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Co<sub>2</sub>olBricks

WP5 Education and Economic Promotion

# Radiant heating, convection heating systems, wall tempering

Educational product: New lecture material for training modules dealing with knowledge and skills how to apply suitable methods of energy efficient refurbishment of historic constructions and how innovation can be combined with cultural heritage



## Radiant peating, convection heating systems, wall tempering

**Target group:** architecture, construction, energy audit students

**Educational objectives:** To show the possibilities and methods for using innovating heating systems in historic buildings.

This measure can help to save up to 30% total energy used in building in special cases (buildings with huge spaces e.g. churches).

**Lecture course:** 2 academic hours

### References:

Bojić, Milorad, et al. "Performances of low temperature radiant heating systems." *Energy and Buildings* (2013).

Harrestrup, Maria, and Svend Svendsen. "Changes in heat load profile of typical Danish multi-storey buildings when energy-renovated and supplied with low-temperature district heating." *International Journal of Sustainable Energy* ahead-of-print (2013): 1-16.

Ren, Jianbo, et al. "Very low temperature radiant heating/cooling indoor end system for efficient use of renewable energies." *Solar Energy* 84.6 (2010): 1072-1083.

Causone, Francesco, Stefano P. Corgnati, and Bjarne W. Olesen. "Radiant heating/cooling and ventilation: convective heat transfer enhancement." (2011).



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**Radiant heating** is a technology for heating indoor and outdoor areas. Radiant heating as a technology is typically more narrowly defined. It is the method of intentionally using mostly the principles of radiant heat to transfer radiant energy from an emitting heat source to an object. Designs with radiant heating is seen as replacement for conventional convection heating. But also as a way of supplying confined outdoor heating.

Radiant heating heats a building through radiant heat, rather than other conventional methods such as radiators (mostly convection heating). The technology has existed since the Roman use of hypocaust heating. Another example is the Austrian/German *Kachelofen* or masonry heater. The heat energy is emitted from a warm element, such as a floor, wall or overhead panel, and warms people and other objects in rooms rather than directly heating the air. The internal air temperature for radiant heated buildings may be lower than for a conventionally heated building to achieve the same level of body comfort, when adjusted so the perceived temperature is actually the same. One of the key advantages of radiant heating systems is a much decreased circulation of air inside the room and the corresponding spreading of airborne particles.

The radiant heating systems can be divided into:

## Underfloor heating systems—electric or hydronic



### *Electric Radiant Floors*

Electric radiant floors typically consist of electric cables built into the floor. Systems that feature mats of electrically conductive plastic mounted on the subfloor below a floor covering such as tile are also available.

Because of the relatively high cost of electricity, electric radiant floors are usually only cost-effective if they include a significant thermal mass such as a thick concrete floor and your electric utility company offers time-of-use rates. Time-of-use rates allow you to „charge“ the concrete floor with heat during off-peak hours (approximately 9 p.m. to 6 a.m.). If the floor’s thermal mass is large enough, the heat stored in it will keep the house comfortable for eight to ten hours without any further electrical input, particularly when daytime temperatures are significantly warmer than nighttime temperatures. This saves a considerable number of energy dollars compared to heating at peak electric rates during the day.

Electric radiant floors may also make sense for home additions if it would be impractical to extend the heating system into the new space. However, homeowners should examine other options, such as mini-split heat pumps, which operate more efficiently and have the added advantage of providing cooling.

### *Hydronic Radiant Floors*

Hydronic (liquid) systems are the most popular and cost-effective radiant heating systems for heating-dominated climates. Hydronic radiant floor systems pump heated water from a boiler through tubing laid in a pattern under the floor. In some systems, controlling the flow of hot water through each tubing loop by using zoning valves or pumps and thermostats regulates room temperatures. The cost of installing a hydronic radiant floor varies by location and depends on the size of the home, the type of installation, the floor covering, remoteness of the site, and the cost of labor.



## ***Types of Floor Installations***

Whether you use cables or tubing, the methods of installing electric and hydronic radiant systems in floors are similar.

So-called „wet“ installations embed the cables or tubing in a solid floor and are the oldest form of modern radiant floor systems. The tubing or cable can be embedded in a thick concrete foundation slab (commonly used in „slab“ ranch houses that don't have basements) or in a thin layer of concrete, gypsum, or other material installed on top of a subfloor. If concrete is used and the new floor is not on solid earth, additional floor support may be necessary because of the added weight. You should consult a professional engineer to determine the floor's carrying capacity.

Thick concrete slabs are ideal for storing heat from solar energy systems, which have a fluctuating heat output. The downside of thick slabs is their slow thermal response time, which makes strategies such as night or daytime setbacks difficult if not impossible. Most experts recommend maintaining a constant temperature in homes with these heating systems.

Due to recent innovations in floor technology, so-called „dry“ floors, in which the cables or tubing run in an air space beneath the floor, have been gaining in popularity, mainly because a dry floor is faster and less expensive to build. But because dry floors involve heating an air space, the radiant heating system needs to operate at a higher temperature.

Some dry installations involve suspending the tubing or cables under the subfloor between the joists. This method usually requires drilling through the floor joists to install the tubing. Reflective insulation must also be installed under the tubes to direct the heat upward. Tubing or cables may also be installed from above the floor, between two layers of subfloor. In these instances, liquid tubing is often fitted into aluminum diffusers that spread the water's heat across the floor in order to heat the floor more evenly. The tubing and heat diffusers are secured between furring strips (sleepers), which carry the weight of the new subfloor and finished floor surface.

At least one company has improved on this idea by making a plywood subfloor material manufactured with tubing grooves and aluminum heat diffuser plates built into them. The manufacturer claims that this product makes a radiant floor system (for new construction) considerably less expensive to install and faster to react to room temperature changes. Such products also allow for the use of half as much tubing or cabling, because the heat transfer of the floor is greatly improved compared with more traditional dry or wet floors.

## ***Floor Coverings***

Ceramic tile is the most common and effective floor covering for radiant floor heating, because it conducts heat well and adds thermal storage. Common floor coverings like vinyl and linoleum sheet goods, carpeting, or wood can also be used, but any covering that insulates the floor from the room will decrease the efficiency of the system.

If you want carpeting, use a thin carpet with dense padding and install as little carpeting as possible. If some rooms, but not all, will have a floor covering, then those rooms should have a separate tubing

loop to make the system heat these spaces more efficiently. This is because the water flowing under the covered floor will need to be hotter to compensate for the floor covering. Wood flooring should be laminated wood flooring instead of solid wood to reduce the possibility of the wood shrinking and cracking from the drying effects of the heat.

## Wall heating systems



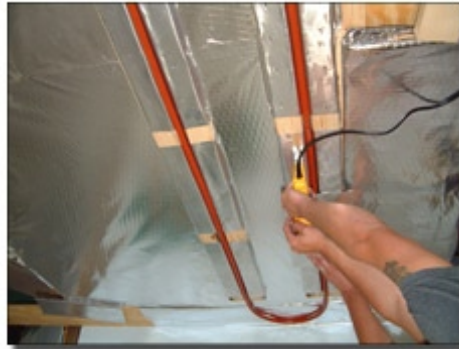
Wall- and ceiling-mounted radiant panels are usually made of aluminum and can be heated with either electricity or with tubing that carries hot water, although the latter creates concerns about leakage in wall- or ceiling-mounted systems. Most commercially available radiant panels for homes are electrically heated.

Like any type of electric heat, radiant panels can be expensive to operate, but they can provide supplemental heating in some rooms or can provide heat to a home addition when extending the conventional heating system is impractical.

Radiant panels have the quickest response time of any heating technology and -- because the panels can be individually controlled for each room—the quick response feature can result in cost and energy savings compared with other systems when rooms are infrequently occupied. When entering a room, the occupant can increase the temperature setting and be comfortable within minutes. As with any heating system, set the thermostat to a minimum temperature that will prevent pipes from freezing.

Radiant heating panels operate on a line-of-sight basis -- you'll be most comfortable if you're close to the panel. Some people find ceiling-mounted systems uncomfortable because the panels heat the top of their heads and shoulders more effectively than the rest of their bodies.

## Radiant ceiling panels



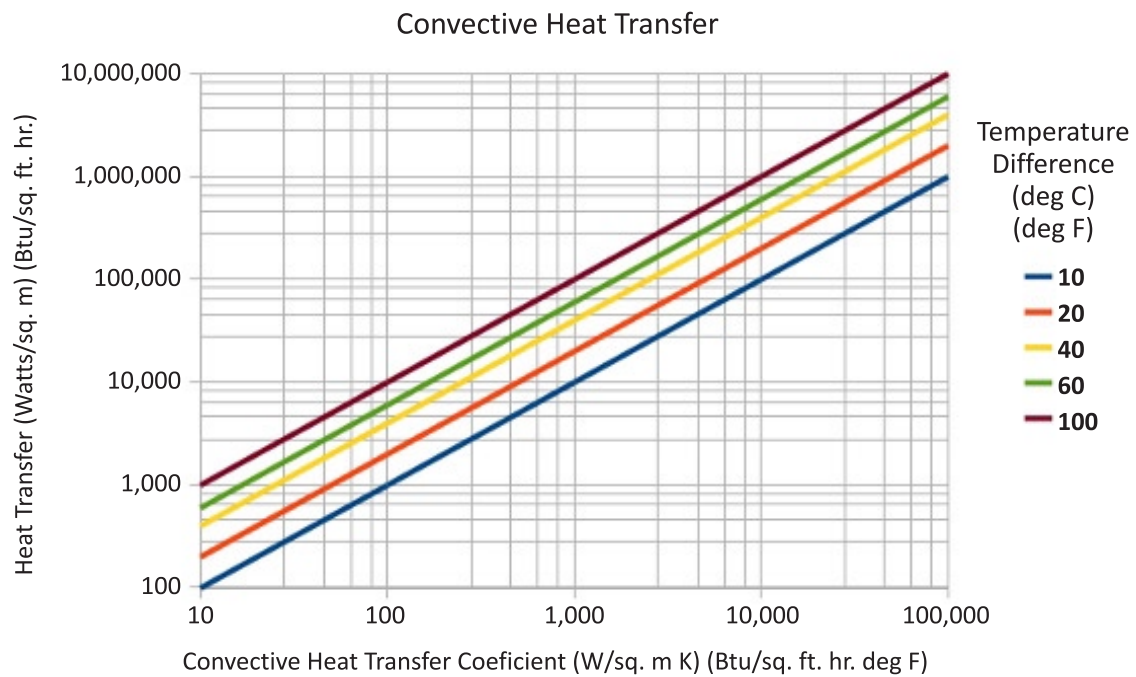
Underfloor and wall heating systems often are called low-temperature systems. Since their heating surface is much larger than with other systems, a much lower temperature is required to achieve the same level of heat transfer. This provides a much improved room climate with healthier air humidity levels. The maximum temperature of the heating surface can vary from 29–35 °C depending on the room type. Radiant overhead panels are mostly used in production and warehousing facilities or sports centers; they hang a few meters above the floor and their surface temperature is much higher.

Electric systems use fewer components and are simpler to install and commission than hydronic systems but direct heating with electricity can be more expensive than some other sources of heat. Some electric systems use line voltage technology while others use low voltage technology. Low voltage electrical radiant floor heating in respect of line voltage heating has the added complexity of the voltage regulators and transformers, so it can be more failure prone. The amount of power dissipated is, of course, equal, as all energy is given off in the form of heat.

In some cases, the cost of electric heat can be offset by other factors such as with thin film radiant heating. In this technology 99.9% of the electricity is converted to long wave infrared radiant energy, and 85% of the surface area is covered with heating element. As heat is a transfer of energy: when you increase the heated surface area, you increase the efficiency of the thermal transfer. In this way the radiant heating film warms up more area, more quickly and at lower temperatures using less energy, which can significantly increase efficiency.

## Convection heating systems

Convection is the transfer of thermal energy from one place to another by the movement of fluids or gases. Although often discussed as a distinct method of heat transfer, convection describes the combined effects of conduction and fluid flow or mass exchange.



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- The heat transfer per unit surface through convection was first described by Newton and the relation is known as the **Newton's Law of Cooling**.

The equation for convection can be expressed as:

$$q = h_c A dT \quad (1)$$

where

$q$  = heat transferred per unit time (W)

$A$  = heat transfer area of the surface ( $m^2$ )

$h_c$  = convective heat transfer coefficient of the process ( $W/m^2K$  or  $W/m^2°C$ )

$dT$  = temperature difference between the surface and the bulk fluid (K or  $°C$ )





## Heat Transfer Coefficients - Units

- $1 \text{ W/m}^2\text{K} = 0.85984 \text{ kcal/h m}^2 \text{ }^\circ\text{C} = 0.1761 \text{ Btu/ft}^2 \text{ h }^\circ\text{F}$
- $1 \text{ Btu/ft}^2 \text{ h }^\circ\text{F} = 5.678 \text{ W/m}^2 \text{ K} = 4.882 \text{ kcal/h m}^2 \text{ }^\circ\text{C}$
- $1 \text{ kcal/h m}^2 \text{ }^\circ\text{C} = 1.163 \text{ W/m}^2\text{K} = 0.205 \text{ Btu/ft}^2 \text{ h }^\circ\text{F}$

## Convective Heat Transfer Coefficients

The convective heat transfer coefficient -  $h_c$  - is dependent on the type of media, gas or liquid, the flow properties such as velocity, viscosity and other flow and temperature dependent properties.

In general the convective heat transfer coefficient for some common fluids is within the ranges:

- *Free Convection - Air* : 5 - 25 ( $\text{W/m}^2\text{K}$ )
- *Free Convection - Water*: 20 - 100 ( $\text{W/m}^2\text{K}$ )
- *Forced Convection - Air*: 10 - 200 ( $\text{W/m}^2\text{K}$ )
- *Forced Convection - Water*: 50 - 10.000 ( $\text{W/m}^2\text{K}$ )
- *Boiling Water* : 3.000 - 100.000 ( $\text{W/m}^2\text{K}$ )
- *Condensing Water Vapor*: 5.000 - 100.000 ( $\text{W/m}^2\text{K}$ )

The convective heat transfer coefficient of air is approximately equal to

$$h_c = 10.45 - v + 10 v^{1/2} \quad (2)$$

where

$v$  = the relative speed of the object through the air (m/s)



Two types of convective heat transfer may be distinguished:

- **Free or natural convection:** when fluid motion is caused by buoyancy forces that result from the density variations due to variations of temperature in the fluid. In the absence of an external source, when the fluid is in contact with a hot surface, its molecules separate and scatter, causing the fluid to be less dense. As a consequence, the fluid is displaced while the cooler fluid gets denser and the fluid sinks. Thus, the hotter volume transfers heat towards the cooler volume of that fluid. Familiar examples are the upward flow of air due to a fire or hot object and the circulation of water in a pot that is heated from below.
- **Forced convection:** when a fluid is forced to flow over the surface by an external source such as fans, by stirring, and pumps, creating an artificially induced convection current.

Internal and external flow can also classify convection. Internal flow occurs when a fluid is enclosed by a solid boundary such when flowing through a pipe. An external flow occurs when a fluid extends indefinitely without encountering a solid surface. Both of these types of convection, either natural or forced, can be internal or external because they are independent of each other. The bulk temperature, or the average fluid temperature, is a convenient reference point for evaluating properties related to convective heat transfer, particularly in applications related to flow in pipes and ducts.

### ***Types of residential convection heaters***

Typical residential electric convection heaters include (listed from lowest to highest in terms of cost and performance):

- wall-mounted panel heaters
- wall-mounted or freestanding fan heaters
- oil column or nightstore storage heaters, which incorporate a small amount of thermal mass
- ducted central heating systems with floor or low-wall grilles.

Typical residential gas-fired convection heaters include (listed from lowest to highest in terms of cost and performance):

- balanced flue gas heaters
- wall-mounted furnaces, which may incorporate fans
- boiler supplying hot water radiators
- ducted central heating systems with floor or low-wall grilles.

### ***Characteristics of convection heaters***

Convection heaters:

- heat the space from the top down – for larger spaces or spaces with high ceilings, it will take some time for the heat to reach occupant level, particularly when the occupants are sitting
- raise room air temperature more quickly than radiant heaters
- use more energy to achieve the same temperature change as radiant heating in larger spaces
- change the air temperature gradually (fans may increase the rate of air movement), which means that occupants only gradually feel warmer
- make the air warmer close to the heater, so space heating relies on adequate air movement
- create convection currents and temperature gradients as warmer air from the heater rises.



## ***Convection heaters with thermal mass***

Convection heaters may also incorporate thermal mass. Examples include hot water radiators, nightstore or oil column heaters, underfloor heaters and solar hydronic heaters. Heaters with high thermal storage generally don't get as hot on the surface as heaters with low thermal storage, and therefore have steadier heat output.

High thermal storage heaters can be useful for:

- heating spaces with longer periods of occupancy, for example, beyond about 15 minutes
- heating larger spaces that require more even temperature throughout
- providing low impact heating (lower rates of temperature change and lower air velocity)
- spaces where there is a significant distance to the occupant from the heater
- situations where air temperature needs tighter control over extended periods of time
- rooms where there are high transmission heat losses through walls or the floor or ceiling (for example, a conservatory in winter).