Design of low-temperature domestic heating systems

A guide for system designers and installers

Bruce Young, Alan Shiret, John Hayton and Will Griffiths

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Front cover photographs:
Stelrad Compact K3 radiator (left)
Dimplex SmartRad® intelligent fan convector (top right)
Hep2O underfloor heating system by Wavin (bottom right)

Back cover photograph:
Hep2O underfloor heating system by Wavin

Page 1:
Photograph courtesy of Vokera

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Photograph courtesy of Wavin

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Executive summary

Low-temperature heating systems can improve energy efficiency and hence reduce fuel consumption and CO_2 emissions. There is growing interest in low-temperature hydronic central heating systems, ie those where water is used as the medium to distribute heat around the building and in which the water leaving the heat generator is limited to a lower temperature than in normal system design. This BRE Trust Report is aimed as a guide for those who wish to install low-temperature heating systems in dwellings, and concentrates on the calculations and other conditions necessary to ensure that low-temperature operation can be achieved.

It became apparent during the preparation of this guide that there is no generally well-established and understood design method for low-temperature domestic heating systems. Instead of simply gathering information on current practice, the authors found it necessary to engage in extensive debate about many of the technical parameters governing system sizing, configuration and selection of components. Some of these have not been fully resolved. In particular, leading designers should give more attention to:

- selection of a representative external temperature for heat loss calculations
- allowance for building exposure
- suitable heat loss calculators, conforming to stated rules
- refined intermittency factors, perhaps using the advanced method set out in BS EN 12831:2003
- evaluation of emitter responsiveness, especially for emitters with fans
- temperature-limiting controls, and modulation by reference to an upper temperature limit.

The last item (controls) is especially important, as it is the water temperature at the heat generator that is the principal determinant of efficiency when low-temperature heating system designs are contemplated. Further development of standard design and operating practices (especially for controls) for low-temperature heating systems will be necessary before such systems can be recognised as a mature option capable of providing energy savings in all cases.

1

The benefits and technical aspects of low-temperature heating

1.1 Introduction

There is growing interest in low-temperature hydronic central heating. This is taken to mean systems able to provide a full heating service while the mean temperature of the water in circulation is 50°C or lower. Interest is prompted by the development of high-output heat emitters (such as extended-surface and fan-assisted radiators) as well as perimeter and underfloor heating (UFH) emitters able to provide plentiful heat for well-insulated new homes with a low heat demand. The widespread adoption of condensing boilers capable of operating continuously at lower temperatures, and the recent focus on heat pumps, has raised interest further. Low-temperature operation raises the efficiency of both boilers and heat pumps. However, little has been done to help designers and installers (who are often designers too, for domestic systems) to produce such systems. This report has therefore been written to provide guidance to system designers and installers by demonstrating the effect of installation of such systems. It provides a design process and highlights the critical issues regarding implementation in practice, where an example design, installation and commissioning checklist is provided for assistance (Appendix A).

1.2 What is low-temperature heating?

In this guide a low-temperature heating system means one in which the hot water leaving the heat generator is always supplied at a lower temperature than that of a traditional central heating system, even on the 'design day' (ie a day with cold weather conditions chosen for calculating the maximum heat losses from the building). The definition does not include heating systems in which the water temperature is lower only some of the time, such as those with weather compensation or load compensation controls, nor does it include UFH in which a thermostatic mixing valve is used to blend water at a high temperature with cooler water before entering the UFH system floor*.

Low-temperature heating systems should not be confused with low-surface-temperature (LST) radiators, which are installed to protect vulnerable occupants. The conditions for low-temperature heating system operation are NOT achieved by selecting LST radiators. The need for LST radiators is reduced or eliminated in a low-temperature heating system, as high water temperatures should not occur.

Low-temperature heating requires a different system design, mainly to ensure that the heat emitters (radiators, fan-assisted radiators† or convectors, or UFH pipes) can deliver the same amount of heat at the lower temperature as a traditional system would have done at normal temperature. The emitters must be sized correctly to ensure they are capable of doing this. The design procedure explained here is limited to hydronic heating systems in dwellings of the UK. The key parameter governing low-temperature design is the mean water temperature (MWT), ie the average of the flow and return temperatures at the heat generator (a boiler, heat pump or micro combined heat and power (micro-CHP) unit). This determines the heat output from emitters in individual rooms.

1.3 Efficiency improvement potential

Most types of heat generator operate more efficiently when the water passing through them is at a lower temperature. When the efficiency of the heat generator is higher the fuel consumed to produce the same amount of heat is lower, and hence the energy consumption, CO_2 emissions and fuel costs are also lower. These are benefits that persist over the whole lifetime of the heat emitters, typically 20 years.

In the case of boilers, the efficiency rises more sharply as the flue gas temperature drops below the dew point because condensation of flue gas vapour occurs. Efficiency is affected mainly by the return water temperature. Figures 1 and 2 show how the theoretical efficiency of typical condensing gas and oil boilers rises as the return water temperature is reduced. Low-temperature operation is practicable only for condensing boilers.

Figure 1 includes part-load and full-load efficiency range bars for 1250 condensing modulating gas boilers that were tested in accordance with the Boiler (Efficiency) Regulations[1] and are listed within the Product Characteristics Database (PCDB) that supports the National Calculation Methodology for energy rating of dwellings (SAP[2]). These laboratory measurements (allowing for measurement uncertainty) support the theoretical predictions.

In the case of heat pumps the seasonal performance factor is affected both by the flow temperature and the difference between source and sink temperatures. The sink temperature for a heat pump in a hydronic heating system is the flow temperature. Figures 3 and 4 show how the efficiencies of typical heat pumps rise as the flow temperature is reduced. Note that the efficiency is a seasonal value for space heating only, without hot water service, calculated in accordance with BS EN 15316-4-2:2008[3], which is utilised within SAP. The data used are sourced from the SAP PCDB for a heat pump selected from the 90th percentile when ordered from the best to worst performing; most heat pumps will perform better than this. It is assumed the heat pump systems include weather-compensating controls, which reduce the effect of low-temperature heating systems.

The efficiency characteristics of micro-CHP cannot be generalised in a single graph as many design types are possible. It may not be feasible for micro-CHP with an engine or fuel cell to heat water to a lower temperature, and if it did so there may be no performance benefit. However, some micro-CHP units include an auxiliary burner that behaves in a similar way to a boiler and would have performance characteristics resembling those shown in Figures 1 or 2. Before the benefit of low-temperature heating with micro-CHP can be assessed, evidence will be needed from the designer of the product to show how efficiency varies with water temperature.

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* Underfloor systems may still use a mixing valve, but only as a protection device.

† Fan-assisted radiators, fan coil units and fanned convectors deliver most of the heat by forced convection and are described generically as convectors in this guide.

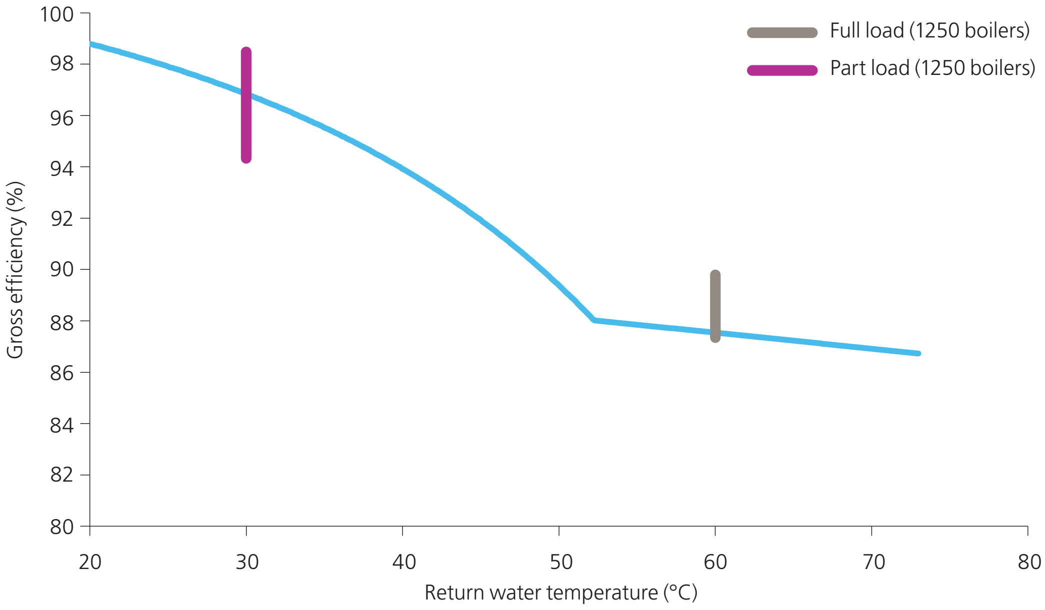

Figure 1: Typical modern condensing gas boiler: efficiency vs. return temperature relationship

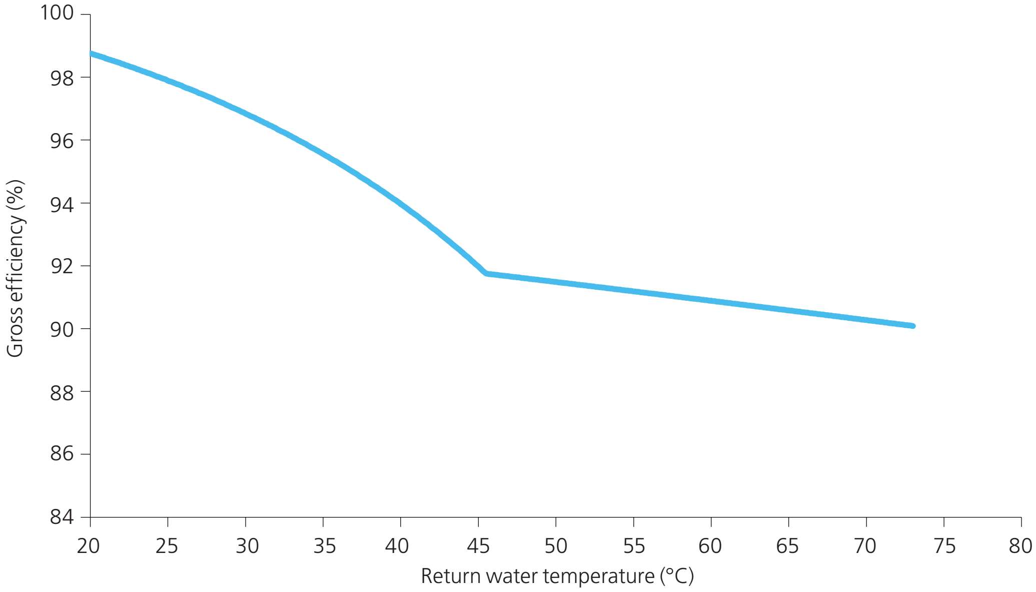

Figure 2: Typical modern condensing oil boiler: efficiency vs. return temperature relationship

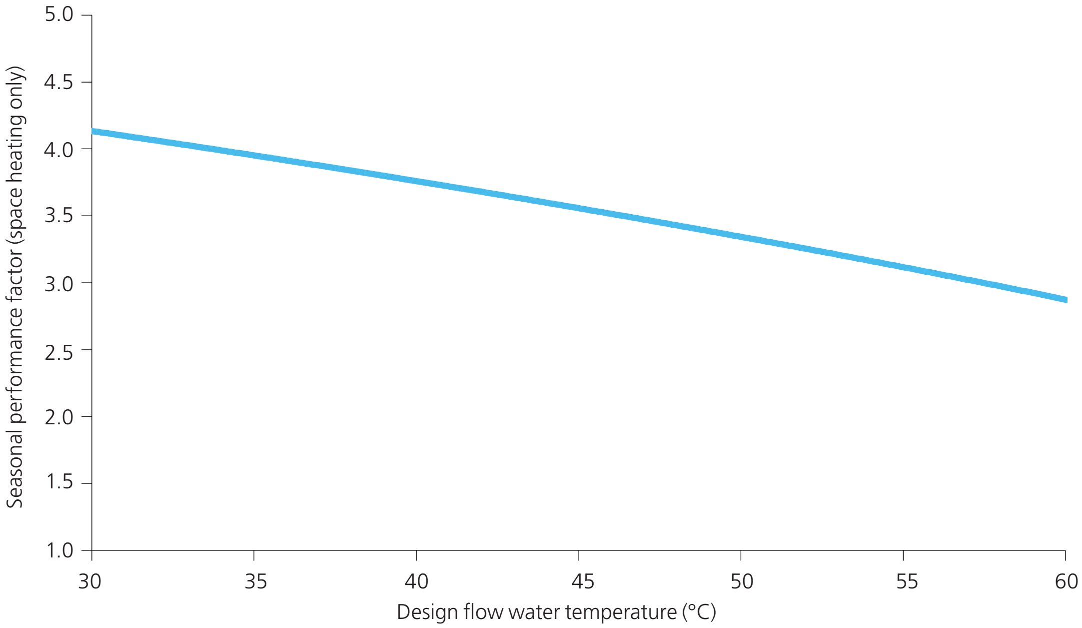

Figure 3: Ground source heat pump: efficiency vs. flow temperature relationship

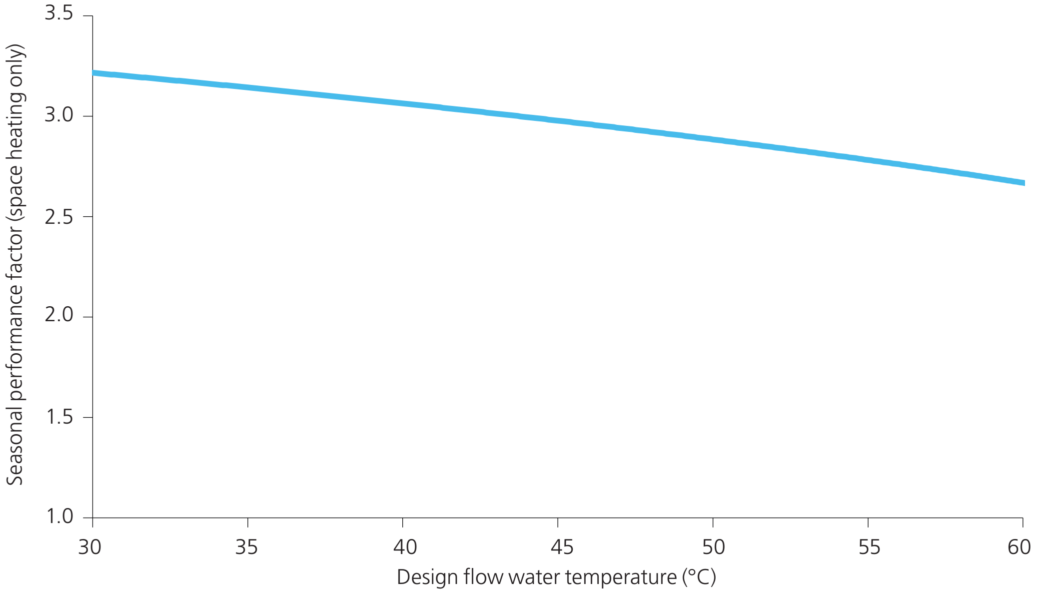

Figure 4: Air source heat pump: efficiency vs. flow temperature relationship

1.4 Comparison of performance with conventional heating systems

The performance of a low-temperature heating system should be compared with that of a system designed to operate at a conventional temperature so that savings in energy, CO_2 emissions and fuel costs can be estimated. The savings can only be indicative as they depend on conditions in use, such as weather conditions, hours of operation, intervening hot water demand and other factors.

Figure 5 shows the space heating (only) energy savings for a typical condensing gas boiler with modulating burners compared with a system with a design MWT of 70°C (75.4°C flow temperature) plotted for a range of lower design mean water temperatures. It was derived from the efficiency relationship shown in Figure 1 and an emitter temperature calculated for an average heating season day, a radiator emitter system ($n = 1.3$[‡]) and intermittent heating[§].

Figures 6 and 7 shows the space heating (only) energy savings for ground source and air source heat pumps respectively compared with a system with a design MWT of 51.1°C (55°C flow temperature) plotted for a range of lower design mean water temperatures. It was derived from the efficiency relationship shown in Figures 3 and 4 for a radiator emitter system ($n = 1.3$) with continuous heating (24 hours/day) and accounts for the daily variation in emitter and source temperature. This represents the performance of the heat pump alone, excluding any supplementary heaters, and assumes it is capable of satisfying the full heat load under all weather conditions.

For micro-CHP, savings cannot be estimated generically and evidence will be needed from the designer of the product to show how efficiency varies with water temperature.

In practice the same heat generator is often used to provide hot water service, and it should be remembered that the energy savings from low-temperature space heating systems do not extend to hot water production.

In relation to the indicative savings obtained from Figures 5–7, it should be confirmed that the higher installation cost of a low-temperature heating system is considered worthwhile and acceptable by the customer.

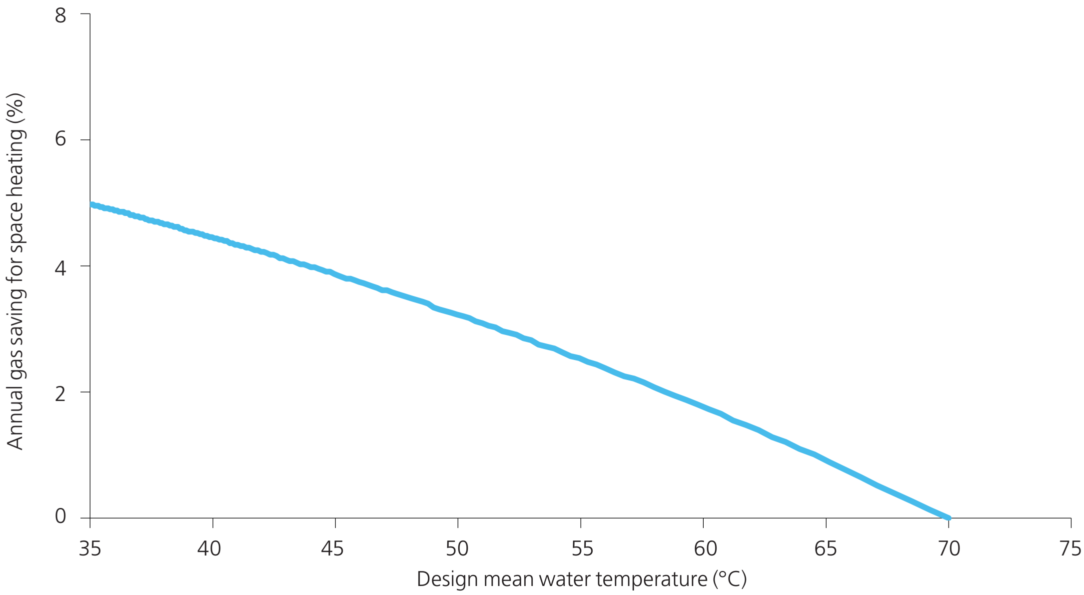

Figure 5: Typical gas condensing boiler: reduction in fuel consumption for oversized emitters

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[‡] The *n*-exponent is explained in detail in Section 2.4.4 of this guide.

[§] Intermittent heating of 77 hours per week during the heating season, as defined within SAP.

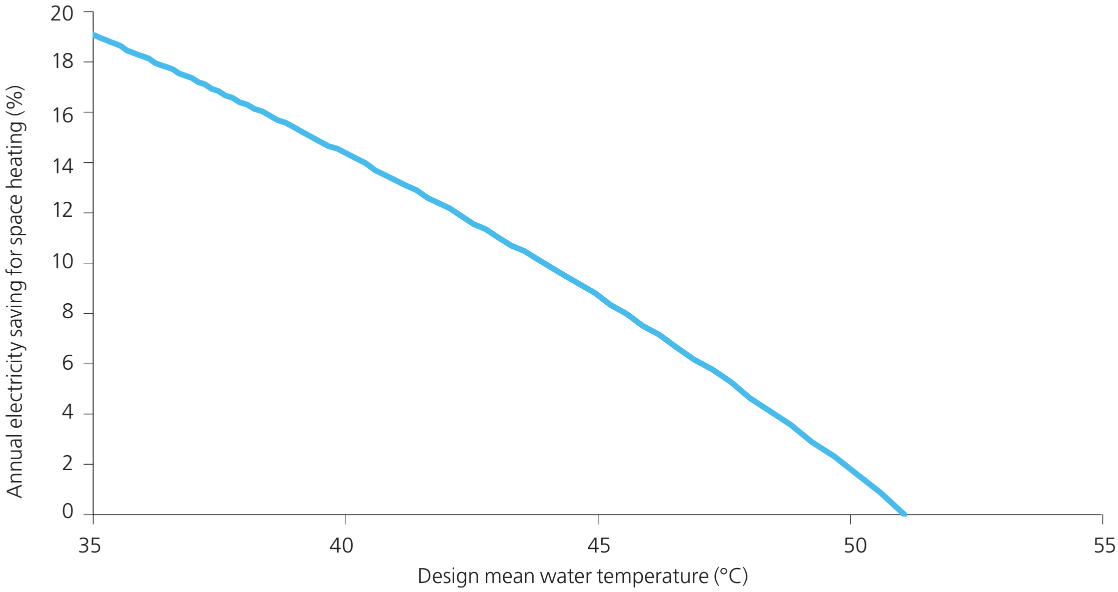

Figure 6: Ground source heat pump: reduction in electricity consumption for oversized emitters

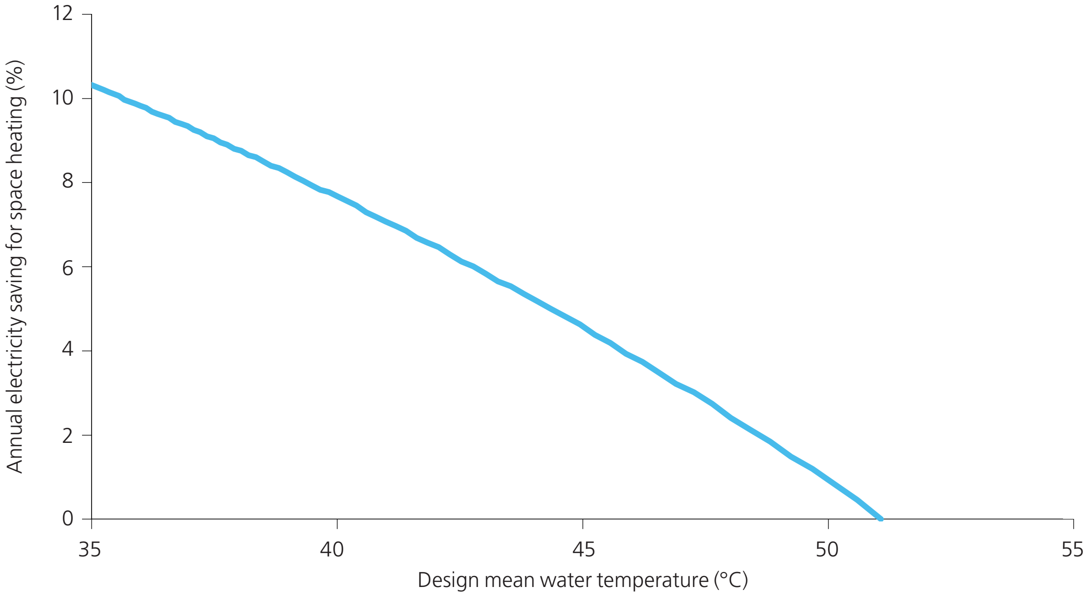

Figure 7: Air source heat pump: reduction in electricity consumption for oversized emitters

2

Design procedure for designer and installer

2.1 Importance of correct heating system design

Part 2 of this guide contains the procedure for designers and installers to follow when designing low-temperature domestic heating systems. The steps are outlined in Table 1 and explained in further detail in the sections that follow.

Detailed consideration should be given to the specification and sizing of the heat generator. The principal issues of concern are:

1. The heat output rating of the heat generator, since this affects on/off cycle times. Where heat output is strongly influenced by external conditions (eg with some types of air source heat pump), sizing of the heat generator to satisfy heat demand on the design day may result in more cycling under light loading in mild weather. The heat output modulation range of the heat generator should be considered when investigating whether excessive on/off cycling is likely to result from low-temperature operation.

2. Whether more frequent on/off cycling, if induced by low-temperature operation, will lead to a significant drop in overall thermal efficiency.

3. Whether continuous operation at low temperature is acceptable with respect to the heat generator's specification (this is unlikely to be the case for non-condensing boilers); refer to the manufacturer if in doubt.

To allow the heating system to deliver the same amount of heat to the rooms of the building when the water temperature is lower, the heat emitters need to be larger – not necessarily physically larger but capable of emitting a greater amount of heat. For radiators and convectors, this means selection on the basis of a larger amount of heat emitted at the standard temperature quoted in data tables, so that the right amount of heat is emitted when the water temperature is lower. This is sometimes called 'oversizing'. For UFH, there is a method to adjust heat output by modifying the pipe spacing. In both cases a design method has to be followed to ensure that heat output will be sufficient.

In relation to the indicative energy savings obtained from Figures 5–7, it should be confirmed that the higher installation cost of a low-temperature heating system is considered worthwhile and acceptable by the customer.

Table 1: Outline of design and installation steps

1	Carry out heat loss calculations for every room of the building that is to be heated.
2	Choose an MWT that is compatible with the type of heat generator to be installed (and for UFH compatible with floor type). Confirm that the heat generator can operate satisfactorily at the design flow temperature without excessive on/off operation (cycling) being necessary to reduce the thermal output, which may reduce thermal efficiency.
3	Determine emitter sizes to give the requisite amount of heat at the MWT. Select suitable emitters from the manufacturer's catalogue and data tables and check that they can be installed in all the rooms to be heated. If not, repeat from step 2 with a higher MWT.
4	Work out the oversize factor (for radiators) or performance adjustment factor (for UFH) from the full set of emitters selected.
5	Compare performance with a conventional system and estimate energy/CO_2/fuel cost savings.
6	In relation to the estimated savings, confirm that the higher installation cost of a low-temperature heating system is considered worthwhile, and that non-simultaneous space heating and water heating is considered acceptable by the customer.
7	Ensure that the heat generator is controlled in such a way that the design flow temperature corresponding to the chosen MWT for space heating is not exceeded, and that this cannot be overridden by the occupants.
8	If hot water service is to be provided by the same heat generator, ensure that controls are installed to prevent simultaneous space heating and hot water service, and that a higher flow temperature will be used for hot water service only.
9	Install the heat emitters in accordance with the design. Install temperature-limiting controls and interlock so that water heating cannot be in operation at the same time as space heating. Such controls must prevent adjustment by the householder after the installer has commissioned the system.
10	Commission and label the installation.
11	Complete and sign the commissioning certificate (see example in Appendix B) and supply it to the customer (and SAP assessor if requested), together with relevant data from the calculations carried out in steps 1–6.

MWT – Mean water temperature. UFH – Underfloor heating.

Table 2: Design room temperatures and ventilation rates

Room	Design room temperature (°C)	Ventilation rate (air changes per hour)		
		A	B	C
Living room	21	1.5	1	0.5
Dining room	21	1.5	1	0.5
Bedsitting room	21	1.5	1	0.5
Bedroom	18	1	1	0.5
Hall and landing	18	2	1	0.5
Kitchen	18	2	1.5	1.5
Bathroom	22	3	1.5	1.5
Toilet	18	3	1.5	1.5

2.2 Calculation of the heat loss from each room

The heat loss under design conditions must be calculated for each individual heated room. A whole-house method is not sufficient because heat emitters must be sized individually for each room.

The heat loss calculation should use a method that complies with the UK National Annex to BS EN 12831:2003[4] and the assumptions under the sub-headings below. The calculation can follow the guidance used in the latest edition of the Chartered Institution of Building Services Engineers' (CIBSE) *Domestic heating design guide*[5]. In new dwellings with very high levels of insulation, modified assumptions can be made, eg lower ventilation rates and allowance for the effect of thermal bridging.

Heat loss calculators that may be suitable for this purpose include the Heating and Hotwater Industry Council's (HHIC) heat loss calculator¶, the Microgeneration Certification Scheme's (MCS) Heat Pump Software** and the worksheets published in the CIBSE *Domestic heating design guide*.

2.2.1 Design room temperatures and ventilation rates

Tables 2 and 3 match the recommendations in the UK National Annex to BS EN 12831:2003. Clients should be consulted to determine if they have any special requirements that would modify the design room temperature (DRT) in particular rooms. Where required, a DRT of 21°C can be used for all rooms except bathrooms, as recommended in the CIBSE *Domestic heating design guide*.

For ventilation rates, select column A, B or C from Table 2 according to which of the following criteria are most applicable:

- Column A: dwellings built before 2000
- Column B: dwellings built in 2000 or later that have double glazing and regulatory minimum insulation
- Column C: dwellings built after 2006 that comply with all current building regulations.

Where a room contains an open fire or chimney, the air ventilation rate should be chosen from Table 3 instead, unless Table 2 gives a higher figure.

Table 3: Alternative ventilation rates for rooms with an open fire or chimney

Room volume	Air changes per hour
≤ 40 m^3 without throat restrictor fitted to flue	5
≤ 40 m^3 with throat restrictor fitted to flue	3
≥ 40 m^3 without throat restrictor fitted to flue	4
≥ 40 m^3 with throat restrictor fitted to flue	2

¶ www.centralheating.co.uk/heat-loss-calculator.

** www.microgenerationcertification.org/mcs-standards/installer-standards/mcs-heat-pump-software.

Table 4: Design external temperature

Location	Altitude (m)	External temperature (°C)	
		A	B
Belfast	68	-2.6	-1.2
Birmingham	96	-5.4	-3.4
Cardiff	67	-3.2	-1.6
Edinburgh	35	-5.4	-3.4
Glasgow	5	-5.9	-3.9
London	25	-3.3	-1.8
Manchester	75	-3.6	-2.2
Plymouth	27	-1.6	-0.2

2.2.2 Design external temperature

Table 4 takes selected data from *CIBSE Guide A*[6]. Data from the closest location should be used, with temperature reduced by 0.6°C for every 100 m by which the height above sea level of the site exceeds that of the altitude given in the table.

For boundary walls other than party walls, select the design external temperature (DET) from column A if the heating system is to be designed for continuous heating operation. Select the DET from column B if the heating system is to be designed to operate intermittently, where an intermittency factor of 0.83 or lower (F_{INTER} in Table 9) will be applied as part of the design.

2.2.3 U-values

Refer to Table 6 of the CIBSE *Domestic heating design guide*. Where this does not include a suitable construction, BRE publication BR 443, *Conventions for U-value calculations*[7], should be consulted.

When calculating the heat loss through a solid floor in contact with the ground, the temperature difference to be used is the DRT (Table 2) minus 10°C (representing annual average external air temperature). Lower values can be used if local conditions are known to be abnormal.

When calculating the heat loss through a suspended floor, the temperature difference to be used is the DRT (Table 2) minus the DET (Table 4).

2.2.4 Adjoining dwellings (party walls)

The temperature of an adjoining dwelling will be unknown but, even if unheated, is likely to be much higher than the DET. For this procedure the adjoining dwelling temperature can be assumed to be 10°C.

2.2.5 Design heat loss

The design heat loss (DHL) for each room in watts, calculated as described above, should be tabulated, and the total of all rooms (DHL_{TOTAL}) recorded for later use.

2.3 System parameters affecting emitter size

The system parameters in Table 5 describe the operating conditions of the heating system.

The first parameter to consider when designing a low-temperature heating system is the MWT, as this is used to determine emitter sizes. The choice of MWT is limited by values of Tf and Tr (and hence Δ_{ROOM}) that are suitable for the heat generator. In the case of UFH, the MWT is also limited by floor type and floor covering.

Flow and return temperatures depend on the characteristics of the heat generator; in particular the modulation range and strategy. They are also affected by emitter sizes and the flow rate, which is governed by the pump setting and resistance of the water circuits. The circuit resistance changes as thermostatic radiator valves (TRVs) – or zone actuators in UFH – open and close in response to changing air temperature. For these reasons it is difficult to determine realistic flow and return temperatures, yet the instantaneous efficiency of the heat generator is strongly affected by them. For design purposes, it is recommended that the temperature drop across the heat emitter circuit is taken to be one-seventh of the flow temperature, ie Δ_{SYSTEM} = Tf/7. This leads to the following relationships:

Table 5: System parameters

Nomenclature	
Tf	Heat generator flow temperature
Tr	Heat generator return temperature
Δ_{SYSTEM}	System temperature drop = Tf – Tr
MWT	Mean water temperature = (Tf + Tr)/2
DRT	Design room temperature
Δ_{ROOM}	Mean water to air temperature difference = MWT – DRT

MWT = 13/14 × Tf

Tf = 14/13 × MWT

Tr = 12/13 × MWT

Traditionally, heating systems with boilers were designed assuming MWT = 70°C (eg Tf = 80°C and Tr = 60°C). As room temperatures are usually around 20°C this means that Δ_{ROOM} = 70°C – 20°C = 50°C, and this is reflected in the European Standard that sets the temperature conditions under which radiators are tested. For low-temperature heating systems the required heat emitter surface area increases significantly as the mean water to air temperature difference (Δ_{ROOM}) is reduced. The ratio of low-temperature emitter size to traditional systems is expressed as an 'oversize factor'. In the case of UFH, the surface area is not changed but a 'system performance factor' (K_H) is developed as part of the design method. Calculation of these factors is described in a later section.

Figure 8 shows how radiators and convectors need to be oversized for low-temperature conditions as Δ_{ROOM} is reduced. For example, it can be seen from Figure 8 that if the MWT is reduced from 70°C to 55°C, with a corresponding change in Δ_{ROOM} from 50°C to 35°C, the required oversize factor is about 1.6 for radiators or 1.4 for convectors.

Figure 9 shows how the performance factor (K_H value) of UFH needs to be increased for low-temperature conditions as Δ_{ROOM} is reduced. This is often accommodated by reducing the pipe spacing.

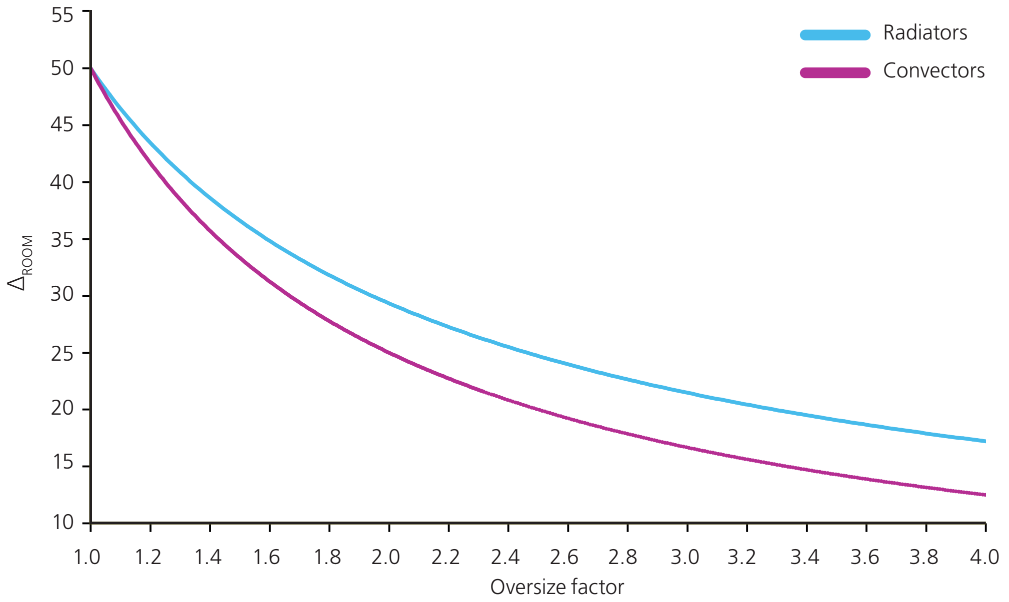

Figure 8: Effect of Δ_{ROOM} on heat emitter sizing

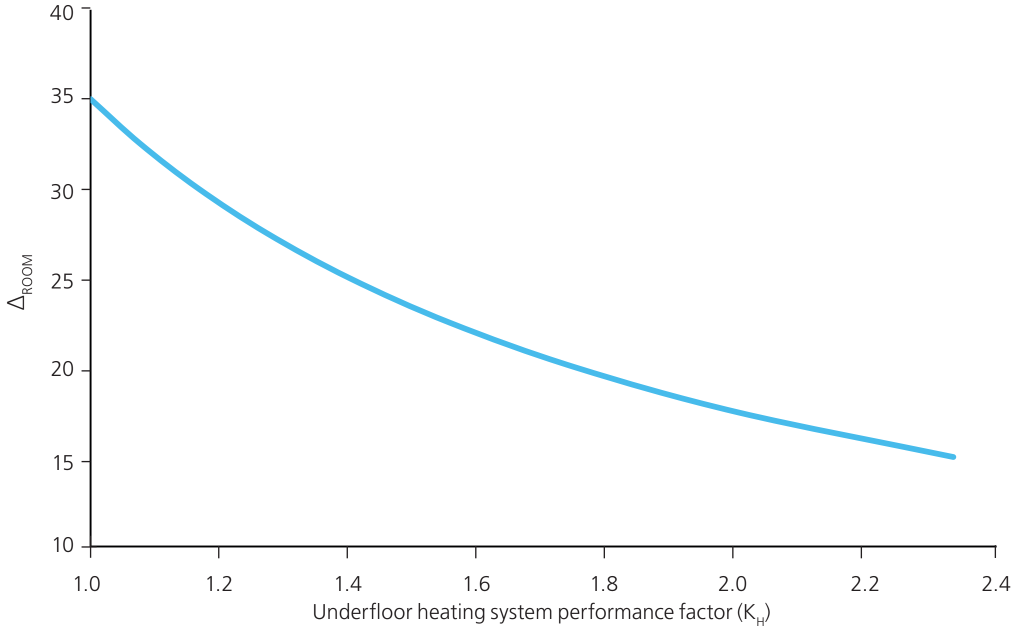

Figure 9: Effect of Δ_{ROOM} on system performance factor for underfloor heating

2.4 Determining emitter sizes

In a low-temperature heating system the heat emitters are oversized relative to standard design practice, ie capable of emitting more heat than required at standard temperature so that the right amount of heat is emitted at a lower temperature. The key to sizing is the MWT, which is the average temperature of the water entering and leaving the emitters. Ignoring small losses in the distribution pipework, this is also the average temperature of the water leaving and entering the heat generator. For radiators and skirting heating, normal design practice assumes MWT = 70°C. For UFH, the types of floor and floor covering impose limits on MWT; surface temperature requirements are set out in BS EN 1264[8].

Radiator manufacturers produce standard heat output tables that are based on $\Delta_{ROOM} = 50°C$. The mean water to air temperature difference (Δ_{ROOM} in this document) is sometimes shown as Δ_t in published tables of radiator properties, and should not be confused with the system temperature drop $\Delta_{SYSTEM} = Tf - Tr$.

The data for $\Delta_{ROOM} = 50°C$ must be adjusted by the use of factors to allow for particular installation conditions, intermittent or continuous heating, and for the smaller amount of heat emitted at the chosen value of MWT. The size of emitter is then chosen to deliver the amount of heat required for the room as established by the heat loss calculations.

2.4.1 Installation factors for radiators

For radiators, a number of installation factors determine heat output under normal conditions and these are evaluated first, before proceeding to oversizing for low water temperature. The installation factors†† are used to take account of surface finish and enclosures, unless they have been allowed for already in the manufacturers' data tables. Table 6 gives the surface finish factor F1 and Table 7 gives the enclosure factor F2.

Table 6: Installation factors (surface finish)

Surface finish	Factor F1
Plain paint	1.00
Metallic-based paint	0.85
Highly polished, eg chrome-plated	Consult manufacturer, or if no information available use 0.65

Table 7: Installation factors (enclosure type)

Enclosure type	Factor F2
Fixed on plain surface	1.00
Shelf over plain radiator	0.95
Fixed in open recess	0.90
Encased cabinet with front and top grill	0.8–0.7

The combined installation factor F_{INST} represents the effect on heat emission due to all the installation conditions, and should be calculated as:

$$F_{INST} = F1 \times F2$$

This means that the heat output from a particular radiator shown in data tables must be multiplied by F_{INST} to obtain the heat output under installed conditions. Conversely, if a particular heat output is required it must be divided by F_{INST} to look up a suitable radiator in the data tables.

2.4.1.1 Example

Suppose the required heat output from a radiator is 2000 W. It is to be installed on a system operating under normal conditions (MWT = 70°C) and the air temperature can be taken as 20°C, so that $\Delta_{ROOM} = 50°C$. The radiator is finished in plain paint, and there will be a shelf over the radiator.

Factor F1 from Table 6 = 1.00

Factor F2 from Table 7 = 0.95

$$F_{INST} = 1.00 \times 0.95 = 0.95$$

Therefore the required radiator heat output to be selected from data tables is calculated as:

$$2000/F_{INST} = 2000/0.95 = 2105 \text{ W.}$$

Where there is no radiator with exactly this heat output the next-largest size should be chosen. Note that this heat output is used only to select a radiator from manufacturers' data tables that give the output based on $\Delta_{ROOM} = 50°C$ and a plain paint finish. The figure is not relevant elsewhere, and should not be used when sizing the heat generator.

2.4.2 Factors for underfloor heating

For UFH systems, a floor surface temperature limit applies. This is mainly for safety and user comfort. The limits are given in BS EN 1264 as a margin above DRT, and are summarised in Table 8 below for common UK conditions.

Vinyl floor covering manufacturers often require the floor surface to be limited to 27°C. A similar limit of 27°C is also recommended by the Underfloor Heating Manufacturers' Association (UHMA)‡‡ for solid decorative wood floor finishes but does not extend more generally to engineered wood floors, laminates or chipboards. Guidance on temperature limits should be sought from an experienced UFH designer.

Table 8: Underfloor heating surface temperature limits

Room type/area	Temperature (°C)
Occupied area of room (at 20°C) + 9°C	29
Peripheral area of room (at 20°C) +15°C	35
Bathrooms (at 22°C) +11°C	33

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†† Factors for different radiator connections (top–bottom opposite ends, etc) are rendered obsolete by the new method of radiator testing introduced in BS EN 442.

‡‡ UHMA is the trade association for underfloor heating and is part of BEAMA (www.beama.org.uk).

Some floor coverings such as carpets reduce heat output and their insulating effect must be taken into account. A limit of 2 tog[§§] for the combined carpet and underlay is usual, and UFH designers will be able to advise further.

The ability of a floor heating system to emit heat can be represented by what is known as the 'system performance factor' (K_H). UHMA intends to publish standard tables for K_H for the most commonly fitted systems, and individual manufacturers will advise where their systems differ from these. The K_H value is calculated as:

K_H = FSHO/(MWT – DRT)

where FSHO = floor surface heat output, MWT = mean water temperature and DRT = design room temperature.

The K_H value is raised by between 2% and 6% where polybutylene pipe is used. No adjustment is made for cross-linked polyethylene (PEX) or polyethylene raised temperature (PE-RT) pipes. The resulting K_H value is then used in conjunction with pipe spacing selection graphs to choose the pipe spacing required.

An important parameter for UFH is the design heat loss divided by the heated floor area of each room, giving the heating requirements in W/m². This can be used to look up, in tables or graphs, what is achievable at the maximum allowable MWT for the type of floor. A feasible design must be found that allows the varying heat requirements of different rooms to be provided by a system with a single value of MWT, with some flexibility being available by alteration of K_H, eg by adjusting the pipe spacing.

2.4.3 Factors for intermittent heating

For heating systems with boilers and radiators, it is usual to allow for intermittent heating. With underfloor emitters continuous heating is more common, and heat pump systems are frequently designed for continuous heating too. Where there is intermittent heating, larger heat emitters are needed to bring the building up to temperature reasonably quickly. The factor F_{INTER}, taken from Table 9, expresses this requirement for the purposes of emitter sizing.

Table 9: Intermittency factor

Heating pattern	Factor F_{INTER}
Intermittent heating (one or two periods per day)	0.83
Continuous heating	1.00

2.4.4 Adjustment for low-temperature operation

For radiators, convectors and skirting heating, an adjustment must be made to allow for a lower MWT than assumed in the published data tables. Firstly Δ_{ROOM} = MWT – DRT is calculated. In most cases it is an acceptable approximation to assume that Δ_{ROOM} = MWT – 20°C in all the rooms.

Radiators are tested[¶¶] to BS EN 442[9]. This requires that heat outputs are measured and quoted at Δ_{ROOM} = 50°C (eg MWT of 70°C and DRT of 20°C). In conformity with the standard, radiator manufacturers show heat output for Δ_{ROOM} = 50°C in their catalogues. This is sometimes described in table headings as 'Δ_t = 50'. The catalogue may have separate tables for other values of Δ_{ROOM}, and, where lower design values of Δ_{ROOM} are required they should be taken from the catalogue tables if available.

When not available, the heat output shown in the catalogue at Δ_{ROOM} = 50°C should be multiplied by a factor F_{TEMP} to adjust for a different Δ_{ROOM}. Where the manufacturer's catalogue states the *n*-coefficient or the *n*-exponent[***], the radiator factor F_{TEMP} can be calculated from the relationship:

$F_{TEMP} = (\text{required } \Delta_{ROOM}/50)^n$

Where the radiator manufacturer's heat emission factor, *n*-coefficient or *n*-exponent is not stated, then the value of *n* should be taken from Table 10. Values for F_{TEMP} for commonly occurring values of *n* can be found in Table 11 overleaf.

Table 10: Default *n*-coefficient values

Emitter type	*n*
Standard radiators	1.3
Fan coil units	1.1
Fan convectors	1.0

[§§] Tog = 10 x thermal resistance (m²K/W).

[¶¶] Since 1997 all radiators sold in Europe need to conform to BS EN 442. Under this standard it is necessary to test radiators with a flow temperature of 75°C and a return temperature of 65°C in a test room with a constant air temperature of 20°C.

[***] The *n*-exponent is a factor obtained from tests to BS EN 442 and should be declared by the manufacturer.

Table 11: F_{TEMP} for various values of Δ_{ROOM} and *n*

Δ_{ROOM}	*n* = 1.0	*n* = 1.1	*n* = 1.2	*n* = 1.25	*n* = 1.3	*n* = 1.35
50	1.000	1.000	1.000	1.000	1.000	1.000
45	0.900	0.891	0.881	0.877	0.872	0.867
40	0.800	0.782	0.765	0.757	0.748	0.740
35	0.700	0.675	0.652	0.640	0.629	0.618
30	0.600	0.570	0.542	0.528	0.515	0.502
25	0.500	0.467	0.435	0.420	0.406	0.392
20	0.400	0.365	0.333	0.318	0.304	0.290
15	0.300	0.266	0.236	0.222	0.209	0.197
10	0.200	0.170	0.145	0.134	0.123	0.114

2.5 Selection of suitable heat emitters

Once the design heat loss of each room has been determined, suitably sized heat emitters can be selected. Check that heat emitters can be installed in all of the rooms that are to be heated. No exceptions can be made. If they cannot be installed, then the selected value of MWT is not practicable and a higher value must be chosen.

2.5.1 Radiators

The combined factor F represents the effect on heat emission due to installation conditions, intermittency and low MWT, and should be calculated as:

$F = F_{INST} \times F_{INTER} \times F_{TEMP}$

This means that the heat output from a particular radiator shown in data tables for Δ_{ROOM} = 50°C must be multiplied by F to obtain the heat output under the intended installation and operating conditions. Conversely, if a particular heat output is required it must be divided by F to look up a suitable radiator in the data tables.

If data tables are published for the intended value of Δ_{ROOM} then these can be used instead and the combined factor F is simplified to:

$F = F_{INST} \times F_{INTER}$

2.5.1.1 Example

Suppose the required heat output from a radiator is 2000 W. It is to be installed on a system operating at MWT = 45°C and the air temperature can be taken as 20°C, so that Δ_{ROOM} = 25°C. The radiator is finished in plain paint and is to be mounted on a plain surface without enclosure. The heat generator is a boiler and intermittent heating is required.

Factor F1 from Table 6 = 1.00

Factor F2 from Table 7 = 1.00

$F_{INST} = 1.00 \times 1.00 = 1.00$

F_{INTER} from Table 9 = 0.83

n from Table 10 = 1.3 for radiators

Therefore, F_{TEMP} from Table 11 = 0.406

$F = F_{INST} \times F_{INTER} \times F_{TEMP} = 1.00 \times 0.83 \times 0.406 = 0.337$

Therefore the required radiator heat output to be selected from data tables for Δ_{ROOM} = 50°C is:

2000/F = 2000/0.337 = 5935 W.

Where there is no radiator with exactly this heat output the next-largest size should be chosen. Note that this heat output is used only to select a radiator from manufacturers' data tables that give the output based on Δ_{ROOM} = 50°C. The figure is not relevant elsewhere, and should not be used when sizing the heat generator.

2.5.2 Heat emitters with fans

Heat emitters with integral fans, such as fan convectors and fan-assisted radiators, have a higher heat output than a conventional radiator of the same physical size. The forced movement of warm air produces a more rapid heating effect. Such emitters are particularly useful where there is insufficient space to fit a conventional radiator of the same heat output. The procedure for sizing fanned heat emitters is as for radiators but factors F1 and F2 do not apply and so F_{INST} is taken as 1.0. Factor F_{INTER} is taken from Table 9. For F_{TEMP} manufacturers' data are needed, as the relationship assumed in Tables 10 and 11 does not apply when different fan speeds are chosen. Manufacturers' advice should be followed for selection of suitable fan speeds.

2.5.3 Skirting heating

Skirting heating relies on natural convection and some radiation from heat emitters placed along the walls just above floor level. Heat emission is quoted per unit of length (W/m). The linear heat output can be found from manufacturers' catalogues, and as the maximum length is limited by the perimeter of the room (excluding doorways), the first step is to check that this length gives sufficient heat output to satisfy the room's requirements. There is some flexibility to restrain output where heat output would be too much, using restrictor valves or TRVs. Manufacturers often provide dedicated software to assist with the design of a system.

Skirting heating emitters are tested to BS EN 442 and the procedure for sizing skirting heating is as for radiators but factors F1 and F2 do not usually apply. Factors F_{INTER}, n and F_{TEMP} are found from Tables 9, 10 and 11 in the same way as for standard radiators.

2.5.4 Underfloor heating

Where the same heat generator provides UFH in some rooms together with conventional radiator heating in others, higher flow and return temperatures will normally be required and a thermostatic mixing valve is used to limit the temperature of the water entering the floor. Unless the radiator heating is also designed for low-temperature operation in accordance with this guide, such systems are not considered to be low-temperature heating because the heat generator still operates at a high temperature. However, when suitable controls have been installed to prevent the heat generator from running at high temperature during normal service conditions, a thermostatic mixing valve may still be installed to protect the floor from high-temperature water under exceptional conditions.

For UFH the surface temperature of the floor and Δ_{ROOM} are low and a specialist design procedure must be used, taking into account manufacturers' instructions on temperature limits. The floor type, floor finish and maximum surface temperature must be decided, and a value of MWT chosen that ensures the maximum is not exceeded. It is essential to check there is sufficient heat output to meet the calculated heat requirements, and a feasible design must be found that allows the varying heat requirements of different rooms to be provided by a low-temperature heating system with a single value of MWT. Some flexibility is available by alteration of the pipe spacing. For detailed design procedures and data tables refer to the CIBSE *Underfloor heating: design and installation guide*[10].

2.5.4.1 Underfloor heating design method

The design procedure for UFH differs from other emitters. The size and surface temperature of the floor, mean water to air temperature difference (Δ_{ROOM}) and system performance factor (K_H) are all critical factors that govern heat output. Assistance is available from many specialist system manufacturers and suppliers who are able to provide detailed information about their product ranges.

The following method has been derived from BS EN 1264 by UHMA and may be used to design an UFH system, room by room, for a target mean water temperature.

2.5.4.2 Required specific heat output, q_R (W/m²)

a. Calculate the design heat loss (DHL) for the room in accordance with Section 2.2 of this guide.

Table 12: Limiting factors for floor surface temperature

Floor type	Maximum floor surface temperature
Normally occupied space	DRT + 9°C ($q \approx 100$ W/m²)
Peripheral zones	DRT + 15°C ($q \approx 175$ W/m²)
Vinyl floor finish limit	27°C ($q \approx 75$ W/m² when DRT = 20°C)

b. Measure the active or exposed area of the heated floor (AH). This should normally exclude areas underneath permanent fixtures such as baths or kitchen cabinets.

c. Divide the design heat loss by the active area of the floor to obtain the specific heat output (q).

For example:
DHL = 1000 W
AH = 21 m²
$q = 1000/21 = 48$ W/m²

d. Divide this value by the intermittency factor (F_{INTER}) taken from Table 9 to produce the required specific heat output (q_R).

For example:
$F_{INTER} = 0.83$ (intermittent heating)
$q_R = 48/0.83 = 58$ W/m²

e. Observe the limiting factors for floor surface temperatures in Table 12, which restrict the available specific heat output from a UFH system.

2.5.4.3 Mean water to air temperature difference, Δ_{ROOM}

Calculate Δ_{ROOM} using the design room temperature (DRT) in accordance with Section 2.2 of this guide and the chosen target mean water temperature (MWT).

For example:
MWT = 45°C
DRT = 21°C (living room)
$\Delta_{ROOM} = \text{MWT} - \text{DRT} = 45 - 21 = 24°C$

2.5.4.4 Required system performance factor, K_H

Using the required specific heat output (q_R) calculated in Section 2.5.4.2 and Δ_{ROOM} calculated in Section 2.5.4.3 of this guide, calculate the required system performance factor (K_H) in W/m²K using the relationship $K_H = q_R/\Delta_{ROOM}$.

For example:
$q_R = 58$ W/m²
$\Delta_{ROOM} = 24°C$
$K_H = q_R/\Delta_{ROOM} = 58/24 = 2.4$ W/m²K

2.5.4.5 Pipe spacing and floor finish

Refer to the literature of the UFH system supplier to identify what pipe spacing and floor finish combinations will provide a K_H value greater than or equal to the value calculated in Section 2.5.4.4 of this guide for the planned floor construction.

Table 13: System performance factor K_H (W/m^{2}K)

System	Pipe centres	Tog value of floor finish								
		0.00	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**
Floating screed floor	100 mm	6.27	5.32	4.63	4.10	3.68	3.34	3.06	2.83	2.62
	150 mm	5.42	4.66	4.10	3.66	3.32	3.04	2.80	2.60	2.43
	200 mm	4.70	4.09	3.64	3.28	3.00	2.76	2.56	2.39	2.24
	250 mm	4.09	3.60	3.23	2.95	2.71	2.52	2.35	2.20	2.08
	300 mm	3.56	3.17	2.88	2.65	2.46	2.30	2.16	2.03	1.92
Floating dry floor inc. 18 mm chipboard	150 mm	3.60	3.26	2.98	2.74	2.53	2.36	2.21	2.07	1.95
	200 mm	3.34	3.04	2.78	2.57	2.39	2.23	2.09	1.97	1.86
	250 mm	3.04	2.79	2.57	2.38	2.22	2.08	1.96	1.85	1.75
	300 mm	2.73	2.51	2.33	2.17	2.04	1.92	1.81	1.71	1.63
Floating dry floor inc. 18 mm gypsum fibreboard	150 mm	5.58	4.80	4.21	3.75	3.38	3.07	2.82	2.60	2.42
	200 mm	5.10	4.43	3.91	3.50	3.17	2.89	2.66	2.47	2.30
	250 mm	4.58	4.02	3.58	3.23	2.94	2.70	2.49	2.32	2.16
	300 mm	4.04	3.59	3.23	2.94	2.69	2.48	2.31	2.15	2.02

Table 14: Typical tog values of generic floor coverings

Floor covering	Tog value
Ceramic or stone + adhesive	0.05 – 0.15
Vinyl + adhesive	< 0.25
7 mm laminate + UFH underlay	1.0
18 mm hardwood or engineered wood + UFH underlay	1.5
12 mm carpet (with pile) + UFH underlay	2.0

In the absence of supplier information, use Table 13 for the typical floor systems shown in Section 2.5.4.7.

> For example:
> System = floating screed floor
> Required $K_H \geq 2.4$
> Therefore, values for the permitted combinations of floor finish (tog value) and pipe spacing are shown within the red bounded box of Table 13

2.5.4.6 Design tog value

The design tog value of the floor covering identifies the most suitable pipe spacing from the range of combinations already found in Section 2.5.4.5. The tog rating for specific floor coverings can be obtained from manufacturers' data. Typical values are provided in Table 14 for use when manufacturers' data are not available.

> For example:
> Design tog value = 1.5 tog
> Required pipe spacing = 200 mm (highlighted in red in Table 13)
> This gives a K_H of 2.56 W/m^{2}K

2.5.4.7 Typical underfloor heating system constructions

Figures 10 and 11 show typical floor constructions incorporating UFH.

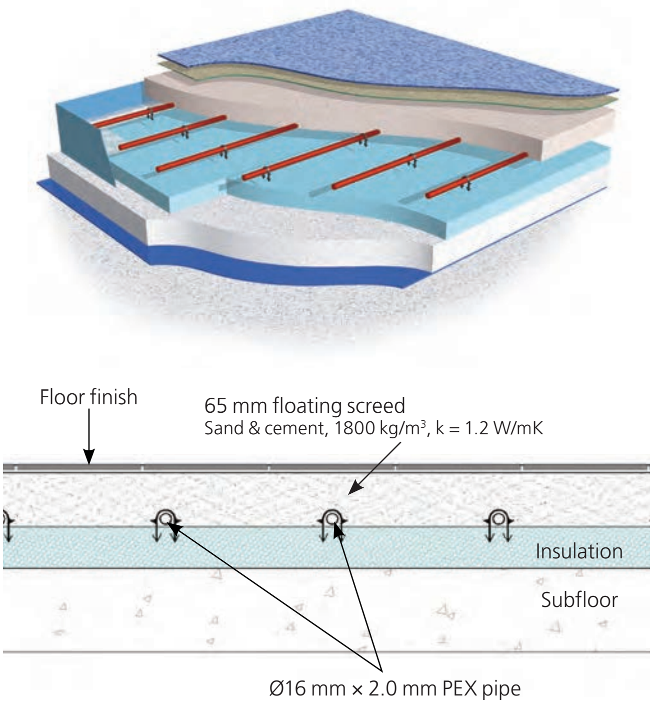

Figure 10: Cross-section of a typical floating screed floor system with UFH

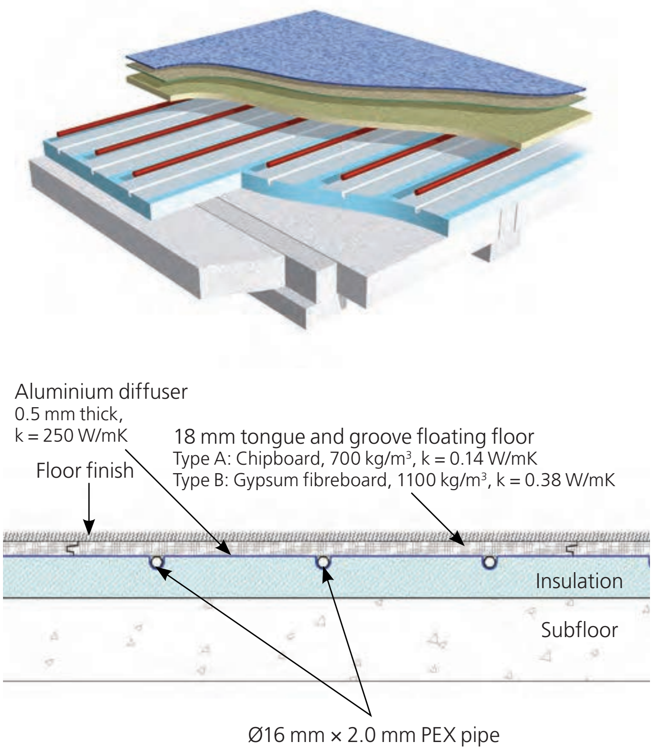

Figure 11: Cross-section of a typical floating dry floor system with UFH

2.5.4.8 Review the design

If the chosen system cannot provide the required K_H value with any pipe spacing in combination with the design tog value of the floor finish, one or more of the following steps can be taken to overcome the problem:

- Reduce the design tog value of the floor covering.
- Replace the screed or dry floor panels with a more thermally conductive alternative. For example, replace a standard sand and cement screed ($\lambda = 1.2$ W/m K) with an anhydrite screed ($\lambda = 1.8$ W/m K). Numerous alternatives are available, and advice should be sought from manufacturers and suppliers. In this document, only chipboard and gypsum fibreboards for dry floating floors have been used as examples.
- Select a different floor construction for higher thermal performance.
- Increase the mean water temperature to reduce the required system performance factor K_H.

2.6 Oversize factor for radiators and convectors

The design heat loss of each room and the heat output of all the selected heat emitters at $\Delta_{ROOM} = 50°C$ should be tabulated. The oversize factor for the heat emitter system due to low-temperature operation is then calculated as follows:

$$\frac{F_{INTER} \times \sum\{(\text{Installed emitter output @ } \Delta_{ROOM} = 50°\text{C}) \times F_{INST}\}}{DHL_{TOTAL}}$$

The top line summation is the sum of the installed emitters rated at $\Delta_{ROOM} = 50°C$ adjusted by the factors for the radiator installation characteristics (surface finish and enclosures). F_{INTER} is the factor adopted for intermittent heating. The bottom line is the sum of the design heat losses (DHL) for each room, excluding any allowance for intermittency or other factors.

2.7 Controls to achieve low-temperature conditions

Heating controls must be installed to ensure that two operating conditions are met. The first condition is that the flow temperature from the heat generator does not exceed the design temperature Tf. A control such as a traditional boiler thermostat, accessible to the householder, is inadequate. Load and weather compensation controls are also inadequate since they do not define a maximum flow temperature (Tf). Such controls must prevent adjustment by the householder after the installer has commissioned the system. Ideally this would be achieved by provisions within the heat generator control system, allowing it to be programmed to limit the flow temperature and modulate heat output under low-load conditions against this maximum. One method of satisfying this condition may be the OpenTherm communication standard[†††], which consists of a communication protocol and an interface specification. The certification of heat generators and controllers to the OpenTherm standard signifies that a range of mandatory control parameters have been implemented. One of the mandatory control parameters is

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[†††] OpenTherm Association, www.opentherm.eu.

maximum flow temperature, which can be specified by installers, sometimes using some form of password protection to prevent householder adjustment. As discussed in Section 2.1, the heat generator must be capable of satisfactory operation at the design flow temperature without excessive on/off operation (cycling) being necessary to reduce the thermal output.

The second condition applies when hot water service is to be provided by the same heat generator. Controls must be installed to prevent simultaneous space heating and hot water service, and to allow a higher flow temperature during hot water service only. This can cause inconvenience to the householder in some circumstances, eg returning from a holiday to a cold house and finding that the heating system gives priority to hot water service. Some provision should be made to allow a temporary reversal of priority in those circumstances.

2.8 Installation, commissioning and labelling

The installation should be completed in accordance with the design specification, produced by the methods above. Heating controls must be commissioned such that they limit the heating system flow temperature to the value of Tf specified by the design and cannot be overridden by householders. The installation should be labelled to indicate that it has been designed as a low-temperature heating system and that the operating conditions should be maintained as designed. A design, installation and commissioning checklist is provided in Appendix A.

2.9 Commissioning certificate

A design, installation and commissioning certificate should be completed as evidence that the heating system has been designed and installed to operate at a low temperature, following the procedure set out in Part 2 of this guide. In future it is possible that the National Calculation Methodology for energy rating of dwellings (SAP) will recognise the energy performance of low-temperature heating systems and take them into account in the SAP rating. An example of a suitable form of certificate is shown in Appendix B.

2.10 References

1. The Boiler (Efficiency) Regulations 1993, SI (1993) No. 3083, as amended by the Boiler (Efficiency) (Amendment) Regulations 1994, SI (1994) No. 3083. London, The National Archives, 1994.
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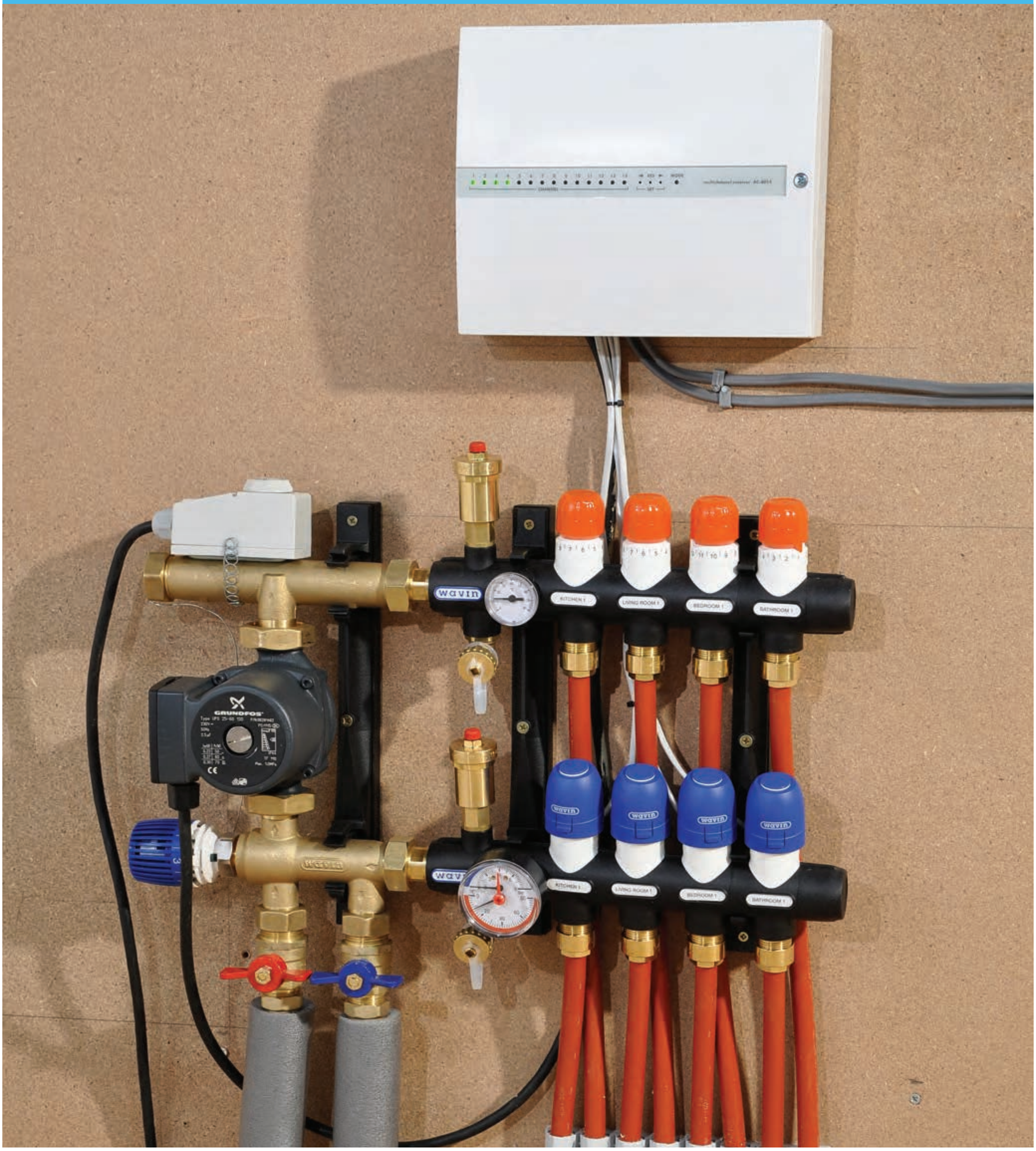
3 Appendices



Appendix A: Design, installation and commissioning checklist

To help establish consistent practice, the design and installation steps in producing a low-temperature heating system have been built into a checklist, which is set out below.

Confirmation that the design and installation procedure has been followed should be provided in the form of a label and commissioning certificate (see Appendix B), mentioned in steps 10 and 11 of the checklist. This is important to ensure continued operation under the intended conditions, and as evidence of improved energy performance. The certificate and supporting technical information will be needed during future maintenance and repairs, and may be used as evidence to qualify for an improved building energy rating.

Design, installation and commissioning checklist		
1	Measure each room of the building and identify types of floors, walls, windows and roof. Carry out heat loss calculations. Confirm that a heat loss calculation has been carried out for every room that is to be heated. State: (i) which heat loss calculator was used; (ii) the assumed external temperature; and (iii) the assumed internal temperature where different from Table 2.	
2	Choose an MWT that is compatible with the type of heat generator to be installed.	
3	Determine the sizes of heat emitters to give the requisite amount of heat at the chosen value of MWT. Select suitable emitters of at least this size from manufacturers' catalogue and data tables. Check that the selected heat emitters can be installed in all of the rooms that are to be heated. If not, repeat from step 2 with a higher MWT. Record final value of MWT, after any iterations necessary.	
4	For radiators and convectors, work out the oversize factor from sizes of emitters selected. Check that it is close to the value anticipated in Figure 8. Record the oversize factor. For UFH, work out the system performance factor (K_H) values and pipe spacings. Record both the K_H values and pipe spacings.	
5	Compare performance with a conventional system and use Figures 5–7 to estimate the savings in energy/CO_2/fuel costs*. For UFH systems, note that savings cannot be claimed where a thermostatic mixing valve is installed to blend water at a higher temperature with cooler water before entering the system (see Section 1.2). Record the estimated savings as a percentage.	
6	In relation to the estimated savings, confirm that the higher installation cost of a low-temperature heating system is considered worthwhile and acceptable by the customer.	
7	Ensure that the heat generator can operate satisfactorily at the chosen design flow temperature (Tf) that corresponds to the final value of the MWT for space heating without excessive on/off operation (cycling) being necessary to reduce the thermal output. Ensure that it is controlled in such a way that this temperature is not exceeded and cannot be permanently overridden by the householder. Explain how confirmation of acceptable heat generator operation at the design flow temperature has been determined. Explain how temperature-limiting controls have been implemented, the device(s) used and how overriding by householders is prevented.	

* Figures 5–7 only apply when the heat generator has been sufficiently sized to satisfy all of the design day heat load. If supplementary heating (including electrical heating elements within a heat pump) is needed to satisfy the heat load then savings will be lower.

MWT – Mean water temperature. UFH – Underfloor heating.

Design, installation and commissioning checklist (continued)		
8	If hot water service is to be provided by the same heat generator, ensure that controls are installed to prevent simultaneous space heating and hot water service, and that a higher flow temperature will be used for hot water service only. Explain how this has been done and what controls are used.	
9	Install the heat emitters in accordance with the design. Install temperature-limiting controls and interlock so that water heating cannot be in operation at the same time as space heating.	
10	Commission the installation, including setting the space heating design flow temperature (Tf). Attach a label, close to the heat generator, to indicate that it has been designed for low-temperature space heating and that control settings must be maintained accordingly. Record the control settings for use in future re-commissioning after maintenance or repairs.	
11	Complete and sign the commissioning certificate, including data from the calculations carried out in steps 1–6, and supply to the customer (and SAP assessor if requested).	

Appendix B: Example design, installation and commissioning certificate

Low-temperature heat emitter system: commissioning certificate	
Address at which central heating system is installed	
Date on which installation was completed and commissioned	
Type of heat generator (boiler/heat pump/other)	
Heat loss calculator program used for the design	
Confirm heat generator can operate satisfactorily at the design flow temperature without excessive on/off operation (cycling) being necessary to reduce the thermal output. Supply evidence	
Assumed external temperature for heat loss calculations	External temperature = °C
Confirm that assumed internal temperatures were as given in Table 2 of the guide*. If there are any exceptions they should be listed here	
Mean water temperature (MWT) assumed in the design	MWT = °C
For radiators and convectors, the oversize factor calculated from emitter sizes after selection	
For UFH, the system performance factor (K_H) values and pipe spacing (attach separate sheet if necessary)	
Estimated fuel cost savings, taken from the guide*	
Type of temperature-limiting control installed to ensure design flow temperature from heat generator is not exceeded	
Design flow temperature (Tf), which is permanently set for the heat generator during commissioning. Note that for UFH this must allow for any thermostatic mixing valve if fitted (see Section 1.2 of the guide*)	Tf = °C
If the heat generator also provides hot water service, state what controls are used to ensure it does not supply hot water service and space heating service simultaneously	

I certify that:
(i) the central heating installation at the premises whose address is shown above has been designed for low-temperature operation in accordance with the guide*
(ii) the design included a heat loss calculation for every room of the building that is heated by the installation
(iii) the installation conforms to the design
(iv) controls to ensure continued low-temperature operation (limiting flow temperature) have been installed and commissioned in accordance with the design and cannot be overridden by the householder
(v) controls to prevent simultaneous space heating and hot water service have been installed

Name (print):

Signature:

Position/qualifications:

Date:

* *Design of low-temperature domestic heating systems*, published by IHS BRE Press.

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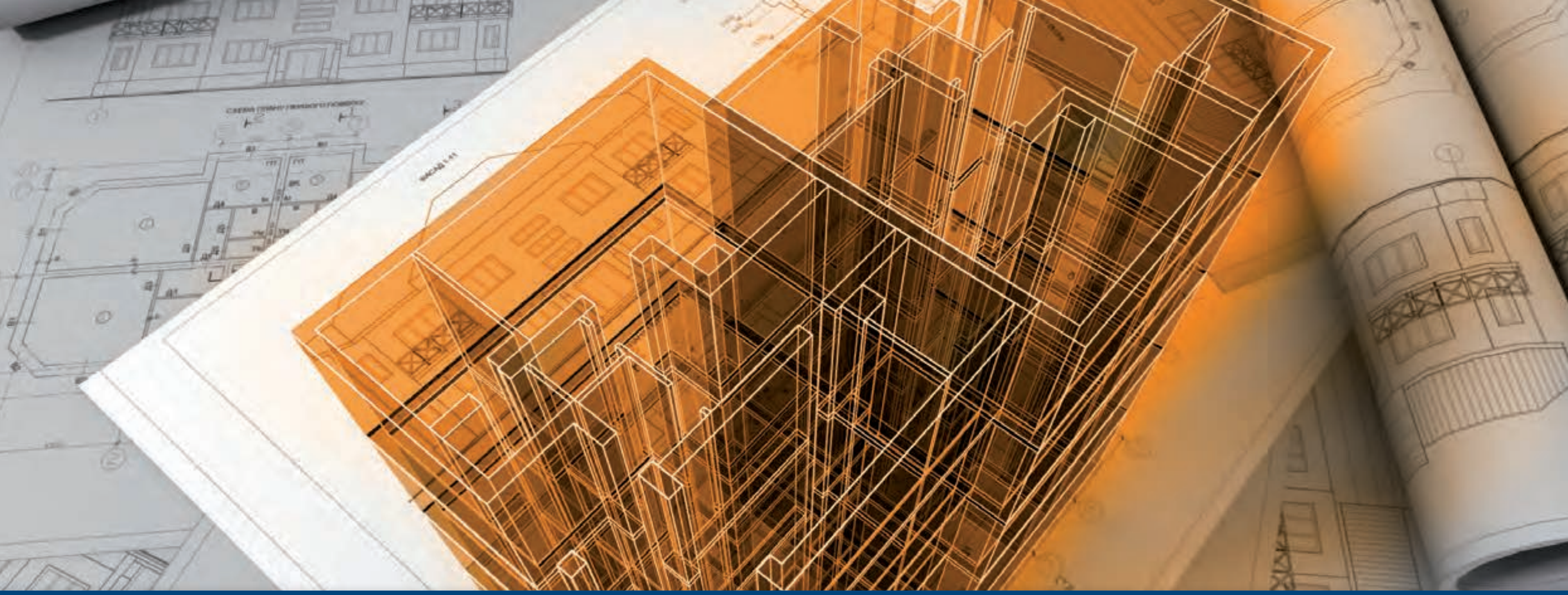

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