Underfloor Heating

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Nearly half the energy we consume in the UK is used to produce heat, representing the single biggest reason why we use energy in our society. Currently we meet around 2 per cent of this demand with heat from renewable sources 1 and 80 per cent of all heat in the UK is supplied by natural gas2. Optimising the use of gas and extending the application of renewable energy to space heating are key objectives that underfloor heating (UFH) is helping to achieve on the road to meeting the UK's emissions reduction targets.

Flexibility for the future

UFH is a well-established technology for space heating in new build projects and is particularly notable in schools and self-build domestic properties in the UK, where it has become de rigeur. By using the floor as a heat emitter, UFH frees up wall space that would otherwise be taken up by radiators, providing considerable flexibility for future modifications to room layouts and usage. It is already established as the most commonly occurring form of heating in Scandinavian homes and is popular in other parts of northern and central Europe, such as Germany. Its success is due in part to the perceived level of comfort. People typically feel comfortable at a room temperature one or two degrees lower with UFH than they would with conventional radiator heating and an internal design temperature of 21˚C is recommended for radiator systems in most areas, but only 20˚C for UFH systems3. This is due in part to the way UFH heats a space – using radiant rather than convective heat transfer and heating from the bottom of a room up. Having the

feet slightly warmer than the head is considered to provide optimum comfort4. The gentle heat and draught free environment, with even temperature distribution across each room and very little in the way of the temperature stratification between floor and ceiling, also contribute towards exceptional thermal comfort. The combination of lower room temperature, near absence of stratification and low heating water flow temperature enable high standards of energy efficiency to be achieved. For conventional radiator heating systems stratification is a significant issue and the increase in heat loss arising at a ceiling height of 4.5m is estimated at 2.5 per cent, increasing to 10 per cent for a ceiling height of 7.5m5. For UFH systems these factors can be ignored as there is little stratification.

Warmth by conduction

Wet UFH systems are based on the circulation of hot water through pipework under floors. The UFH pipework warms the floor structure by conduction, causing the surface to radiate heat into the room above it. The primary heat source in a wet UFH system is typically a boiler, although there are many other options. The boiler heats water, typically to a temperature of 40-50˚C, which is distributed in plastic or plastic/metal composite pipes to manifolds. Each manifold comprises a flow and a return header from which loops are taken to serve the building. At the smaller end of the scale, such as a two-storey office, the ground floor could be served by a single manifold and the first floor by an another. Small rooms are served by a single loop of up to 100m and larger rooms are typically served by multiple loops. 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.

The radiant heat output from a floor is dependent upon both the base materials and the floor finish. An ideal combination is to have the good conductivity and large thermal mass of a concrete floor screed to absorb heat from the UFH pipes and conduct it into stone, terracotta or ceramic floor tiles whose high emissivity will optimise the radiation of heat from the floor surface to the conditioned space. Where this combination is used, UFH heated floors can achieve an average output of 100 W/m2. Where floor finishes of lower emissivity are added to screed floors, the average heat output at a given floor temperature will drop below this optimum. For materials such as engineered timber flooring this reduction in emissivity can be compounded by an interruption of the heat flow from screed to floor by the fixing arrangements. Fixing battens to the screed and then fixing floorboards to the battens introduces an air gap between floor boards and screed, significantly reducing heat transfer into the floorboards, which are intended to be the radiant heat emitters. Furthermore, there is a risk

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MODULE 3 : UNDERFLOOR HEATING

of damaging UFH pipes when fixing the battens down with screws, or nailing the boards to them. Another option available for some types of engineered flooring is to fix the floorboards directly to screed using an adhesive. Whilst this will improve heat flow to the floor, it exacerbates the risk of flooring damage due to potential limitations of the adhesive to endure elevated floor temperatures. Furthermore, there is likely to be a specification by the flooring manufacturer for the temperature to which the timber flooring is exposed to be limited, or for the heat output to be limited, e.g. to around 75 W/m2, reducing heat output to about a quarter below the optimum.

Applying UFH to flooring systems that have not been optimised to absorb heat from the pipe loops and radiate it into the building can lead to even lower heat output and ultimately to poor performance if key design principles of UFH systems are not applied.

Suspended timber floors

UFH systems can be used with suspended timber floors, however even with the appropriate materials and equipment to conduct heat from the UFH loops into the floor and radiate it into rooms above, the design heat output achievable is of the order of 70W/m2, which is a little lower than using them on screed floors and nearly a third lower than optimum for UFH. If good conduction is not achieved between the UFH pipes and the suspended timber floor, the heat output could be considerably less than this, presenting a risk of under-heating. Thus achieving good conduction between UFH loops and the floor structure is essential. One option for suspended timber floors is the inclusion of a sand / cement mix, particularly at ground floor level to improve heat transfer. UFH loops are fixed to insulation on boards between joists and below the finished floor level. A sand / cement dry mix is then laid over the pipe loops, embedding them in a pug of good thermal conductivity and high thermal mass. Floorboards or other floor finishes can then be laid over the joists in the normal manner. Alternatively, grooved emission plates, or insulation panels with a high emissivity surface may be used to span the joists. The UFH loops are pushed into the grooves and floorboards laid over them. These arrangements are not as robust as the screed options on solid concrete floors, leading to a lower rate of heat transfer from UFH pipes into the floor. This is then compounded by materials of lower surface emissivity typically being used on suspended floors than on solid ground floors. These lower surface emissivities introduce resistances to radiant heat transfer and when used in combination with insulating materials such as carpets, floor temperatures may need to be raised to meet peak heating demands. If this is not taken into account at the design stage, it can lead to localised problems with some types of floor finish becoming seasonally or permanently distorted or damaged due to over-heating.

UFH system designers take floor emissivity into account when sizing floor loops and the spacing between pipes to ensure that there is a sufficient length of UFH pipe in the floor to achieve the slightly elevated floor temperature required when carpets and other combinations of insulating materials and low emissivity surfaces are used. The greater length of pipe increases the surface area available for heat transfer from the heating water and the floor, allowing the UFH water flow temperature to be maintained at its characteristically low temperature, limiting the potential for localised overheating of flooring. However, one impact of increasing the length of pipe loops is that the spacing between pipes reduces, increasing the propensity for heat transfer between them. In some circumstances this can reduce the effectiveness of the UFH system. For example if there is excessive heat transfer between the flow and return ends of a loop, the flow of heat into the floor can be reduced. This problem can also occur if adjacent loops serving different zones become too close, causing the return water temperature of one to become elevated and the flow temperature of the other to dip, with the potential to cause short-circuiting at the manifold. However, these problems are easily avoided through careful design of UFH loop layout and application of a control philosophy appropriate to the scale and complexity of UFH system.

Minimising UFH flow temperatures and maximising the surface area of pipe in contact with the flooring is ideal for the thermal efficiency of the UFH system. However, flow rates and pressure drops for each loop connected from the manifold to the floor must be calculated and a complication of increasing length of UFH pipe and the increasing number and tightness of bends associated with closer spacing is greater resistance to water flow. This in turn has an impact upon pump sizing and hence pump motors' electricity use. Ideally, the flow rates and pressure drops calculated will fall within the standard range associated with the pump options for the UFH supplier's manifold. However, if the pressure drops and flow rates exceed these limits, then further adjustment may be required to reduce resistance to flow, increase pumping power, or both. One option is to increase pipe diameters to reduce resistance to heat flow. A second is to split long loops into two or more and to use either manifolds with a greater number of ports or to increase the number of manifolds and associated pumps, pipework etc. with associated increases in supply and installation costs. The pressure drop through the UFH pipe not only depends upon these aspects of the hydraulics of the system, but also upon the type of UFH pipe that is used, as different internal pipe surface materials have different frictional properties.

Slow response times

UFH systems have slow response times compared to radiator heating systems. Consequently, they are not ideally suited to applications with intermittent occupancy or significant variation in local heat gains. They should be designed to operate with a setback of the space temperature set point of 3˚C outside of occupancy, for example reducing a daytime temperature set point of 20˚C to 17˚C at the end of occupancy. This ensures a reasonably short heat up period at the next occupancy start. In well insulated, air tight buildings this relatively small setback in space temperature should have only a modest penalty in energy use outside of occupancy. For older, poorly insulated or draughty properties, UFH can use more energy than radiator heating systems without necessarily achieving the design internal temperature.

Once an UFH system has been installed and the flooring finished, it is not unheard of for the uninitiated or unaware contractor to cut a hole through it when fixing partition walls, or other items to the floor. Whilst the immediate impact of this is system failure, it can be remedied by cutting out the damaged pipe and connecting in a new piece. This is likely to lead to a permanent increase in resistance to flow on the affected loop, which could cause a slower response, or in the worst case, under-heating. Damaging UFH after installation is a rare occurrence, as it is protected by the floor above it from incidental damage and with its increasing popularity in the UK, contractor awareness of it is ever-growing. As it is inaccessible for inspection and maintenance after installation, it is important that it is protected and tested at the installation stage. This is particularly important when the pipes are to be embedded in a screed or pug. The pipework must be pressurised and the pressure maintained for a period of about 24 hours both before and after the screed is laid over it.

The low water temperatures of UFH systems promotes good combustion performance from boilers. Typically 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, which is 57˚C or of heating oil, which is 47˚C. Thus UFH systems enable boilers to operate in condensing mode continuously and 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 weather5.

The low water flow temperatures means they are also well-suited to the application of combined heat and power (CHP), renewable sources of energy and ground source heat pumps (GSHP) in particular. Low-temperature CHP systems are typically designed to operate at conventional low temperature hot water temperature range of 82˚C flow, 71˚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. However, low grade heat like this is ideal for UFH systems. GSHPs that use solar energy stored in the ground as their primary source of heat have the greatest coefficient of performance when supplying water at below 50˚C. UFH systems can be designed to operate with flow temperatures below 50˚C, providing they are serving areas with low heat losses and there is sufficient, unobstructed floor area in which to install pipes. There is a risk in applying GSHPs to existing radiator heating systems as radiators are typically designed to provide their required heat output with a water flow temperature of 82˚C. On new systems larger radiators, or low surface temperature radiators can be used. However, this would tend to increase convective heat transfer over radiant heat transfer6 leading to greater temperature stratification and heat loss.

Ground source heat

GSHPs take their heat from solar energy stored in the ground. They use pipes buried under the ground either in trenches or boreholes to extract the available heat. Depending upon ground properties, installation and load characteristics, GSHCs can take so much heat from the ground that they cause it to freeze. This reduces heat transfer and hence both the efficiency and heat output of the GSHP. This is a difficult problem to overcome, particularly where the GSHP is extracting heat for heating and hot water throughout the year. Systems that provide cooling in summer can overcome, or mitigate this problem. Reversible heat pumps can operate in either heating or cooling modes. When in cooling mode a GSHP will provide cooling into a building and reject heat into the ground, which can reduce ground freezing. When in cooling mode, GSHPs have their highest COP when operating at relatively

high cooling water temperatures – approaching 12°C. This high chilled water temperature is a challenge for conventional chilled water cooling systems, such as fan coil units and air handling units, which tend to operate on chilled water temperatures of 6°C. However, underfloor cooling can be operated at temperatures compatible with GSHPs. There is a modest risk of condensation forming on the floor surface which must be mitigated by limiting humidity and maintaining the floor temperature above the dew point of the air in the conditioned space. This will tend to include maintaining a humidity of less than 50 per cent and a floor temperature above 19°C, although seasonal and site-specific variations must also be taken into account. This elevated floor temperature is compatible with GSHPs and the same pipe loops can be used for UFH in winter and cooling in summer.

The use of thermal stores, or other arrangement for storing and mixing hot water from multiple sources can further extend the application of UFH to a range of heat sources of differing temperatures. They can help to reduce the mismatch between the availability of renewable sources of heat, such as solar thermal and space heating demand, which may be primarily after sunset and before sunrise in the coldest months in a domestic setting. They are also an important part of biomass heating strategies. Biomass boilers are not as responsive to changes in space heating demand as gas-fired boilers and they have a smaller turn down ratio. Thermal stores help to reduce peaks and troughs in the heating load, improving efficiency of operation and enabling a smaller boiler to be selected than would be required without the thermal store, optimising the capital cost of the system.

The renewable heat incentive (RHI) was launched in November 2011 as a scheme designed to promote the application of renewable energy to space heating. It gives a long term financial benefit in the form of a payment per kWhth of heat generated and it could give a new boost to wet UFH systems. The payment provided by the scheme varies between the eligible technologies, which include ground source heat pumps (GSHP), solar thermal collectors and biomass boilers. Ground source heat pumps must achieve a coefficient of performance (COP) of at least 2.9 to be eligible for the RHI. There are strict requirements on the information and evidence to be supplied to prove that the COP meets the requirements. GSHPs work more efficiently and effectively at low heating water flow temperatures and hence combining them with UFH is a good way to show that the COP requirements will be met. Whilst their COP may be improved by operating in cooling mode over summer, the energy produced for cooling is not eligible for the RHI and the metering and monitoring systems must be capable of quantifying heat pump cooling output and associated electricity use to ensure that RHI is claimed for heating only.

So far the RHI has mainly been applied to biomass boilers. Ofgem reported on the performance of the renewable heat incentive scheme in October 2012, stating that take up of ground source heat pumps (GSHP) has been negligible. It is reviewing the level of payment that should be made for heat pumps to stimulate greater take up. It is likely that the tariff for large scale GSHP (over 100 kW) will double from 3.5 p/kWh to over 7 p/kWh. Air source heat pumps will be included in the scheme in the future, which would be likely to lead to a significant increase in take up of both the RHI and UFH.

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SERIES 11 MODULE 3: 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 percentage of the UK's energy consumption is used to produce heat?

☐ Nearly 2% ☐ Nearly 20% ☐ Nearly 21% ☐ Nearly 50% ☐ Nearly 80%

2. What percentage of heating energy use comes from renewable sources in the UK?

☐ Around 2% ☐ Around 20% ☐ Around 21% ☐ Around 50% ☐ Around 80%

3. What percentage of all heat in the UK is supplied by natural gas?

☐ 2% ☐ 20% ☐ 21% ☐ 50% ☐ 80%

4. What is the single biggest reason we use energy in the UK

☐ Heating ☐ Lighting ☐ Cooling ☐ Industry ☐ Transport

5. What is the recommended internal design temperature for radiator heating systems in most areas?

☐ 2˚C ☐ 20˚C ☐ 21˚C ☐ 50˚C ☐ 80˚C

6. What is the recommended internal design temperature for UFH systems in most areas?

☐ 2˚C ☐ 20˚C ☐ 21˚C ☐ 50˚C ☐ 80˚C

7. How does UFH contribute towards achieving optimum thermal comfort?

☐ By having the head slightly warmer than the feet
☐ By having the head slightly lower than the feet
☐ By having the feet slightly cooler than the head
☐ By having the feet slightly warmer than the head
☐ By having the feet slightly higher than the head

8. For conventional radiator heating systems, what is the percentage increase in heat loss arising from stratification at a ceiling height of 4.5m?

☐ Negligible ☐ 2.5% ☐ 5% ☐ 10% ☐ 20%

9. For conventional radiator heating systems, what is the percentage increase in heat loss arising from stratification at a ceiling height of 7.5m?

☐ Negligible ☐ 2.5% ☐ 5% ☐ 10% ☐ 20%

10. For UFH systems, what is the percentage increase in heat loss arising from stratification at a ceiling height of 4.5m?

☐ Negligible ☐ 2.5% ☐ 5% ☐ 10% ☐ 20%