Hypocausts were used from the third century B.C. in ancient Europe.

Part 2

History of Radiant Heating & Cooling Systems

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Part 1, published in January, covered developments of radiant heating and cooling in Asia.

From the third century B.C., ancient Europe developed an underfloor heating system called *Hypocaustum*.[1] The system was defined by the furnace (*hypocausis*) and a series of flue passages realized under the floor by means of pillars carrying a slab and then exhausted through cavities in the walls.

Roman oyster farmer, Gaius Sergius Orata was commonly thought to have introduced or developed this type of heating during the first century B.C. However, "*Hypocausts* of the third and second centuries B.C. are known, for instance, at Gortys in Greece and at Gela, Megara Hyblaea, and Syracuse in Magna Graecia."[2] Additionally, the use of floor heating in ancient European and Middle Eastern lands was widespread with variations of the *hypocaust* found in Afghanistan,[3] Syria,[4] and other countries.[5]

With the exception of late antiquity *hypocaust* type systems in the Middle East, Europe's use of floor heating went into hibernation for many centuries while systems in Korea, China and parts of Japan continually evolved.

Rebirth in Europe

Between the 12th and 17th centuries, open fires were used in Europe, the Middle East and North America. The *Russian Fireplace*, the *Steinofen* and *Kachelofen* in Europe, and the *Tandoor* with *Tab-khaneh* (other spellings include tanur/taba khana) in Afghanistan[6,7] lead up to the development of the 18th century

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Franklin Stove, which became a preferred heating system in many buildings.[8]

Floor heating in Europe reappeared during this era. "John Evelyn, writing in 1691, indicated that heating greenhouses by the radiation from flues in floors and walls was by no means a novelty, (and it) is…believed that the technique was a survival from classical times in Russia but had been lost in the rest of Europe."[9,10]

From Stetiu, "…(the) hot water boiler was introduced around this time, together with its system of large pipes through which the hot water was carried. The first known such design is attributed to Sir John Stone, who installed a heating system of pipes in the Bank of England in 1790."[11,12]

Hypocaust flues from Roman baths.

However, a parallel evolution existed in other countries with time lines offset by only a few decades. Also at this time was the development of the understanding of radiant heat transfer. "John Leslie discovered in 1801 that the diminished output of James Watts' 1784 tin plate steam radiator had to do with its emissivity, discovering that a coat of pigment to a metallic surface greatly enhanced its output."[13]

Benjamin Thompson, who determined the specific heats of various substances and thermal conductivities of insulating materials, observed in the 1800s:

> *Close to the windows it will indeed be possible to feel the heat caused by the calorific radiations; but nothing can hinder the currents of air, caused by the cooling, which takes place through the panes of glass, from spreading over the entire extent of the room. But when the windows are double layer, the layer of air which is enclosed between the two windows being an excellent non-conductor of heat, the inside window is well protected from cold from without and the descending currents of air just mentioned no longer existing, it would be easy, with good stoves moderately heated to establish a pleasant and equable temperature.*[13]

Today's thermally activated building systems are foreshadowed in this quote: "…a Mr. Hay of Edinburgh proposed an early form of thermal storage to heat a building using steam to heat stone-filled pits in each room. The stones were heated once a day as required."[13]

Two significant patents leading up to modern-day fluid based systems were issued during this century to Angier March Perkins. The first in 1839 was for an "apparatus for transmitting heat by circulating water, and the second in 1841 was for an "apparatus for heating by the circulation of hot water; construction of pipes for such and other purposes."[14]

Also during this period we see the beginning of the end for *hypocaust* type systems when King Edward VII laid the foundation stone in 1904 to what was to become Liverpool Cathedral."The whole floor of the Nave, Transept and Chancel forms one large radiator and it was reputed to be the largest single radiator in the world."[15] Then just a few years later: "The modern development of radiant heating started in 1907(8), when Arthur H. Barker, a British professor, discovered that small hot water pipes embedded in plaster or concrete formed a very efficient heating system."[16]

Image credit: U.S. National Park Service

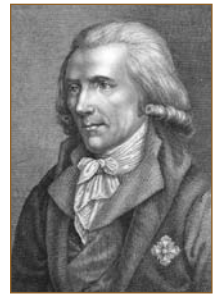

Image credit: Smithsonian Institution

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c. 1600, France, heated flues in floors and walls used in greenhouses.

c. 1700 Benjamin Franklin studies the French and Asian cultures and makes note of their respective heating systems leading to the development of the Franklin stove. Steam based radiant pipes are used in France.

c. 1800 Beginnings of the European evolution of the modern water heater/boiler and water based piping systems including studies in thermal conductivities and specific heat of materials and emissivity/reflectivity of surfaces (Watt/Leslie/Rumford [shown]).

c. 1864, ondol type system used at Civil War hospital sites in America. Reichstag building (shown above) in Germany uses the thermal mass of the building for cooling and heating.

c. 1904, Liverpool Cathedral (England) heated with system based on the hypocaust principles.

An earlier 1800s version is the John Soane house and museum, "Here the architect, after trying a number of expedients, turned to the newly developed Perkins high pressure hot water system…he could conceal the small bore pipes under the bases of the marble antiquities in the Belzoni Chamber, place a coil of pipes under the table in the Monk's Room, and run a circuit of piping around the base of his many skylights to counter the flow of cold air…."[9] Patent No. 28477 was granted on Barker's system of heating, which was called panel warming.[17]

This patent was later sold to R. Crittal & Company Limited who used the concepts to heat the Royal Livre building in Liverpool in 1909. Crittal appointed representatives in several countries including Sulzer Brothers of Winterthur, Switzerland. It conducted extensive long-term studies with the Swiss National Research Laboratory.[18] During this era, systems were installed in an open air school in Amsterdam (1929), a private residence in Germany (1930) and a large department store in Zurich (1936–38).[17] At this time came the impetus for a reevaluation of radiant piping systems stemming from an accidental (re) discovery of polyethylene by Gibson and Fawcett in 1933 at the ICI laboratories in England, which later led to the development of PEX pipe and a solution to many challenges associated with earlier piping materials.[18]

Introduction of Radiant Cooling Systems

There is anecdotal reference to early 8th century *radiant cooling* using snow-packed walls in buildings constructed in Mesopotamia (modern day Iraq),[19] in Turkey with cooled water[11] and much later in 20th century Europe where "After the war, the Bank of England got a nice new hydronic radiant heating system that was installed under the direction of a fellow named Dr. Oscar Faber. Dr. Faber's system used copper pipes embedded in concrete floors and plaster ceilings and it was used to cool the building in the summer and heat it in winter."[20]

Pre-World War II radiant cooling included "The historic Reichstag building—the German parliament—was at the time of its inauguration in December of 1894 one of the most sophisticated and technically advanced buildings of its time. The design incorporated central heating, humidification and summer 'cooling' with the help of thermal mass."[21]

Solving the Issue of Latent Loads

"Most of the early cooling ceiling systems developed in the 1930s failed…because condensation often occurred…. Subsequent studies showed that this problem could be avoided if the radiant system was used in conjunction with a small ventilation system designed to lower the dew-point of the indoor air. This combination proved successful in a department store built in 1936-1937 in Zürich, Switzerland and in a multi-story building built in the early 1950s in Canada."[11]

Since the later part of the 20th century, industry has developed a better understanding of controls for radiant-cooled environments and with dedicated outdoor air systems and improved controllability larger applications of cooling developed in extreme climates like Bangkok with its cooled Suvarnabhumi Airport system.[22]

North America

In the 18th century, Benjamin Franklin studied radiant floor heating in Asia and French technology to develop his Franklin

Image courtesy of Dan Holohan


Photo credit: James Steakley

c. 1905, Frank Lloyd Wright makes first trip to Japan, later incorporates various early forms of radiant heating in his projects.

c. 1907, England, Prof. Barker granted Patent No. 28477 for panel warming using small pipes. Patents later sold to the Crittal Company who appointed representatives across Europe. A.M. Byers of America promotes radiant heating using small bore water pipes. Asia continues to use traditional ondol and kang – wood is used as the fuel, combustion gases sent underfloor.

c. 1930, Faber in England uses water pipes to radiant heat and cool several large buildings.

c. 1933, explosion at England's Imperial Chemical Industries (ICI) laboratory during a high pressure experiment with ethylene gas results in a wax like substance – later to become polyethylene and the beginnings of PEX pipe.

c. 1937 Frank Lloyd Wright designs the radiant heated Herbert Jacobs house, the first Usonian home.

Stove. Edgerton shares a story of Franklin writing to a friend in Boston about stoves he had seen in the Bank of England.

By means of an elaborate down draft, the smoke was drawn through tubes in the center of the stoves themselves and out under the floor by means of ducts to the chimneys. This technological feat intrigued Franklin and he thereupon designed his own interpretation, which consisted of an urn on a pedestal, all within a cast-iron niche in the chimney. He added another idea which the French had actually explored before, of having the smoke consumed as it passed through the fire. The smoke which collected in a tile urn was drawn down through the stove, burned, and the unadulterated hot air went under the floor, warmed up the hollow niche, and radiated into the room.[23]

Roughly a century later, rudimentary forms of radiant heating were used during the American Civil War:

The plan which…gave the utmost satisfaction, was that known as the California plan. A pit was dug about two-and-a-half feet deep outside the door of the hospital tent; from this a trench passed longitudinally through the tent, terminating outside its farther or closed extremity. At this point a chimney was formed by barrels placed one upon the other, or by some other simple plan. The joints and crevices of this chimney were cemented with clay. The trench in the interior of the tent was roofed over with plates of sheet-iron issued for that purpose by the Quartermasters Department. A fire was built in the pit, and the resulting heat, radiating from the sheet-iron plates, kept the interior of the tent warm and comfortable even in the coldest weather.[24]

The description is remarkably similar to versions used in ancient Asia. One could speculate that the term "California Plan" came from the west coast Chinese immigrants who influenced those around them during those times leading up to the civil war.[25] According to J. Lawrence, project coordinator of Sheridan's Field Hospital at Shawnee Springs, there is some evidence that the heating system was adopted from the frontiers during the gold rush in the 1840/50s.[26]

Most Chinese immigrants entered California through the port of San Francisco...(they) formed part of the diverse gathering of peoples from throughout the world who contributed to the economic and population explosion that characterized the early history of the state of California… (and) brought with them to the United States traditions and practices that were integral to their daily lives.[25]

Image courtesy of Dan Holohan

Levittown house built by developer William Levitt as part of the first mass-produced suburb in U.S.

Following the Civil War era, the A.M. Byers Company published that "In 1909 a small school was constructed in the Village of Glen Park, Indiana. Pipes carrying steam were suspended between the floor joist, over which conventional wood floors were laid." "…in 1911, wrought iron heating coils were placed behind steel plates in the walls of certain rooms in the Phipps Psychiatric Clinic in Baltimore. This institution is part of John Hopkins Hospital."

The influence of early British systems is shown with these words from the Chase Brass & Copper Co.: "The early successes of Radiant Heating on the Continent and in England so aroused the interests of certain engineers in the United States as to lead Professor Theodore Crane of the Yale School of Fine Arts to undertake in 1910 the design and installation of probably one of the first of this country's technically designed systems."[27] Another important radiant heated project in the U.S. was the British Embassy in Washington.[27]

It was during this time American architect Frank Lloyd Wright popularized the use of radiant heating. As Franklin before him, Wright was influenced by Asian architecture and radiant heating even before he made his first trip to Japan in 1905.

It is interesting that I, an architect supposed to be concerned with the aesthetic sense of the building, should have invented the hung wall for the w.c. (easier to clean under),

c. 1939 first small scale polyethylene plant built in America.

c. 1945 American developer William Levitt builds large scale developments for returning G.I.s (see photo above). Water based (copper pipe) radiant heating used throughout thousands of homes.

c. 1950, Korean War wipes out wood supplies for ondol; population forced to use coal. Developer Joseph Eichler in California begins the construction of thousands of radiant heated homes.

c. 1951 Dr. J. Bjorksten of Bjorksten Research Laboratories announces first results of what is believed to be the first instance of testing three types of plastic tubing for radiant floor heating in America.

c. 1965, Thomas Engel patents method for stabilizing polyethylene by cross linking molecules using peroxide (PEX-A) and in 1967 sells license options to a number of companies.

and adopted many other innovations like the glass door, steel furniture, air-conditioning and radiant or 'gravity heat.' Nearly every technological innovation used today was suggested in the Larkin Building in 1904.[28]

Wright was a pioneer in radiant floor heating, using it in many of his projects such as the Johnson Wax Building (1937) and the Jacobs Residence.

Following the end of World War II, the U.S. had its first large-scale multi-building project heated with radiant systems realized with copper pipes embedded in a concrete slab in historic Levittown.[29] In all there was to be 2,000 homes built in the New York project with radiant heating using copper pipe. Thousands more were built, including those later constructed by California developer Joseph Eichler.[18]

In Canada, the use of radiant heating found application in the early 1960s home of an NRC researcher who writes, "Decades later it would be identified as a passive solar house. It incorporated innovative features such as the radiant heating system supplied with hot water from an automatically stoked anthracite furnace."[30]

Photo credit: Jerome Puma private collection

Larkin Administration Building, Buffalo, N.Y. Designed by Frank Lloyd Wright, it was one of the first to use radiant floor heating.

Market Acceptance

As noted in Part I, almost all buildings in Korea (95%) and Northern China (85%) use radiant floor heating[31] with strong growth showing in Japan. In Europe, fluid-based systems dominate the construction industry.[32] Unlike Asia and Europe, the combined general market share for residential hydronic/steam systems in Canada and the United States is a nominal 5% with the volume closely following on the rise and fall of building permits. The exception is when home owners become directly involved in the HVAC decision-making process resulting in a 10% to 12% use. Approximation based on hydronic data available from Stats Canada and U.S. Census Bureau. It is also reported that since 2005, the number of commercial radiant system specifications has increased by 36% with 7.5% of new construction specifying radiant systems, a number expected to double by 2013.[33]

Image credit: Dan Holohan

1950s controls for radiant systems.

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c. 1970 evolution of Korean architecture leads to multistory housings. Flue gases from coal based ondol results in many deaths leading to the removal of the home based flue gas system to a central water-based heating plant. Oxygen permeation becomes corrosion issue in Europe.

c. 1980 The first standards for floor heating are developed in Europe. Water-based ondol system is applied to almost all residential buildings in Korea.

c. 1985 floor heating becomes a traditional heating system in residential buildings in Middle Europe and Nordic countries, and applications in non-residential buildings increase.

c. 1995 The application of floor cooling and TABS (Thermo Active Building Systems) in residential and commercial buildings are widely introduced into the market.

c. 2000 The use of embedded radiant cooling systems in Middle Europe becomes a standard system with many parts of the world applying radiant based HVAC systems as means of using low temperatures for heating and high temperatures for cooling.

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