Fundamental

SERIES 9 MODULE 03

CURRENT THINKING ON...

Underfloor Heating

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Underfloor heating systems have been in use for millennia in one form or another, most notably in early British history by Roman hypocausts – wood fires producing warm air and smoke that was passed beneath ground floors of buildings to warm them.

Domestic energy use accounts for 28.5 per cent1 of total UK energy use and space heating makes up an estimated 60 per cent2 of this. Therefore, domestic space heating alone accounts for of the order of 17 per cent of the UK's energy consumption. Heating energy use in all building types combined is a considerably greater percentage.

As space heating represents such a significant proportion of energy use in the UK, UFH has an important role to play in reducing total primary energy use, costs and carbon emissions. Average indoor temperatures rose by an estimated 2˚C between 1990 and 2004, helped partly by the installation of central heating systems. UFH systems are helping to mitigate this trend, providing greater comfort at lower room temperatures than conventional, convective heating systems. UFH achieves this by raising the mean radiant temperature of surfaces in a room. This in turn reduces the net radiant heat loss from people. Typically over 50 per cent of sensible heat loss from people in office and domestic environments is by net radiant heat loss to their surroundings3. Hence, the impact of UFH upon people's heat loss and therefore their sensation of comfort is significant. This effect is, however, significantly reduced in spaces where there are competing, cold surfaces, such as single-glazed windows and poorly insulated walls and roofs. Buildings with poor levels

of insulation are usually unsuitable for the application of UFH, as in order to overcome the high heat loss from the building fabric, the floor temperature would have to be high. UFH suppliers typically advise that the floor temperature should be maintained below 27-29˚C. Above this people can become uncomfortable and selected flooring materials, such as solid wood and engineered floorboards can become excessively dry, resulting in cracks and other damage. This limit to floor temperatures limits their heat output and renders UFH unsuitable for spaces with high radiant heat loss.

The heat output (Q) of a radiant emitter can be determined by the equation: $Q = B \times C \times A \times T^4$, where B is the surface emissivity, C is the Stefan Boltzmann's constant, A is the area of the heated floor and T is its temperature in degrees Kelvin. The formula shows that the heat output of an UFH system is proportional to the fourth power of its temperature. Hence its heat output remains significant at a relatively modest temperature differential to its surroundings.

The effect of low mean surface temperature upon thermal comfort can be applied positively to reduce summer overheating. Radiant cooling can be achieved by low temperature surfaces such as, ceiling and wall panels, floor cooling, cooling of the building structure, or other radiant cooling solutions. The effect is the converse of that achieved by UFH, i.e., radiant cooling systems reduce the average surface temperature in a room, thereby increasing the net heat loss from its occupants. The effect of radiant cooling is to achieve a sensation of thermal comfort at higher space temperatures than is achievable by conventional, convective cooling systems, such as fan coil units and ducted air supply systems. Active radiant cooling is typically provided by either wall or ceiling-mounted panels or underfloor cooling. Underfloor cooling is effective at mitigating the overheating potential of solar radiation incident upon internal surfaces – and floors in particular.

Radiant cooling panels

Ceiling-mounted radiant cooling panels have typically less line of sight obstruction than underfloor cooling systems, increasing their perceived cooling effect. For both systems an important limitation in their application is the risk of the development of conditions favourable to the production of condensation on the chilled surface. If the radiant cooling surface falls below the dew point of the space for a sustained period of time, condensation will form. The dew point of a room at 26˚C and relative humidity of 60-70 per cent could be as high as 20˚C. Clearly there is significant risk of the formation of condensation in UK space temperatures and weather conditions. This risk can be well managed through close control of chilled water flow temperatures, radiant surface temperatures and through the use of dehumidification equipment in the higher risk areas.

Underfloor heating falls primarily into three categories: wam air systems based upon the distribution of warm air in subfloor trenches (such as the Roman hypocaust); wet systems, based upon the circulation of water through pipework under floors (hydronic) and electrical systems, deriving their heat from electric heating elements located under floors. This article focuses upon hydronic systems.

UFH systems warm the floor

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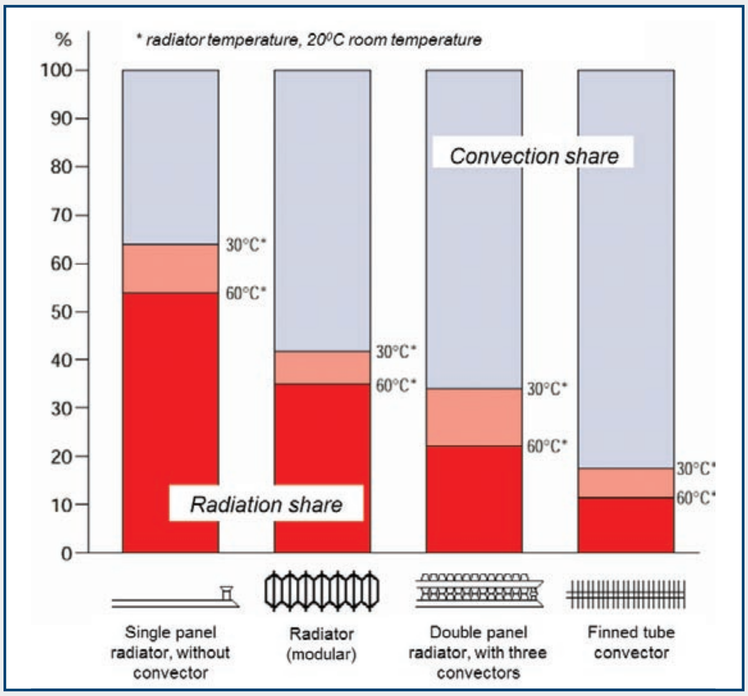
structure by conduction, causing the surface to radiate heat into the space. The primary source of heat in a wet UFH system is typically a boiler, although there are many other options, such as ground source heat pumps. The water temperature flowing to UFH manifolds is typically in the range of 40˚C to 50˚C. Water is distributed in plastic or plastic/metal composite pipes to manifolds. Each manifold typically comprises:

- flow and return headers;
- a thermostatic or motorised valve controlling the flow of water from the boiler to the manifold;
- a pump circulating water from the return manifold mixed with water from the boiler flow into a flow header; and
- multiple pipe loops taken from the flow header to serve the building, returning to the return header.

Each loop is a continuous pipe, leaving the flow header and returning to the return header with no breaks or fittings, minimising future maintenance problems such as leaking joints, or air ingress. Domestic and commercial systems' manifolds would typically have up to ten loops of 16mm nominal bore, or micro bore pipes, each with a maximum length of 100m. Industrial and large open plan buildings could have considerably longer loops and larger bore pipes. Each loop will have a flow regulator to enable the water flow rate through it to be manually adjusted, allowing them to be balanced on commissioning.

Motorised solenoid

The majority of manufacturers' systems also include a motorised solenoid, or otherwise automated 2-port valve on each loop that can be closed off in response to a temperature or time related command. For small systems with areas of similar occupancy patterns and heat loads, a single thermostat or temperature sensor and time programme may be provided for each manifold. However, where there is variation between areas served, a temperature sensor may be advisable for each room. For larger rooms served by multiple loops a single temperature sensor should be installed to control all of its loops. It



Source: Energy Institute, European Energy Manager Course (EUREM), Space Heating Module

is not uncommon for each room in a building heated by an UFH system to have dedicated, automated time and temperature controls. This is more practicable to achieve than with radiator heating systems due to the use of manifolds which allow actuators and controls to be grouped together, reducing cable runs – particularly if wireless temperature sensors are used.

As successive loops close the heating water flow rate required at the manifold reduces. However, fixed speed pumps are typically used in UFH manifolds and consequently, the flow rate in loops that remain open will increase as others shut off. Both pump electricity use and space temperature control can be improved by using variable speed pumps. Whilst the energy savings may not fund the cost of installing variable speed controls for manifold pumps at the domestic and small commercial scale of UFH systems, they may be sufficient for manifolds supplying large areas, or for UFH heating pumps supplying multiple manifolds. The common application of 2-port motorised valves on UFH systems, as opposed to the typical 3-port approach taken with radiator heating systems and air handling unit heater batteries lends them well to the application of variable speed drives. For a heating pump supplying multiple manifolds, pump speed can be varied either based upon the pump differential pressure and using an integral speed control characteristic designated by the pump manufacturer; or based upon maintenance of constant pressure at system extremities, using remote differential pressure sensors[4]. The use of remote differential pressure sensors will give closer flow control and lead to greater energy savings. However, multiple sensors may be required and the system can become both complex and expensive. The reduction in power consumption of a pump is proportional to the cube of the reduction in its speed. Thus if a pump's speed is reduced to 25 per cent of its rated value, its power is reduced to (25 per cent)^3, i.e. 1.6 per cent of full load power, leading to energy cost savings for systems with pump motors of over 5 kW with extensive hours of variable flow operation.

Getting good conduction between UFH loops and the floor structure is essential. The floor structure must either be conductive, or conductive elements must be in contact with it and the UFH pipe loops. Different methods of transferring heat from the pipes to the floor are applied for different floor structures. For solid floor construction, UFH pipes are usually fixed to the floor insulation and a concrete screed is laid over them. Floor tiles, carpets, or other finishes are then laid over the screed. Where floor tiles are used average heat output is 100W/m^2. Carpets reduce the rate of heat transfer and a higher UFH flow temperature would be required to achieve an output of 100 W/m^2 than would be required for ceramic tiles.

A number of UFH system suppliers recommend the inclusion of a sand/cement mix below suspended timber flooring, particularly at ground floor level to boost heat output. UFH loops are fixed to an insulant or other sub-flooring material and a sand/cement dry mix is laid over them. Floorboards or other floor finishes can then be laid over the joists in the normal manner. Ideally engineered flooring is used in preference to solid wood to reduce damage caused by expansion and compression caused by warming and moisture loss from solid wood products.

Aluminium emission plates

As an alternative to a sand/cement mix for suspended timber floors, grooved aluminium emission plates, or bespoke insulation panels with a high emissivity surface may be used to span the joists. The UFH loops are pushed into the grooves in the emission plates or insulation panels and floorboards laid over them. Where there is a gap between the UFH loops and the floorboards it is essential that it is tightly sealed, allowing no air movement. The design heat output achievable with suspended timber floors at 70W/m^2 averaged across the floor is 30 per cent lower than for screed floors. The additional weight of pipework, heat transfer plates, insulation and sand/cement mix must all be taken into account when sizing floor joists to ensure that they are of appropriate cross section for the weight and span.

UFH systems have large heat emission areas compared to radiators, allowing the heat load to be met by a much lower heat emitter surface temperature. The design surface temperature of a radiator on a conventional radiator heating system would typically be 77˚C[5]. By contrast, the design surface temperature of the floor on an UFH system should be below 29˚C[5]. This difference leads to less convective heat transfer from UFH systems compared to radiators and greater radiation. Radiation accounts for only 30 per cent of heat transfer from a modular radiator operating at a mean water temperature of 77˚C compared to over 60 per cent from UFH, or a panel radiator without convector fins operating at 30˚C.

Air movement

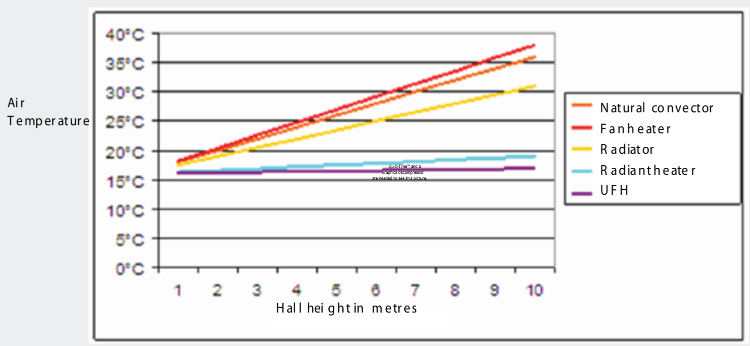
The transfer of heat by convection from radiators, natural and fan convector heaters leads to air movement both in the vicinity of the heat emitter and in other parts of the heated space. In rooms with large windows or other cold spots, air volume flow rates are greater, as warm, buoyant air rises from the heat emitter, is cooled by the cold spots, becoming denser, dropping back to the floor and returning to the heat emitter to complete the circuit. Conventions in radiator heating system design mitigate this effect by avoiding placing radiators opposite windows or other cold spots. Even with such measures in place, heating systems that rely upon convection for transfer of heat into the space subject occupants to air movement that they perceive as draught. CIBSE recommends an internal design temperature of 21˚C for radiator systems in most areas, but only 20˚C for UFH systems[5]. This 1˚C reduction in space temperature would save an estimated 8 per cent in space heating energy use[6].

The surface temperature of radiators can be reduced and indeed in many applications, such as hospitals and care homes it is recommended as a safety measure to avoid the risk of scalding. The fitting of guards to existing radiators will reduce the surface temperature exposed to the room. However, it would also reduce the heat output of the radiator by an estimated 60 per cent, leading to a requirement for more, or larger radiators. The preferred method of reducing radiator surface temperatures is to install low surface temperature radiators, with a design surface temperature of 43˚C. However, these tend to increase convective heat transfer rather than to reduce it[7].

Convective systems cause warm air to rise to the top of the heated space where it increases heat loss by conduction through the ceiling or roof and offers no benefit to the people in the building. Conversely, colder, denser air drops to floor level. In standard sized rooms, the effect can generally be ignored in terms of system design. However, as the room height increases, heat loss increases. The increase in heat loss for a ceiling height of 4.5m is estimated at 2.5 per cent, rising by a further 2.5 per cent for every 1m increase in ceiling height up to an additional 10 per cent heat loss for a ceiling height of 7.5m[2]. For UFH systems these factors can be ignored as there is little stratification with this system type. The converse is more likely, with temperature inversion occurring: the air at head height being at approximately 20˚C and that at floor level reaching 24˚C. Having the feet slightly warmer than the head is considered to provide optimum comfort[8].

UFH systems operate at low return water temperatures and radiant cooling systems run at high chilled water temperatures, promoting good boiler combustion performance and chiller seasonal energy efficiency rating (SEER) respectively. Typically UFH flow temperatures are 40-50˚C with a 10˚C drop, ensuring that the return temperature is consistently below the dew point of either natural gas (57˚C) or fuel oil (47˚C), theoretically enabling heating-only systems to operate in condensing mode continuously. However, the boiler manufacturers' instructions may preclude operating condensing boilers below the dew point temperature for extended periods, particularly for oil-fired boilers, as the condensate can have a pH value as low as 2, approaching the acidity of battery acid. Furthermore, where domestic hot water is also provided by the boiler, either by a cylinder or thermal store, a higher boiler flow temperature will be required, reducing the incidence of heat recovery from flue gases by condensation. For carefully designed and operated systems, the seasonal efficiency of a gas-fired condensing boiler serving a UFH system could be expected to average 90 per cent compared to 87 per cent for a condensing boiler serving a heating system with standard sized radiators and weather compensation control to depress heating water flow temperatures in mild weather[9].

Radiant cooling systems can operate at considerably higher chilled water temperatures than conventional cooling systems that use air as a cooling distribution medium. A ducted comfort cooling system will typically operate with a chilled water flow temperature of approximately 6-9˚C, whereas for radiant panels and underfloor cooling the chilled water temperature could be 12-16˚C, or higher depending upon the dew point of the space. However, in order to meet the cooling load at such high chilled water flow temperatures, radiant cooling systems tend to have considerably higher chilled water flow rates than conventional systems.



Source: Energy Institute, European Energy Manager Course (EUREM), Space Heating Module

The low mean water temperatures of UFH systems and high chilled water temperatures of radiant cooling systems also lend themselves well to the application of combined heat and power (CHP), absorption cooling and renewable sources of energy, such as ground source heat pumps (GSHP) and solar thermal collectors.

Low temperature CHP systems are typically designed to operate at conventional low temperature hot water temperature range of 82˚C flow, 72˚C return. However, this generally leads to heat from engine lubricating oil being rejected as the oil must typically be cooled to below 50˚C. UFH systems can take advantage of this low grade heat for space heating. Absorption chillers can be used to generate chilled water from CHP units and other sources of heat, including waste heat. The higher the chilled water flow temperature, the greater the efficiency of the absorption cooling system.

GSHPs that use energy stored in the ground as their primary source of heat have the greatest coefficient of performance when supplying water at below 40˚C for space heating and at above 12˚C for cooling applications - depending upon the heat pump characteristics. UFH systems can be designed to operate with flow temperatures below 40˚C, providing they are serving areas with low heat losses and there is sufficient, unobstructed floor area in which to install pipes. Radiant cooling systems can operate at chilled water temperatures considerably higher than 12˚C and hence are optimise the efficiency of GSHP installations.

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SERIES 9 MODULE 03: QUESTIONS

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.

1. What proportion of total domestic sector energy use is for space heating?

☐ 25% ☐ 28.5% ☐ 60% ☐ 40%

2. What is the average heat output of UFH systems in screeded floors?

☐ 70 W/m2 ☐ 80 W/m2 ☐ 100 W/m2 ☐ 0 W/m2

3. What is the typical water flow temperature of UFH systems?

☐ 40-50˚C ☐ 65-70˚C ☐ 25-35˚C ☐ 75˚C

4. What is the typical mean water temperature of a radiator heating system?

☐ 72˚C ☐ 82˚C ☐ 77˚C ☐ 40-50˚C

5. How much can the space temperature be depressed by in buildings heated by UFH systems compared to those heated by radiator heating systems to achieve a similar level of thermal comfort?

☐ 1˚C ☐ 2˚C ☐ 3˚C ☐ 4˚C

6. What is the difference in seasonal boiler efficiency achievable by condensing boilers supplying UFH systems compared to those supplying standard sized radiators with weather compensation?

☐ 10% ☐ 8% ☐ 5% ☐ 3%

7. How does radiant heat output of an emitter vary as the emissivity of its surface increases?

☐ Increases
☐ Decreases
☐ Variable
☐ No effect

8. What is the typical design floor surface temperature of an UFH system?

☐ 20˚C ☐ 29˚C ☐ 40-50˚C ☐ 82˚C

9. What physical parameter limits the minimum surface temperature advisable for radiant cooling systems?

☐ Stoichiometric
☐ Air density
☐ Dew point in room
☐ Dew point of oil

10. How is the seasonal energy efficiency rating (SEER) of a chiller or heat pump affected by chilled water flow temperature (TCHW) setpoint?

☐ N/A
☐ SEER<TCHW
☐ SEER>TCHW
☐ SEER decreases as TCHW increases