hydronic ] RH110-09
2. Radiant heat on concrete [ Hydronic ] Poured Gypsum RH111-09
3. Cementitious Self Leveling Underlayment [ Hydronic ] Thin-set RH112-09
4. Latex Portland Cement Mortar ( Electric ) Thin-set RH115-09
5. Cementitious Self Leveling Underlayment ( Bonded Electric ) Thin-set RH116-09

Wood Floors

3. Radiant Heat Wood Subfloor EGP Latex Cement Mortar ( Electric ) RH130-09
4. Radiant Heat Backer Board ( Electric ) Thin-set RH135-09
5. Radiant Heat 19.2” o.c. Joist Spacing w/Cement Self Leveling ( Electric ) / Thin-set RH140-09

CONCERNS NOTED:

A concern with electric radiant systems is EMF which stands for ElectroMagnetic Field and it is a byproduct of alternating electric current passing through wires and appliances. Human exposure to ambient levels of EMF is the subject of continuing scientific scrutiny and the results are a matter of public record. For those who are concerned, the Federal Government recommends minimizing exposure to EMFs in the home and workplace. Elevated EMF levels can also interfere with electronic devices including computer screens and is usually included on lists of causes for "sick building syndrome".

1 - RH111 - Potentially problematic for slab on grade construction as excessive Moisture Vapor Transmission would be trapped under the membrane and potentially soften the gypsum.
2 - RH112 - Same issue as with RH111, states neither installation is to be used below grade.
3 - RH115
4 - RH116
5 - RH130 - When using the “mat” system, what is the expected Tensile or Shear bond value of the assembly?
6 - RH135
7 - RH140

IMPORTANT NOTES REGARDING INSTALLATION PROCEDURES

He purpose of this report is to provide reference materials and is NOT to provide specific installation details or instructions for the systems referenced within this entire report. ALWAYS refer to the manufacturer of the system specified for use regarding their installation instructions, methods and warranty procedures. Refer to the Radiant Panel Association, Marble Institute of America and the Tile Council of North America handbooks for further elaboration of their specific details.

CNA - www.tileusa.com
PA - www.radiantpanelassociation.org
IA – www.marble-institute.com
REPORT INDEX

Page 1 – History of Hypocaust
Page 2 – History of Ondol / Hydronic system
Page 3 – Different Types of Hydronic heating systems
Page 4 - Different Types of Hydronic heating systems
Page 5 - Different Types of Hydronic heating systems
Page 6 - Different Types of Electric Radiant heating systems
Page 7 - Different Types of Electric Radiant heating systems
Page 8 - Different Types of Electric Radiant heating systems
Page 9 - Different Types of Electric Radiant heating systems
Page 10 – “Other” Areas of Use for Electric Radiant heating systems
Page 11 - Troubleshooting Electric Radiant heating systems
Page 12 – Installation details for Hydronic heating systems
Page 11 – Installation details for Hydronic heating systems
Page 12 – Installation Reference details for Hydronic and Electric heating systems
Page 13 - Installation Standards details for Hydronic and Electric heating systems
Page 14 – Report Index
**Resources Used for this Report**

1. TCNA – 2010 TCA HANDBOOK For Ceramic Tile Installation
2. MARBLE INSTITUTE of America
3. Radiant Panel Association

Websites cited


- [http://www.answers.com/topic/hypocaust-system](http://www.answers.com/topic/hypocaust-system) / 5-5-2010

- [http://www.pages.drexel.edu/~jpm55/AE390/A5/hypocaust.htm](http://www.pages.drexel.edu/~jpm55/AE390/A5/hypocaust.htm) / 5-5-2010


- [http://www.hydronicpros.com/hydronicheating/services.php](http://www.hydronicpros.com/hydronicheating/services.php) / 5-6-2010

- [http://www.warmzone.com/diagrams/driveway-heating.asp](http://www.warmzone.com/diagrams/driveway-heating.asp) / 5-6-2010

- [http://www.warmzone.com/roofheat.asp](http://www.warmzone.com/roofheat.asp) / 5-11-2010

- [http://www.warmzone.com/otherproducts.asp](http://www.warmzone.com/otherproducts.asp) / 5-11-2010


- [http://www.tristatehomeservices.com/Content/03/Radiator.aspx](http://www.tristatehomeservices.com/Content/03/Radiator.aspx) / 5-11-2010

- [http://www.finaltouchinteriors.com/emotor/index.php/site/comments/radiant_flooring_heating_system_guide](http://www.finaltouchinteriors.com/emotor/index.php/site/comments/radiant_flooring_heating_system_guide) / 5-5-2010

- [http://www.otpco.com/ProductsServices/RadiantHeatSystems.asp](http://www.otpco.com/ProductsServices/RadiantHeatSystems.asp) / 5-10-2010


- [http://www.aimradiantheating.com/store/FinTubeBaseboard_1_2_ElementAssembledSinglePackAssembled.html](http://www.aimradiantheating.com/store/FinTubeBaseboard_1_2_ElementAssembledSinglePackAssembled.html) / 5-11-2010

- [http://www.irinfo.org/Articles/5_1_2008_durston.html](http://www.irinfo.org/Articles/5_1_2008_durston.html) / 5-11-2010


************************************************************************************************************