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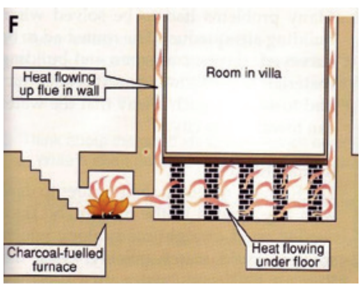
MARK THROWER MANAGING EDITOR

Underfloor heating comes of age

By Patrick Waterfield, principal environmental engineer at JCP Consulting Ltd

The Romans (and before them the Ancient Greeks) realised the benefit of underfloor heating via the hypocaust system - the term is derived from Greek words literally meaning "under-burning". A fire was lit at underfloor level and the heat drawn through a sub-floor void under action of flues in the walls (which also allowed the relevant wall areas to act as heat emitters).



Source: http://mcauleyhistory.edublogs.org/2012/10/24/the-roman-villa-project/hypocaust/

Slightly earlier (ca 1,000BC) were the traditional Korean "Ondol" (warm stone) dwellings, which also featured a form of underfloor heating. The Ondol used smoke from the cooking fire, i.e. heat that would have been generated anyway, making better use of the fuel. Indeed, there is evidence of similar features in excavated Neolithic settlements.

Heating elements or cables

An underfloor heating (UFH) system essentially comprises heating elements - either PVC piping carrying warm water ("wet" system), or electric heating cables - located beneath the floor surface. In the case of wet systems, the pipes are usually laid in a sand/cement "dry" screed or self-levelling liquid screed on top of insulation on a concrete floor slab, though they can also be laid in a dry screed on a suspended timber floor. The screed absorbs heat from the piping and conducts it to the floor covering where it is radiated into the room. Electric types are found in the form of cable arrays and mats which can be laid in a thin screed or tiling adhesive layer or direct under a wood floor, for example.

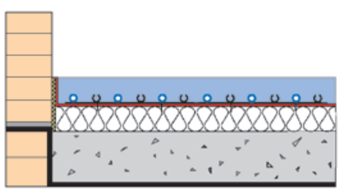
Underfloor heating – a brief timeline

Neolithic period	Evidence of stone-covered trenches in dwellings in Asia and Aleutian Islands
5,000 BC	Evidence of "baked floors" found in Korea and Manchu;
3,000 BC	Korean fire hearth used as both kitchen range and heating stove;
1,000 BC	Ondol-type system used in the Aleutian Islands and present-day North Korea;
500 BC	Greeks and Romans scale up the use of conditioned floors (and walls) with hypocausts;
500 AD	Asia continues to use conditioned surfaces but replaced in Europe by the open fire and early forms of the modern fireplace;
700	Countries in the Mediterranean Basin use various forms of hypocaust-type heating in public baths and homes (and also use heat from cooking to heat the floors);
1000	Ondol continues to evolve in Asia, with the fire furnace moved outside and the room entirely floored with Ondol in Korea;
1400	Hypocaust-type systems used to heat Turkish Baths of the Ottoman Empire;
1500	Wide-scale adoption of floor heating in China and Korea;
1600	Heated flues in floors and walls used in greenhouses in France;
1700	Hypocaust type system used to heat public baths in modern day Iraq;
1800	Beginnings of the European evolution of the modern water heater/boiler and water-based piping systems (eg in John Soane house and museum, London);
1864	Ondol-type system used at Civil War hospital sites in America;
1904	Liverpool Cathedral heated with system based on the hypocaust principles (also installed in various UK churches in Victorian times);
1937	Frank Lloyd Wright designs the floor-based radiant-heated Herbert Jacobs house;
1980	The first standards for floor heating are developed in Europe. Water-based Ondol system is applied to almost all residential buildings in Korea;
1985	Floor heating becomes a traditional heating system in residential buildings in Middle Europe and Nordic countries and increasing applications in non-residential buildings;
2010	71-storey radiant conditioned Pearl River Tower in Guangzhou, China;

System	Description	Pros	Cons
UFH	Heat emitter is the whole floor. Heat transmitted from floor surface by radiation	• Even heat distribution	• Very slow response
		• Floor warm to touch	• Difficult to retrofit
		• Aesthetics/room layout	• Higher capital cost?
		• Low flow temperature	• Higher running cost?
		• Less dust gathering	• Floor covering options
Radiators	Heat emitters placed against walls – most radiators are actually 2/3 convectors and only 1/3 radiators	• Low capital cost	• Possible conflicts with curtains/windows
		• Readily retrofitted	• Possible conflicts with furniture layout
		• Easily maintained	• Heat "lost" to wall
		• Fairly fast response	
		• Easy to control	
Warm-air	Convective system requiring ducts/grilles for supply (and return) air – can include heat recovery	• Very fast response	• Need for ducting routes
		• Can ventilate too	• Potential comfort issues re dryness/airspeed
		• Heat recovery options	• Difficult to retrofit
		• Easy to control	• Need to replace filters
		• Fairly easily maintained	

Summary comparison of UFH with radiators and warm-air systems

Wet systems are connected to an appliance which heats water (e.g.boiler, heat pump, etc.) while electric systems are fed from an electricity supply. It is the heat emitter part, the piping/cables and the floor, that we shall focus on here.



Section of wet UFH heating array showing (from top down); piping in screed, protection layer, insulation, concrete slab and DPM (note also edge insulation) – source: Nu-Heat.co.uk

Screeds should be laid as soon as possible after the UFH piping is in place to avoid potential damage to the piping. The system must be pressure-tested first and the pressure maintained while the screed is laid to reduce the risk of distortion of the piping.

"Dry" screed must be well mixed and compacted (to minimise voids which reduce the efficiency of the UFH as well as the structural integrity of the screed) and well levelled off. Typical thicknesses range from around 65mm to 100mm. Curing time varies with conditions of temperature and humidity but it can be at least a month before the UFH can be used. On first use the UFH must be run at a low setting and brought up to full temperature slowly. This helps to complete the curing and avoid cracking of the screed.

Liquid self-levelling screeds do what the name suggests and are liquids that are poured onto the subfloor insulation (which must be topped with a vapour barrier) before spreading out to a level finish. Self-levelling screeds are quick and easy to use and minimise the risk of voids. Liquid screeds can be laid thinner than dry screeds (around 50mm as opposed to minimum 65mm) but can actually take even longer to cure. The same advice applies as with dry screeds regarding first use of the UFH.

UFH overlays are a time-saving option and comprise thin boards (around 15-25mm) pre-routed for the pipework. The overlays are laid direct onto the insulated floor and are glued together, with the big advantage that no curing time is required. Another advantage is faster response time in use, due to the reduced thermal mass, though heat output will also be lower. Note that some lighter-weight systems, such as those involving polystyrene panels, may not be suitable for tiling over.

Electric UFH systems are especially suited to situations where a minimal increase in finished floor level is required, for example in retro-fits. Larger systems use cable which is manually laid in place and clipped down at regular intervals, while smaller systems can use UFH mats, where a thinner cable is bonded to a mesh. Mat systems are easy to install (even for the DIY enthusiast) and different products are available for use in wet rooms as well as with a variety of floor coverings. Note that different types of mat, with different maximum output (wattage) per square metre, exist for different types of floor covering (laminate, vinyl, tiles, etc). Therefore, it is important to make sure that electric UFH is an appropriate choice, given the proposed floor covering and level of heat required from the system. When laying mats, take care to avoid areas where kitchen units etc will be installed and leave at least 150mm gap to skirting. Installation costs tend to be lower than for wet systems but running costs will usually be higher.

On-site generated electricity

Electric UFH systems might also be considered where there is a plentiful supply of on-site generated electricity (e.g. from solar PV or wind turbine) and/or where there is no suitable hot water generation (e.g. no central boiler or heat pump, such as you might encounter in a super-insulated dwelling). Naturally, with PV, the peak output from the system will occur at the times you least need heating, though a better match of supply and demand should occur with a wind turbine.

Radiators and warm-air heating systems tend to be controlled on room or zone thermostats. These sense the air temperature and, when it reaches a setpoint temperature, switch the system off until the temperature drops again to below the setpoint. Room thermostats tend to be located at around chest height, as this represents an average height between people seated and standing and also makes for easy viewing and adjustment.

Warm-air systems supply tempered air direct into the room and are thus quick response systems, heating the internal air directly. Most of the heat output from radiators is actually provided by convection rather than radiation, although the response time is a little longer than for warm-air systems. A correctly positioned thermostat sensing room temperature can thus provide good control for radiators and warm-air heating systems.

With UFH systems, however, heat builds up in the floor before it enters the room and will still be leaving the floor for some time after the room air reaches comfort temperature, resulting in a temperature lag. A thermostat sensing air temperature and located at around chest height will thus exaggerate this lag.

Although not often seen, especially in wet systems, a floor-based temperature sensor would reduce the lag, improving the response time of the system. More importantly perhaps, sensing floor temperature may avoid the floor surface reaching high temperatures at which damage might be incurred to floor coverings.

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Electric mat systems tend to include thermostats which are located under the floor.

Zone control is achieved for wet systems by assigning a separate piping manifold to each zone (usually each room) and for electric systems simply by having a separate electric circuit for each room.

In general, a UFH system will perform best in a very well insulated building, as this will allow heat to be trickled in at a slow rate and low temperature. High rates of building heat loss combined with variations in heat requirement, for example caused by intermittent occupancy and/or significant solar heating gains, will be less compatible with the slow response time of a floor-based heating system.

Various systems are available to facilitate installing wet UFH in existing buildings. These include lower-profile wet systems, with and without screed (using UFH overlay products - see above). Generally, retrofitting wet systems will only be considered as part of significant refurbishment as it involves removal and replacement of floors. UFH wet systems can also be installed with suspended timber flooring, with the pipes laid between the joists on top of a layer of insulation. Installing UFH onto existing concrete floors may result in a significant increase in finished floor level, necessitating undercutting of skirting and doors.

Electric UFH systems (see above) are especially suited to situations where a minimal increase in finished floor level is required or minimal level of disruption generally. Mat systems are easy to install (even for the DIY-er) and different products are available for use in wet rooms as well as with a variety of floor coverings. Installation costs tend to be lower than for wet systems but running costs will usually be higher.

With underfloor heating you must always ensure good levels of insulation below the UFH array, ie, below the screed in which the heating pipes are laid in a wet system or, for an electric system, below the electric cable or mat. This will reduce downward heat loss, directing heat upwards into the room where it is wanted. Rigid insulation boards are used which support the floor covering and UFH system itself. Higher levels of insulation in the floor (and elsewhere in the fabric) will reduce the overall heating requirement of the occupied space thus reducing the size of, and demand upon, the UFH system. Note however that, especially in a retrofit situation, problems may arise from increasing the height of the finished floor level.

As your heat source is under the floor, the choice of floor covering will greatly affect the performance of the system. If the thermal resistance of the floor covering is too high then heat will simply not be able to penetrate it and enter the room. Carpets are therefore discouraged – except perhaps for carpet tiles bonded direct to the screed as found in various commercial situations. Lino and vinyl tiles and rubber flooring similarly can be used, as they will not restrict the flow of heat from the screed too much. Thick carpets with underlay should definitely not be considered as they will introduce far too much thermal resistance. The industry advice is for a carpet with a maximum TOG rating of 2.5. The TOG rating (1 TOG = 0.1m2K/W) represents thermal resistance and is commonly seen on duvets to indicate their effectiveness in keeping heat in. Following the industry advice, therefore, you could still end up with a carpet having over half the insulating effect of a summer duvet (TOG rating about 4.5)!

The ideal floor covering would be a ceramic or stone tile laid on a continuous bed of flexible adhesive direct onto the screed. This will ensure optimum conduction of heat from the screed to the top surface of the floor and thence into the room (gaps in the adhesive result in air pockets which have an insulating effect). Some advocate the use of a decoupling membrane to prevent any cracks in the screed from being transmitted to the tiles. The membrane itself will have a small insulating effect though will be thin and should not affect thermal transmission significantly.

A solid timber floor, again laid direct onto the screed with flexible adhesive, would be ok –timber has a higher thermal resistance than ceramic tiles but lower than carpet – provided that it can cope with the temperature (and especially the temperature changes) of the underfloor heating. Kiln-dried timber is likely to be less prone to shrinkage and cupping or crowning. A self-levelling compound can be used to provide a flat surface for optimum thermal connection between the screed and the floor covering. Ideally the UFH would be left running at a low temperature during the heating season to avoid cycling of heat in the timber.

Effective insulation

Laminate floorings, including those with a solid timber veneer and plywood base are not ideal thermally, as the plywood increases thermal resistance and, more significantly, foam under-lays tend to be used which will effectively insulate off the heat from the room. However, they will be inherently more resistant to movement resulting from heating up and cooling down cycles. Of course if you favour a polished screed floor finish then you will avoid any further thermal resistance. A hard surface will also maximise another benefit of UFH systems which is of particular interest to sufferers of respiratory conditions – namely less dust gathering.

A few years ago, I was called as an expert witness to adjudicate on a dispute between three parties - a home owner, an underfloor heating company and a wooden floor company. A solid-walled Victorian house had been renovated, including replacement of suspended timber ground floors with concrete floor slabs and screed containing underfloor heating pipes (wet system). The floor company had laid their product on top of the concrete screed using oriented strand board (OSB) as an intermediate layer so that they could "secret nail" through the tongues of the planks. Unfortunately, the thermal resistance of the OSB was preventing heat from the floor slab from entering the rooms. The UFH installer had tried increasing the flow temperature to compensate but this was not effective. In the "small print" in the UFH manufacturer's literature it was stated that a floor covering resistance of 0.1 m2K/W (1 TOG) had been assumed in sizing calculations, with a maximum recommended value of 1.5 TOG. However, this information was not communicated to the wooden floor company, which also did not think (or know) to check. The floor company agreed to lift the floor and remove the OSB and re-lay the floor using glued T+G joints instead of secret nailing. However, the existing period panel doors and profiled skirting had been undercut to accommodate the additional thickness of the OSB and would now be short of the finished floor level. Sourcing replacement doors and skirting would be expensive and disruptive and could so easily have been avoided.

It seems to be a widely held view that underfloor heating is more expensive to install but possibly cheaper to run than a radiator system. In my opinion the former should not be true, though is possibly a consequence of the work being carried out mainly by specialist companies, while the latter depends entirely on the building and how you operate the system. In summary, underfloor heating is best suited to a very well-insulated space which is not subject to rapid changes in heat gains or requirements. Heat can then be trickled in gently and continuously during the heating season, controlled via a floor-based thermostat. Floor surfaces should be hard (e.g. solid timber or masonry/ceramic) and well connected thermally to the piping/cabling array. In this context, UFH should provide good levels of comfort at reasonable running costs.

Further information

- The Underfloor Heating Manufacturers Association, 39 Ethelbert Road, Birchington, Kent, CT7 9PX
- underfloorheatingexpert.com/underfloor-heating-systems-history/
- www.warmup.co.uk/blog/what-is-the-best-flooring-for-underfloor-heating
- www.self-build.co.uk/choosing-screed-underfloor-heating
- www.thermo-floor.co.uk
- www.nu-heat.co.uk
- http://moss-design.com/radiant-floor/ http://mcauleyhistory.edublogs.org

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UNDERFLOOR HEATING

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. **In which part of the world is underfloor heating most used and established?**
   - ☐ USA
   - ☐ Scandinavia
   - ☐ Korea
   - ☐ UK

2. **Which of the following is NOT required to avoid damage to the screed in a "wet" system?**
   - ☐ Lay screed as soon as possible after underfloor heating pipes are in place
   - ☐ Run heated water through the pipes before laying the screed
   - ☐ Avoid running the system at too high a flow temperature
   - ☐ Bring the system up to working temperature slowly on first use

3. **Which type of floor covering is most suitable for use with underfloor heating?**
   - ☐ Solid wood floor
   - ☐ Engineered timber floor
   - ☐ Carpet tiles
   - ☐ Ceramic tiles

4. **Which of the following is an advantage of underfloor heating?**
   - ☐ Entire floor used as heat emitter
   - ☐ High thermal mass system
   - ☐ Less expensive to run than other systems
   - ☐ Free choice of floor coverings

5. **Which of the following is NOT an advantage of underfloor heating?**
   - ☐ Cheaper to install than other systems
   - ☐ Entire floor used as heat emitter
   - ☐ Even thermal gradient from floor to ceiling
   - ☐ Low flow temperature

6. **Which of the following is NOT an advantage of electric underfloor heating?**
   - ☐ Cheaper to install than other UFH systems
   - ☐ Cheaper to run than other UFH systems
   - ☐ Even thermal gradient from floor to ceiling
   - ☐ Can be DIY-installed

7. **Which of the following is true of underfloor heating?**
   - ☐ Insulation is not needed below the array as heat rises
   - ☐ Underfloor heating is not compatible with a very well-insulated house
   - ☐ Underfloor systems are best run continuously at a low rate
   - ☐ Underfloor heating should only be used on the ground floor

8. **The best type of wooden floor for a wet UFH system is;**
   - ☐ Engineered timber with underlay on screed
   - ☐ Solid timber bonded direct to screed
   - ☐ Solid timber secret-nailed to OSB on screed (facilitates future removal of floor)
   - ☐ Suspended timber floor with floor boards

9. **Which of the following is NOT true of UFH under-lays?**
   - ☐ Systems using under-lays are quicker to install
   - ☐ They have a quicker response time due to lower thermal mass
   - ☐ They have a higher rate of heat output
   - ☐ They are suitable for use in retrofit situations

10. **Which of the following is true of electric UFH systems?**
    - ☐ They are not compatible with bathrooms
    - ☐ Mat systems are suitable for use with any type of floor covering
    - ☐ They can allow a minimal increase in finished floor level
    - ☐ They need a mains electricity supply

Please complete your details below in block capitals

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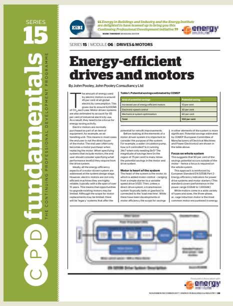

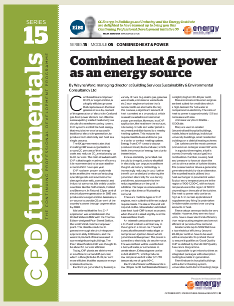

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