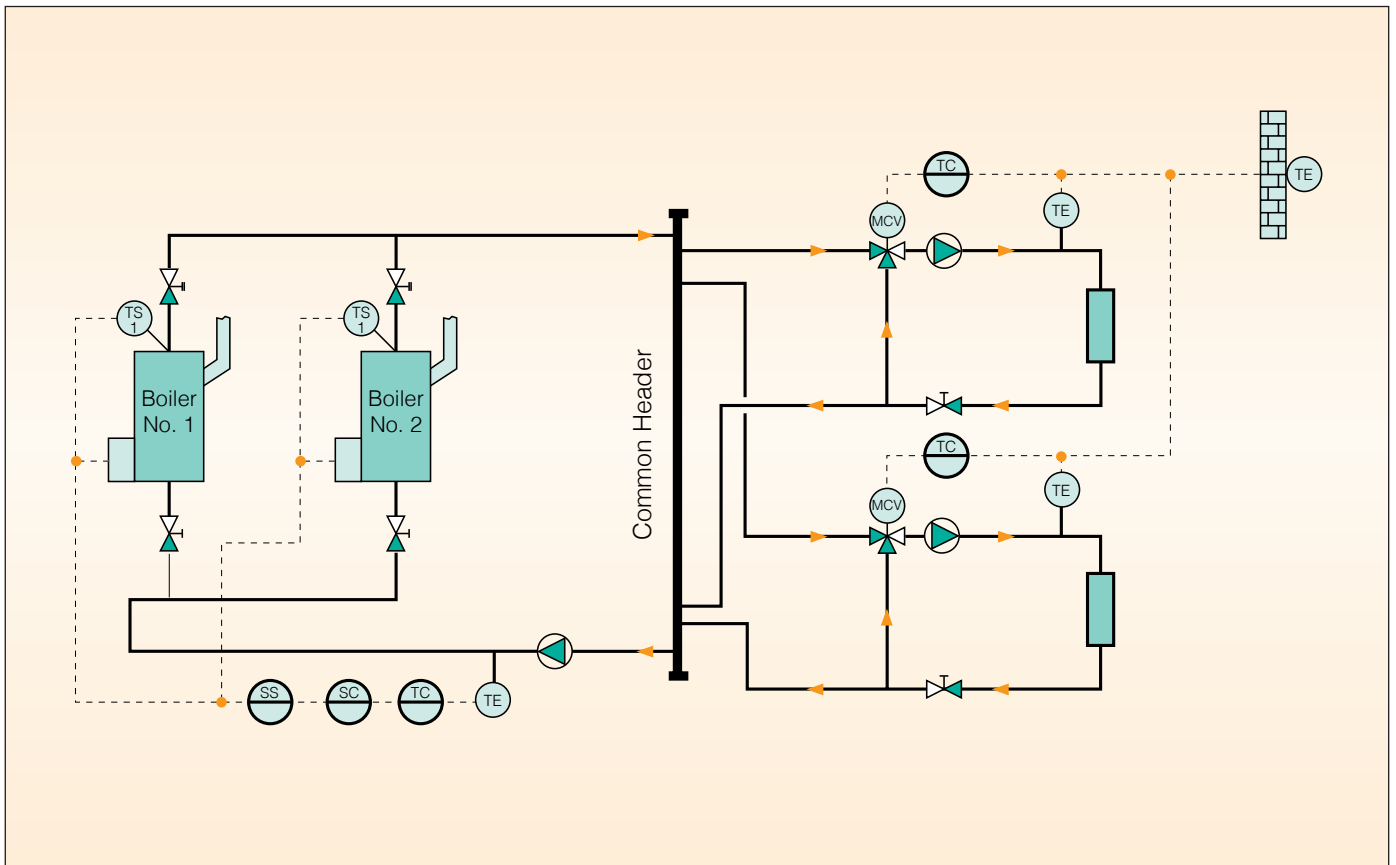


# Heating systems and their control



ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

March 1996

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## **Heating systems and their control**

Prepared for the Department of the Environment by

**BRECSU**

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## GLOSSARY OF TERMS

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<b>Title</b>	<b>Abbreviation</b>
Air handling units	AHU
Building management systems	BMS
Direct digital control	DDC
Differential pressure switch	DPS
Health and Safety Executive	HSE
Heating and ventilating	H&V
Hot water services	HWS
Low temperature hot water	LTHW
Mineral insulated copper sheathed	MICS
Proportional band	PB
Proportional plus integral	P&I
Proportional and integral derivative	PID
Pulse width modulation	PWM
Steel wire armoured	SWA
Thermostatic radiator valve	TRV

## LEGENDS

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<b>Title</b>	<b>Abbreviation</b>
Differential pressure controller	DPC
Differential pressure control valve	DPCV
Differential pressure sensor	DPE
Flow meter	FM
Heat meter	HM
Motorised control valve	MCV
Proportional controller	PC
Step controller	SC
Sequence selector switch	SS
Temperature controller/temperature compensator	TC
Temperature sensor	TS
Temperature sensor/thermostat	TE
Timeswitch	TSW



## 1. INTRODUCTION

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This General Information Report, produced under the Department of the Environment's (DOE) Energy Efficiency Best Practice programme, draws on the extensive experience of manufacturers, designers, installers and commissioning engineers to assist in the installation of reliable and energy efficient heating systems and controls in buildings.

It has been developed primarily to support a series of presentations given at workshops jointly run by BRECSU (for DOE) and CIBSE to professional design engineers and design technicians. Minor changes have been made following feedback from delegates attending workshops in 1995. The workshops are to be continued in 1996.

### 1.1 Overall Objective

It is estimated that 90% of H&V control systems in buildings are inadequate. This costs industry and commerce £500 million per annum in additional energy costs.



- The fundamental objective of the workshop is to provide guidance which will facilitate a substantial increase in the standard of controls installed in UK commercial buildings.

The supporting objectives are to enable the user to:

- ensure that the services are controllable
- select and specify the most suitable type of controls for a specific application
- ensure that the system is correctly installed and set up and continues to operate efficiently.

To achieve these objectives, the workshop:

- explains the operation of various types of controls as applied to different systems
- details the safety and regulatory criteria for systems controls
- provides examples of control of a large variety of common systems
- details recommended practice for specification, installation and commissioning of controls
- specifies simple checks to be undertaken during commissioning to ensure that control systems are operating as designed.

### 1.2 Consequences of Poor Design

- Time wasting coordination of services during construction and commissioning.
- Additional costs.
- Delayed handover.
- Unhappy clients.
- Poor energy efficiency.
- Litigation.

### 1.3 Responsibility

- Professional design team responsible for overall design and specification of control systems.
- Suppliers responsible for detail design to meet specification.

#### **1.4 Solution**

- Professional Design Team must use suitably experienced personnel to design and specify control systems.
- In-house specialists or staff training.
- External specialist providing independent design services (not potential supplier).
- Competent commissioning.



#### **1.5 Guidance**

- The guidance given includes best practice based at October 1994.
- Users must ensure that they conform with all current regulations.

#### **1.6 Further information**

Please contact BRECSU for further information on matters related to energy in buildings.

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#### **1.7 Acknowledgements**

This document has been developed under contract to BRECSU for the DOE by Graham Smith of Birling Systems Design Ltd.

Thanks are due to Paul Compton, Colt Group; David Morris, Consultant; Mike Steddy, Landis & Gyr; and Nick Skemp, BDP – members of the advisory group chaired by Colin Ashford.

If you have any feedback on the report/workshops, please contact: Colin J Ashford, BRECSU, Building Research Establishment, Garston, Watford WD2 7JR. Fax: 01923 664097.



### 2.1 Space Heating System Controls

L2.26 This section is not intended to apply to control systems for commercial or industrial processes.

### 2.2 Temperature Controls

L2.27 The requirement will be met by the appropriate provision of:

- a. thermostats and/or thermostatic radiator valves or any other equivalent form of temperature sensing control for each part of the space heating system designed to be separately controlled; and
- b. where the space heating system uses hot water, an external temperature sensor and a weather compensator controller which regulates the temperature of the water flowing in the heating system.

### 2.3 Time Controls

L2.28 The requirement will be met by the provision of heating time controls to maintain the required temperature in each part of the building designed to be separately controlled only when the building is normally occupied. The timing controls could be:

- a. for space heating systems with an output of 100 kW or less: clock controls which enable start and stop times to be manually adjusted;
- b. for space heating systems with an output in excess of 100 kW: optimising controllers which set the start time for each space heating system depending on the rate at which the building will cool down and then heat up again when the heating is switched off for a period and then re-started.

L2.29 Additional controls may be provided to allow sufficient heating for the prevention of condensation or frost damage during periods when the normal heating service would otherwise be switched off.

### 2.4 Boiler Sequence Controls

L2.30 The requirement will be met by the provision of sequence controls for multiple boiler installations where the boilers jointly serve loads in excess of 100 kW. A sequence controller should detect variations in heating demand and start, stop or modulate boilers in combinations which are effective for the purposes of the conservation of fuel and power.

### 2.5 Hot Water Storage System Controls

L2.31 For a system other than one heated by a solid fuel fired boiler the requirement will be met if:

- a. the heat exchanger in the storage vessel has sufficient heating capacity for effective control: a way of satisfying this requirement would be to provide vessels complying with BS 1566 or BS 3198 or equivalent and in particular with the requirements for the surface areas and pipe diameters of heat exchangers given in these standards; and
- b. a thermostat is provided which shuts off the supply of heat when the storage temperature is reached, and which in the case of hot water central heating systems is interconnected with the room thermostat(s) to switch off the boiler when no heat is required; and
- c. a timer is provided either as part of the central heating system or as a local device which enables the supply of heat to be shut off for the periods when water heating is not required.

L2.32 For systems with solid fuel fired boilers where the cylinder is not providing the slumber load the requirement will be met by the provision of a thermostatically controlled valve.

## 2.6 Alternative Approaches

L2.33 The requirement will be met by adopting the relevant recommendations in the following standards provided they achieve zoning, timing and boiler control performances equivalent to the above:

- a. BS 6880: 1988 Code of practice for low temperature hot water heating systems of output greater than 45 kW;
- b. CIBSE Applications Manual AM1: 1985 Automatic controls and their implications for systems design.

## 2.7 Interpretation of Building Regulations

The general requirements of the Building Regulations are good practice. The following notes clarify application of the regulations.

- Continuously occupied buildings may be heated at all times. However, in buildings such as old peoples homes and hospitals, the temperature requirements should generally be lowered overnight. This results in substantial energy savings.
- The wording of the room temperature control section, stating 'for each part of the space heating system designed to be separately controlled' causes confusion. It must be taken to mean that space temperature should be controlled.

Where a number of rooms form a zone with similar characteristics either of the following should meet the intent of the regulations.

- Control of the zone via a zone control system.
- Space temperature reset of a compensator serving that zone only.

Control of individual emitters is preferable but may not be cost effective.

## 3. DEFINITIONS OF CONTROL TERMINOLOGY

---



### 3.1 Open Loop Control

- A control loop that does not have any feedback from the results of its control action. It therefore does not react to the results of the control action.

### 3.2 Closed Loop Control

- A control loop that has feedback from the results of its control action. It therefore reacts to the results of the control action.
- Floating, proportional plus integral (P&I) and proportional, integral and derivative (PID) control all react to the result of the control action; they therefore must only be used on closed loop applications.

### 3.3 Velocity and Transfer Lags

- Velocity lag is the time taken for the effect of the control action to reach the point where the effect is sensed (closed loop only).
- Transfer lag is the time taken by the sensor to respond to a control action due to thermal capacity and rate of transfer of heat.

### 3.4 On/Off Control and Thermostats

- On/off control of heating, switches an item on when the temperature drops below the setpoint and off again when the temperature reaches setpoint.
- A switching differential is necessary for stable control. The switching differential is the difference in temperature between switching on and off.
- Room thermostats normally have an accelerator heater for improved control of space temperature. This gently heats the thermostat when the heating is switched on, and reduces its reaction time.
- On/off control via thermostats is applicable for both open and closed loop applications.

### 3.5 Time Proportioning Control

- Time proportioning control varies the amount of time that a device is on, compared to the time that it is off, in proportion to the offset from the setpoint.
- It provides more stable control than conventional on/off control in some circumstances.
- Time proportioning control is normally used for closed loop applications.

### 3.6 Floating Control

- Floating control has a deadband, within which no control action takes place. When the measured value goes above or below the deadband, the controller drives the controlled device in the direction required to bring the measured value back within the deadband.
- Floating control can provide stable control where there are step changes in heating output, which can cause considerable problems when setting up other modes of control such as P&I or PID.
- Floating control must only be used for closed loop control applications.

### 3.7 Proportional Control

- Proportional control is defined in BS 1523 pt 1 as the action of a control element proportional to its input signal. Hence the action is in proportion to the offset from the setpoint. There is 100% movement of the control element (valve, dampers, etc.) when the measured value deviates from the setpoint by the amount of the proportional band (PB).
- An offset is necessary to provide a control output. This can be put to good effect with open loop control such as boiler sequence control from return water temperature. With closed loop control an offset will result, the amount of offset is normally acceptable for applications such as space temperature control.

- Controllers where the setpoint is halfway through the PB can cause an immense degree of confusion when applied to boiler sequence control or similar functions, and results in many control systems being incorrectly set up.
- Proportional control can be used for both open and closed loop applications.

### 3.8 Proportional Plus Integral Control

- P&I control is the addition of integral action to the proportional action. The integral action is defined as the area integrated, of the offset from setpoint, over a period of time known as the integral action time.
- The effect of P&I control is to provide stable closed loop control, without any offset from the setpoint.
- P&I control must only be used for closed loop control applications.

### 3.9 PID Control

- PID control is the addition of derivative action to P&I actions. Derivative action is, the rate of change of the measured value.
- PID control provides very close control in situations in which variables are altering very rapidly.
- The benefits in accuracy and stability over P&I control are minimal and, to achieve better control, can be very time consuming during commissioning.
- PID control must only be used for closed loop control applications.

### 3.10 Multistage Control

Multistage control is the control of a number of stages of controller output in sequence with respect to a control variable.

- Control of multiple stepped heat outputs are normally controlled in sequence via a step controller, or digital outputs. Stable control with a closed loop can be difficult to set up due to the step outputs.
- Floating control is the best solution for closed loop control of multiple step outputs as a degree of offset is tolerated without causing an unstable situation.
- Problems with closed loop control are worsened when the devices being controlled have in-built controls or delayed actions.
- Where open loop control is used, proportional control action must be used. If the proportional band is set to match the design temperature drop of the system, reasonably stable flow temperature should result.
- Control of multiple modulating devices can be open or closed loop. Multiple modulating boilers can be controlled in this manner if the individual modulating control is modified to allow control from a single common point on the flow header. The control of each boiler outlet should be retained as a modulating high limit at the design outlet temperature.
- Combinations of modulating and stepped outputs are possible.

### 3.11 Heat Load Control

- Heat load control is the control of plant according to the total heat load on the system as defined by the following:

$$Q = M \cdot \Delta t \cdot c_p$$

- Where Q is heat load in kW, M is mass flow rate in kg/s,  $c_p$  is specific heat in kJ/kg/°C,  $\Delta t$  is system differential temperature in K (°C).

- A dedicated heat metering device or, preferably, a programme in a suitable programmable controller is required.
- Care must be taken in the selection of instruments. Significant errors can result if flow or differential temperature measurements are inaccurate.
- On system start up, flow and return temperature will be equal. The heat meter therefore records no load. Hence the system must have an overriding temperature control for start up.



## 4. SAFETY/PLANT SAFEGUARDS

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### 4.1 Safety Principles

- Safety controls should override all other functions. They can either be applied to individual items of equipment, such as the high limit thermostat on a boiler, or to multiple plant items, such as the panic button in a boilerhouse.
- System design, commissioning, operational and maintenance procedures must ensure compliance with all relevant safety legislation and codes such as the Health and Safety at Work Act and Gas Regulations.

### 4.2 Local Isolators

- Isolators must be designed to shut down the relevant item of plant and not allow it to restart under any circumstances without operator intervention.
- Where isolators are used for motors with star delta starters, or variable speed drives, auxiliary contacts are required. Early break, make late contacts may be necessary. Control lines at low voltage (240 V) should be marked 'Can be live when plant is isolated!'

### 4.3 Panel Switches

- Panel mounted switches are normally of the following types:
  1. Test/Off/Auto
  2. Hand/Off/Auto
  3. On/Off/Auto.
- Switches should not override safety controls or local isolators. The test (hand or on) position and off position should override all other functions.

### 4.4 Safety Shut Off

- All plantrooms and boilerhouses should have panic buttons installed which, when pressed, will stop all plant and shut off fuel supplies.
- Panic buttons should be located internally at each exit.
- A panic button located outside the plantroom is also recommended.



### 4.5 Protection against Condensation and Freezing (Fabric/Frost Protection)

- These functions should not override safety controls, local isolators, or test or off positions of control panel switches.
- They should override all other automatic control functions.

#### 4.5.1 Building Fabric Protection

- The main purpose of fabric protection is to protect the fabric of the building and contents from frost and condensation damage.
- Sensors should be located in the part of the building which is likely to cool fastest or is the most vulnerable to damage. This is normally a north facing corner on the top floor.
- Fabric protection should maintain the building at the minimum required temperature, normally between 4°C and 10°C. The lower the setting the less energy is used for fabric protection.
- For buildings in which fan convectors are the main type of heat emitter, the fans should operate when heating is on for protection against frost or condensation.

#### 4.5.2 Frost Protection

- The first stage runs the system pumps when the outside temperature drops to 2-3°C.
- The second stage starts the boilers when the system return water temperature drops below 5°C. The boilers should be enabled until a return water temperature of 50 to 60°C is reached to prevent boiler cycling and flue gas condensation, unless condensing boilers are used.
- Separate frost protection of pipework is required where pipework is exposed, or likely to be subjected to freezing temperatures. Normally via trace heating.
- Protection of dead legs caused by fully open three port valves required.

#### 4.6 Health and Safety Executive Guidance Note PM5 - Automatically Controlled Steam and Hot Water Boilers



- The control thermostat must be set to shut off the burner at a pre-determined temperature which provides a margin of at least 17°C below the temperature of saturated steam corresponding to the pressure at the highest point, above the boiler, of the circulating system.
- The equivalent margin for the high limit hand reset thermostat is 6°C
- Water temperature must be measured at or near the boiler flow outlet for the purposes of normal controls and independent overriding controls
- All individual boiler control and high limit thermostats should therefore be located in the boiler waterway, near the outlet, or in the outlet pipe prior to any isolation valve.

The following do not meet the requirements of PM5.

- Boilers with burner control thermostats located in the inlet.
- Control systems with the individual burner control thermostats relocated to the main header.

#### 4.7 Pressurised Systems

- Where systems are pressurised, high and low pressure switches should be provided to inhibit operation.

#### 4.8 Maintainability

- Control design must ensure that plant can be maintained without causing incorrect setting or damage to the control systems.
- Provision must be made for temporary isolation or override of systems to allow for maintenance by non-skilled operators.

#### 4.9 IEE Regulations, Latest Edition

- These detail the requirements for electrical installation.

#### 4.10 Other Regulations and Safety Requirements

Gas and oil-fired boiler installation must also comply with:

- British Standards
- European Community Standards (where these are applicable)
- British Codes of Practice
- Local Authority HSE Regulations
- Insurance Company Requirements
- Gas Safety Regulations 1984
- Gas Region Requirements.

These primarily relate to the safety requirements of installation. In particular, boiler stop/start and sequence controls should be designed so as to not interfere with the packaged safety control of individual boilers.



## 5. TIME CONTROLS

### 5.1 Introduction

- Selection of the correct time control for particular applications is critical to the efficient operation of systems.

### 5.2 Timeswitches

- Timeswitches should be used in accordance with the Building Regulations.
- Timeswitches should have a resolution of 15 minutes or less for effective operation.
- Spring reserve or battery back-up is recommended to prevent the time programme being affected by power cuts.

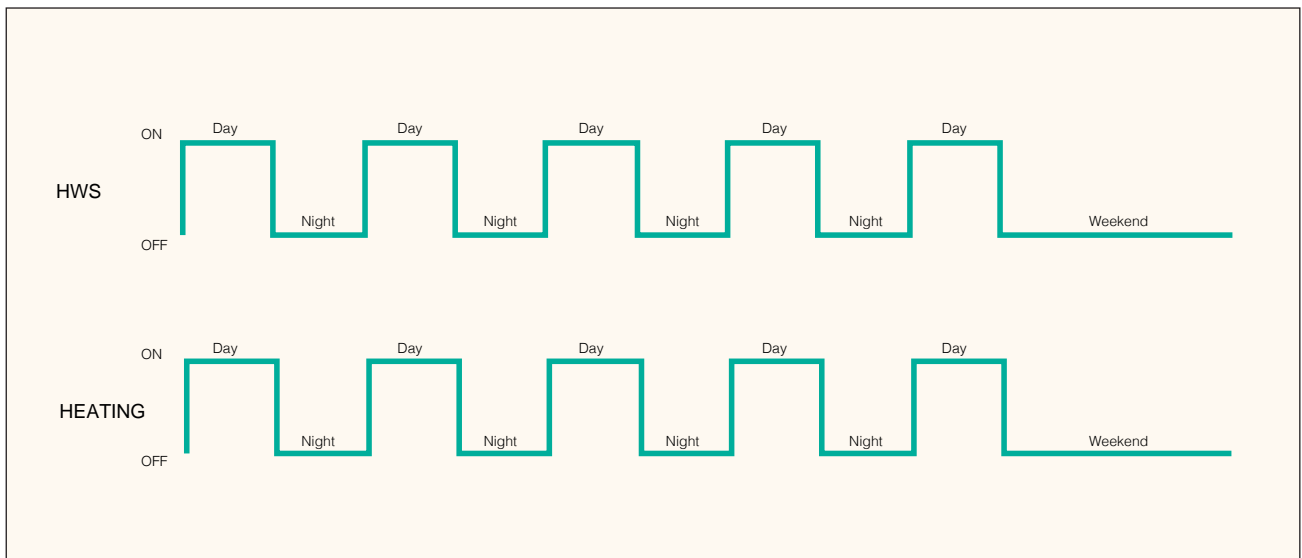


Figure 1 Timeswitch profile for typical office application

### 5.3 Optimum Start

- Optimisers should be used in accordance with the Building Regulations.
- Optimisers may be economically used as low as 30 kW space heating load.
- An optimiser starts the heating system in a building at a variable time, so that the building reaches the desired space temperature at the start of the occupancy time.
- Lower cost optimisers may use outside air temperature only to calculate the optimum start time.
- Most optimisers calculate the start up time from a combination of space and outside temperature sensor outputs - the preheat switching line.
- The preheat switching line is often a linear slope. The accuracy is such that, on average, they only achieve the desired space temperature within thirty minutes or less from the start of occupancy time on 35% of heating days.
- The BRESTART algorithm has a logarithmic preheat switching line which produces significantly more accurate and consistent results. Typically, the desired space temperature will be achieved within fifteen minutes or less from the start of occupancy time on 60% of heating days. It also does not require the use of separate programs for Monday morning or post holiday operation.
- Most optimisers have a self adaptive optimum start function which adjusts the maximum preheat period or switching line over a period of time. Limitations must be included in this program to prevent excessive preheat periods following equipment failure.
- Optimiser performance is poor with emitter margins under 20%.

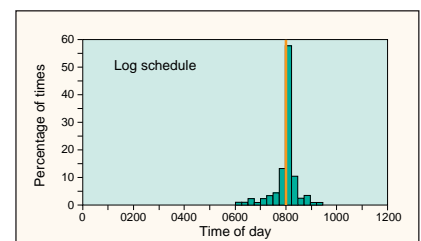
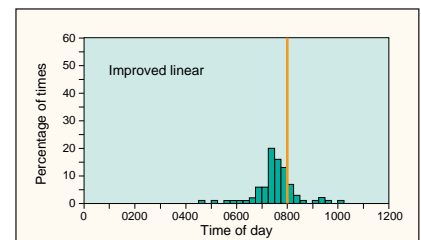
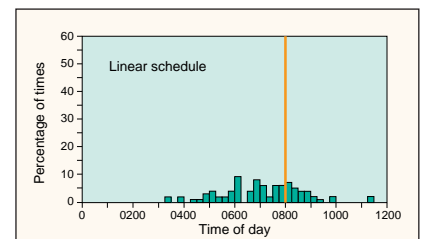


Figure 2 Optimiser performance for 0800 hrs occupation

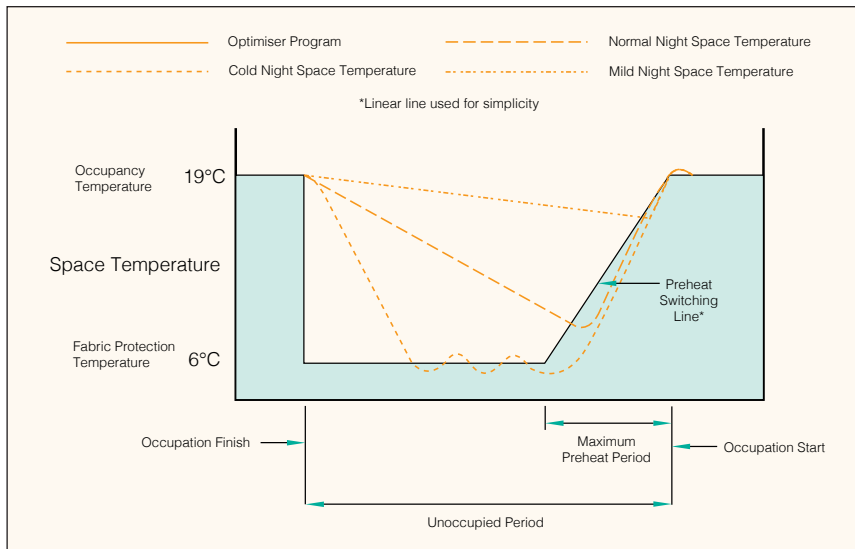


Figure 3 Optimiser function

#### 5.4 Optimum Off

- Optimum off stops the heating prior to the end of the occupancy time to allow the building to cool to a lower preset temperature by the end of occupation.
- Optimum off should be treated with caution and, if used, should be limited to a maximum period at the end of occupation.

#### 5.5 Daytime Optimisation

- Daytime optimisation will switch the heating off during the occupancy period if the rate of temperature decrease is predicted to be slow.
- One internal sensor may not be typical of the whole heated volume in a larger building.
- Not suitable for buildings with long reheat periods.

#### 5.6 Monday/Holiday Start

- Extended preheat period is often required for the first day of occupation.

#### 5.7 Preheat/Boost

- The energy used for preheat is minimised by shortening the preheat period as much as possible.
- The temperature of the compensated circuit is 'boosted' above the normal compensated flow temperature.
- LTHW compensator valve fully open for boost.
- Lightweight buildings boost - 20°C parallel shift of slope to prevent overshoot.
- Other systems boost to maximum flow temperature limit.
- Boost function should be terminated once the space temperature reaches the desired occupancy temperature or time.

#### 5.8 Intermittent, Extended or Random Occupancy Periods

- Schools, village halls, etc require the facility to extend or have additional occupancy periods.
- Some simple control systems have the facility for programming in lower temperature settings during low-occupancy periods. Controls are based on additional internal thermostats and simple timeswitches.




#### 5.9 Override Facilities

- Override facilities should not wastefully heat unoccupied areas.
- Simple override facilities are necessitated in buildings with flexible occupancy periods if users lack the necessary expertise to reset occupancy programs.
- The most successful method is normally to have a pushbutton which overrides the timeswitch or optimiser so providing heat for a preset fixed period of time.


## 6. BOILERS

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### 6.1 Introduction

- Inadequate or incorrect application of boiler control can easily add 15-30% to fuel consumption compared to a well-controlled system.
- Control of multiple boilers is generally poor.
- When fully implemented in 1998 the boiler efficiency regulations will lead to more efficient part load operation for most installations and in the case of low water content boilers will reduce the need for methods to reduce standing losses.
- Prior to 1998 the use of high efficiency or condensing boilers is recommended.
- Where medium and high water content boilers are used methods of reducing standing losses should be evaluated.
- Ideally, boilers whose heat output is not required should be cold or cooling, for low water content boilers this is not normally economically viable and can create other problems if applied.
- Older boilers having standing losses of up to 7% can result in additional annual consumption of 20-30% if standing for long periods at full flow temperature.
- Measures to ensure cold or cooling boilers where heat output is not required must be effectively engineered: half measures can be far worse than no measures.
- Segregation of heating boilers and hot water service (HWS) generation is recommended where economically possible. 
- The reduced standing losses and improved part load efficiency of modern well insulated, low water content boilers normally allows very simple hydraulic arrangements to be used for multiple boilers.
- Simple layouts do not require the use of individual boiler pumps, or automatic isolation valves, which are the cause of many problems with the control of multiple boilers.

### 6.2 The Boiler (Efficiency) Regulations 1993

- New installations from 1 January 1998 must have boilers complying with the boiler efficiency regulations which state minimum full load and part load efficiencies. 
- During the transitional period between 1 January 1994 and 1 January 1998 boilers may either meet the full requirements of the regulations, or any British Standard or OFTEC standard.
- The regulations apply to boilers and burners which have an effective rated output between 4 kW and 400 kW, and a water exit temperature of less than 105°C.
- There are certain exceptions to the regulations such as back boilers.
- In general all boilers have to conform with the minimum efficiency standards at full and part load, and have to be CE certified.

### 6.3 Fuel Shut Off

- Gas/oil valves should be interlinked with the safety shut off system to stop fuel flow in the event of fire or panic button operation.
- Gas-fired boilers should have the gas valve interlocked with a gas detector   
Oil-fired boilers should have the oil valve interlocked with fusible links above each boiler.

#### 6.4 Burner Control

- The objective of burner control is to control the burner to maintain the desired boiler flow (outlet) temperature.
- This applies to all boilers regardless of size, and number of boilers in multiple boiler installations.
- Burner control thermostats and sensors must be located in the boiler outlet.
- Maximum temperature settings for control and high limit functions are governed by HSE PM5.
- On/off burner control is the most common type of control even though part load efficiency is poor compared with the other types.

#### 6.5 Two Stage Burner Control

- Two stage (high/low) burners provide on average 40% of output at low firing rates.
- Control of the burner is normally via a combined control and high limit thermostat.
- The high fire thermostat must be set lower than the burner (low fire) control thermostat. The difference in setting should be at least as great as the switching differential of the burner (low fire) control thermostat to prevent unnecessary operation of high fire. This is normally at least 5°C. Consequently there will be a wide variation in flow temperature from a boiler with two stage burners.
- For multiple installations of boilers with two stage burners the second stage should be part of the sequence control rather than the separate thermostat.
- The burner control (low fire) thermostat must limit outlet temperature at high and low fire where high fire is enabled via the sequence control.



#### 6.6 Modulating Burner Control

- Modulating burners can have a better efficiency at low load than at high load.
- The burner modulates the amount of fuel and air to provide a variable output from 20-30% to 100%.
- Efficiency can be improved by the use of oxygen trim control which continuously optimises the air/fuel ratio. This gives savings in the order of 2% on a well maintained boiler and can yield savings of 3 - 5%.
- Sequence control of modulating boilers may need interfacing with the burner modulation if control is based on sensing of flow temperature.
- Control sensors must be provided at the boiler outlets to limit the outlet temperature of individual boilers as required by HSE PM5.

#### 6.7 Packaged Burner Controls

- Packaged burner controls have an in-built lockout sequence to prevent operation with failure to ignite on start up or flame failure during firing.
- These safety controls must remain in operation for each boiler in multiple boiler installations.
- Where boilers are directly compensated, or multiple modulating boilers are used, the burner control may be overridden to stop firing or reduce output only.

#### 6.8 Boiler Sequence Selection

- Boiler sequence selection shares the duty between multiple boilers over a period of time by changing the order of boiler operation.
- The order is normally manually selected via a sequence selection switch but can be automatically rotated on a time or usage basis.
- Condensing boiler(s) must always be the lead boiler(s).

### 6.9 Boiler Sequence Control

- Boiler sequence control enables only the minimum number of boilers/burners required to meet the system demand.
- Good sequence control avoids short cycling of burner operation and therefore enhances energy efficient and stable operation.
- It achieves this by progressive enabling of burners with increasing system demand and disabling of burners with decreasing system demand.
- Boiler sequence control normally enables the number of boilers required with respect to the boiler circuit return temperature, although flow temperature and other methods are also used.
- Boiler sequence control can reduce standing losses in association with effective automatic isolation where economically viable.



### 6.10 Pressurised Systems

- Individual boiler control and high limit thermostats settings may be increased in line with HSE PM5.
- Increased boiler control and high limit thermostats settings can be subject to misunderstanding during operation maintenance.
- Suitable warnings and record information must be provided to prevent incorrect settings and subsequent control problems.
- High pressure switch should stop boiler operation.
- Low pressure switch should stop the operation of both boiler and pumps.
- Functionally independent of control pressure switches.

### 6.11 Boiler Pump Interlocking

- Boilers cannot operate unless the selected duty pump is running.
- Direct drive pumps - interlock via a starter auxiliary contact is normally adequate.
- Belt drive pumps - water flow switch should be used to prove flow.
- Boiler primary pumps should normally run on for at least two - five minutes after the boiler is stopped, to prevent boiler overheating and lockout.

### 6.12 Flue Dilution

- Boilers should be interlocked with the dilution fan via a differential pressure switch (DPS).
- DPS element should ideally have a temperature rating suitable for the flue gas, or impulse lines of sufficient length to prevent the hot gas coming into contact with the element.

### 6.13 Corrosion

- Condensation can occur when the surface temperature of the boiler falls below the dew point of the constituent parts of the boiler flue gas.
- Corrosion caused by condensation, particularly with oil-fired boilers.
- Condensation will not occur when the boiler is up to temperature.
- Not normally economical to provide special methods to reduce boiler corrosion.
- Rapid warm up of boilers will minimise corrosion.

### 6.14 Boiler Warm Up

- Rapid warm up with separately pumped primary circuit.
- Only primary circuit operates until up to temperature.
- Individually pumped boilers can also operate in a similar manner dependent on circuit design.
- Very large systems - enable zoned circuits sequentially.

## 6.15 Methods for Reducing Boiler Standing Losses




### 6.15.1 Target

- Standing losses should be less than 10% of total consumption.




### 6.15.2 Flue Dampers and Fans

- Air inlet or combustion flue dampers should be used on larger boilers to reduce standing losses from natural draughts through boilers.
- Forced draught boilers should have the fans interlocked with the burner operation.


### 6.15.3 Automatic Boiler Isolation

- Automatic boiler isolation isolates the flow through off-line boilers in multiple boiler installations and reduces losses from individual boilers. 
- Automatic boiler isolation adds to the complexity of multiple boiler systems and often leads to control problems.
- Motorised isolation valves have to be tight shut-off to prevent leakage between ports that will keep the boiler warm.
- No point in installing motorised isolation valves that leak, or are deliberately set to provide a minimum flow. 
- Injection manifold systems normally provide boiler isolation more successfully than other methods but are not without their problems.
- The additional cost of valves, pumps, etc is normally only justified on large boilers. 
- Some manufacturers are concerned about the effects of repeated heating and cooling of boilers and do not recommend isolation valves.

### 6.15.4 Boiler Inhibit

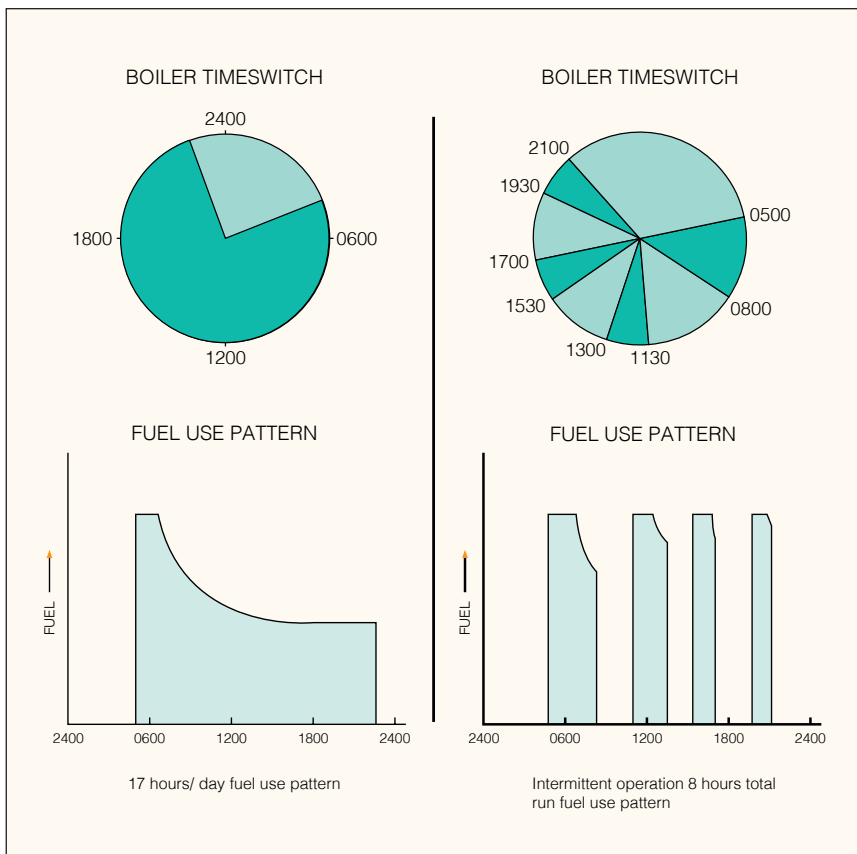
- Boilers and primary circuit inhibited when boiler output is not required. 
- Minimise boiler and pipework standing losses, as well as pump energy.
- Inhibit when compensator valve(s) on full recirculation.
- Time delays required to prevent rapid cycling.
- High outside temperature shutdown for complete heating system.
- Daytime optimisation for complete heating system via optimiser more sophisticated. 
- Where the boilers also serve HWS care must be taken to ensure that adequate response to HWS demand is incorporated.
- Normally limited to small buildings with rapid reheat. 

### 6.15.5 Intermittent Boiler Operation

- Where boiler or primary circuit standing losses are high.
- Intermittent boiler operation for HWS during summer.
- 25-50% energy savings possible.
- Adequate HWS storage capacity required.
- HWS supply temperatures must be above 60°C to avoid risk of legionella.
- Stopgap measure prior to the efficient generation of HWS. 

## 6.16 Control of Single Boilers

- Packaged controls provide temperature, high limit and lock-out functions.
- Domestic boilers without high limit functions should not be used in commercial applications.
- Direct acting compensators most effective where HWS segregated.
- Domestic direct acting compensators with HWS provision possible for small commercial buildings.




**Figure 4 Intermittent boiler operation for summer HWS**

### 6.17 Control of Multiple Boilers Introduction


Many multiple boiler control systems operate unsatisfactorily with:

- Poor economy of operation.
- Reduction in the reliability.
- Reduction in the working life.
- Aim to operate individual boilers at, or near, the point they are at their most efficient via effective sequence control.
- Where possible reduce standing losses.
- Where possible completely segregate HWS.
- Ensure hydraulic balance under all operating conditions.

### 6.18 Return Temperature Sequence Control

- Recommended for the vast majority of applications - simple and effective. 
- Constant flow required for simple proportional control.
- The lead boiler should always be enabled when the primary circuit is in normal operation.
- Subsequent boilers enabled as return temperature reduces.
- Switching differential required for each stage.
- Dilution effect can normally be ignored.

### 6.19 Flow Temperature Sequence Control

- Extensive setting up and maintenance. 
- Effective for modulating burners.
- Can be used with variable flow.
- Essential for compensation of boilers.
- Pressurised system normally required.
- Often ineffective due to common problems.

### 6.19.1 Interaction with Individual Boiler Control Thermostats

- Individual boiler control thermostats must be set higher than sequence control setting to avoid interaction.
- Where interaction sequence control is totally ineffective.
- Setting must take into account actual boiler switching differentials.
- Pressurised system allows higher individual boiler settings.

### 6.19.2 Dilution of Flow Temperature

- Dilution of flow temperature occurs with parallel (non isolated) multiple boilers due to unheated flow through off-line boilers.
- Sequence control setting must be below lowest resultant flow temperature.
- Pressurised system allows higher individual boiler settings.

### 6.19.3 Reaction to Cold Slugs of Water from Isolated Boilers

- Cold slug from isolated boiler brought on-line can cause control instability.
- Overcome by the use of individual boiler pumps and three port valves to recirculate the water around the boiler until the water has heated up.

### 6.19.4 Control Modes

- Flow temperature will reduce with increasing load with proportional control, or a multistage thermostat due to offset.
- Opposite of what required.
- Small proportional bands with proportional control or small switching differentials will result in unstable control.
- P&I control eliminates offset.
- P&I difficult to set up with on/off and two stage burners, etc.
- Floating control acceptable compromise - stability and temperature variation.
- Floating control would normally be easier to set up than P&I.

## 6.20 Control of Individually Pumped Boilers

- Maintain minimum flow rates through on-line boilers.
- Reduce heat losses from off-line boilers only if correctly engineered.
- Economically justified on large boilers only.

### 6.20.1 Injection Manifold Boiler Systems

- Also known as a single pipe high level header.
- Individual boiler flow and return are connected close to each other on the manifold.
- Minimal hydraulic interaction between the manifold and the boiler.
- Flow through the boiler stops when the pump is stopped.
- Manifold should be at a higher level than the boilers to prevent gravity circulation.
- Reduced heat output from boilers where inlet water heated unless higher individual temperature settings with pressurised systems.
- Primary pump selection could be difficult.

### 6.20.2 Parallel Connected Individually Pumped Boilers

- Variable primary circuit flow.
- Proportional return temperature sequence control not possible.
- Cold off-line boilers unlikely unless additional measures.
- Cold slugs if off-line boilers isolated effectively.
- Three port valves and warm up bypass effective but expensive.
- P&I control difficult to set up and maintain.
- Heat load control effective but expensive.

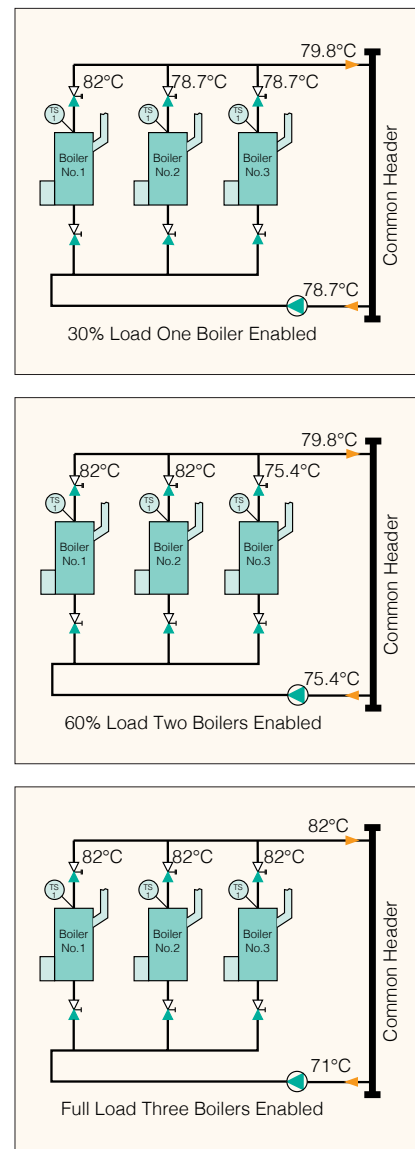



Figure 5 Dilution of flow temperature




### 6.21 Control of Series Connected Boilers

- Return temperature sequence control effective.
- Overall pressure drop through the two series connected boilers will be eight times that through parallel boilers.
- Individual boilers should have relatively low pressure losses.
- Low flow rate, high temperature differential, reduces pumping losses.
- Differential 17K normal economic maximum.

### 6.22 Heat Load Sequence Control

- Use if flow rate varies and flow temperature sequence control will be difficult to set up or maintain effectively.
- Additional cost due to flow meter and possibly dedicated heat load controller.
- Flow meters now cheaper in real terms.
- Magnetic flow and vortex meters successful.
- Differential pressure metering 3 to 1 maximum turndown. 

### 6.23 In-line Modular Boilers

- Equivalent to a row of identical small boilers.
- Normally connected in parallel.
- Dilution effect where large number of parallel modules.
- Constant flow primary circuit required.
- Proportional sequence control from return water temperature.
- Individually pumped modules - control problems. 
- Segregate modules for HWS provision.


### 6.24 Stacked Modular Boilers

- Modular boilers with individual combustion chambers should be controlled similarly to in-line modular boilers.
- With common combustion chamber the lower modules starting first to preheating the upper off-line modules.
- No 1 module fan purges the common combustion chamber on start up.
- The firing order must be fixed; the number one module must always lead.
- A boiler sequence control system must be used.
- Module control thermostats in the inlet contravenes HSE PM5.
- Module control thermostats with different settings must not be used instead of sequence control as slight drift will alter order of firing.

### 6.25 Condensing Boilers - Principles

- Flue gas used to preheat the inlet water via additional heat exchanger.
- Inlet water temperature must be below 54°C to condense and thus release latent heat.
- Low inlet temperatures for significant periods required.
- Systems must have suitable characteristics.

### 6.26 Condensing Boilers - Types and Hydraulic Layouts

- Condensing heat exchanger integral or 'split'. 
- 'Split' exchanger connected to part of the system where return water temperatures are potentially lower.
- Compensated system return, prior to the mixing valve bypass, maximum potential gains.
- Low loads potential may be wasted as heat not needed.
- Multiple secondary circuits must not be connected to common heat exchanger.

### 6.26.1 High Differential Temperature Systems

- Increased periods of condensing if effective.
- 17K differential normal economic maximum.



### 6.26.2 Low Temperature Systems

- Warm water systems.
- Flow/return temperature below 54°C.
- Large heat emitters.
- Low surface temperature.
- Heated floors.

### 6.26.3 Variable Temperature (Compensated) Systems

- Preferably single boilers with separate HWS.
- Minimum boiler flow rate at all times.

### 6.26.4 Combinations of Condensing and Conventional Boilers

- Condensing boilers operate first.
- Arrangement of the sequence selection only.
- No special case for automatic isolation valves.
- Combinations of condensing and high efficiency boilers desirable.
- An injection manifold (high level header) system may be appropriate.



### 6.26.5 Space Temperature Controls

- TRVs and other space temperature controls should be used wherever possible.
- Space temperature controls improve overall energy efficiency.
- Ineffective space temperature control causes overheating and waste.
- Wasting heat to improve boiler efficiency is not effective.

## 6.27 Boiler Energy Saving Devices

- High levels of energy savings claimed (typically 25-30%) from improved control of boilers.
- In general, these are based on provision of more accurate boiler thermostats, coupled with delay devices to reduce the boiler firing cycle rate.
- Will save energy in some situations.
- Not universally applicable.
- Money better spent on the above measures - particularly reduction of standing losses.



## 6.28 Causes of Unsatisfactory Multiple Boiler Operation



- Many multiple boiler installations have unsatisfactory operation.
- Common causes are detailed in the following sections.

### 6.28.1 Leakage through Automatic Isolation Valves

- Purpose - stop flow through off-line boilers and reduce standing losses.
- Butterfly valves often used with 0.5-1.0% Kv let-by which can negate any savings.
- Valves set to allow 5% flow to ensure the boilers are kept warm are a complete waste.
- Tight shut-off valves must be used for effective isolation.

### **6.28.2 Varying Primary Circuit Flow Caused by Automatic Isolation Valves**

- Automatic isolation valves cause the flow in the primary circuit to vary.
- Return water temperature unrepresentative of system load.
- Proportional return water temperature control cannot be used.

### **6.28.3 Varying Primary Circuit Flow Caused by Individually Pumped Boilers**

- Individually pumped boilers connected in parallel vary the flow in the primary circuit.
- Return water temperature unrepresentative of system load.
- Proportional return water temperature control cannot be used.

### **6.28.4 Dilution of Flow Temperature with Multiple Boilers Connected in Parallel**

- Dilution of flow temperature occurs when boilers are off-line.
- Flow temperature sequence control will not be able to maintain the set flow temperature where boiler supply temperature and sequence control temperature settings are the same.
- Can be overcome with higher individual boiler settings with pressurised systems (within PM5).
- Insignificant effect with return temperature sequence control.


### **6.28.5 Reduced Heat Output with Injection Manifold Boiler Systems**

- Inlet temperature to subsequent boilers heated by first in line.
- Reduces  $\Delta t$  and capacity of subsequent boilers.
- Can be overcome with higher individual boiler settings with pressurised systems (within PM5).

### **6.28.6 Unequal Boiler Capacity and Stand-by Control**

- Unequal capacity boilers ideally require individual return temperature sequence control settings.
- Fixed firing order required if individual boiler settings.
- Where HWS not segregated smallest boiler lead in summer, largest in winter.
- Where 100% duty/standby the standby boiler should only be brought in on failure of the duty unit not on sequence control.

### 6.28.7 Lead Boiler Operation

- Control systems which enable and disable the lead boiler can cause unstable operation if the sequence control system and the boiler control thermostat are trying to achieve the same function.
- For most applications, lead boilers should be permanently enabled and other boilers enabled as required by the sequence control. 
- Where the sequence control is directly compensated, or boiler thermostat settings are increased on pressurised systems with flow temperature sequence control, the lead boiler must be enabled and disabled by the sequence control to ensure that the required flow temperature is achieved at low loads.

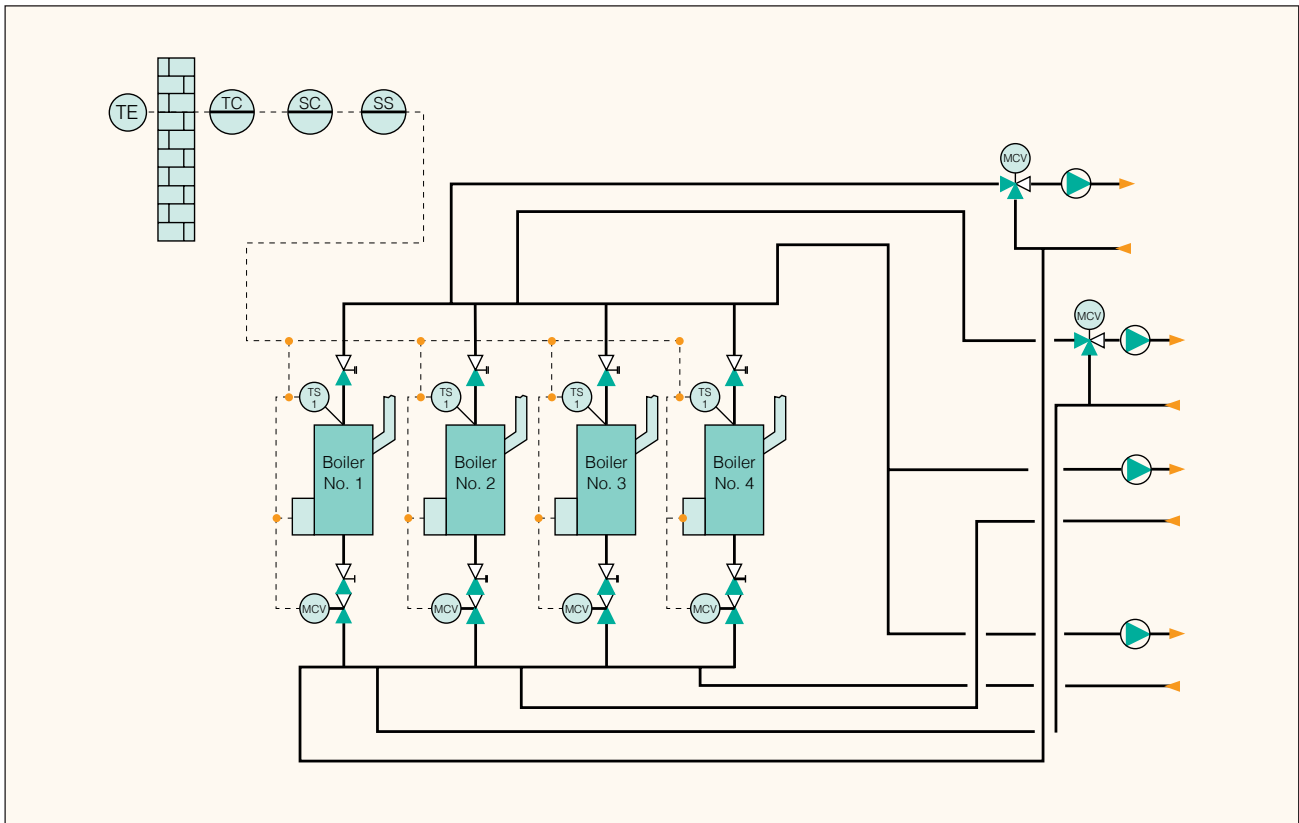

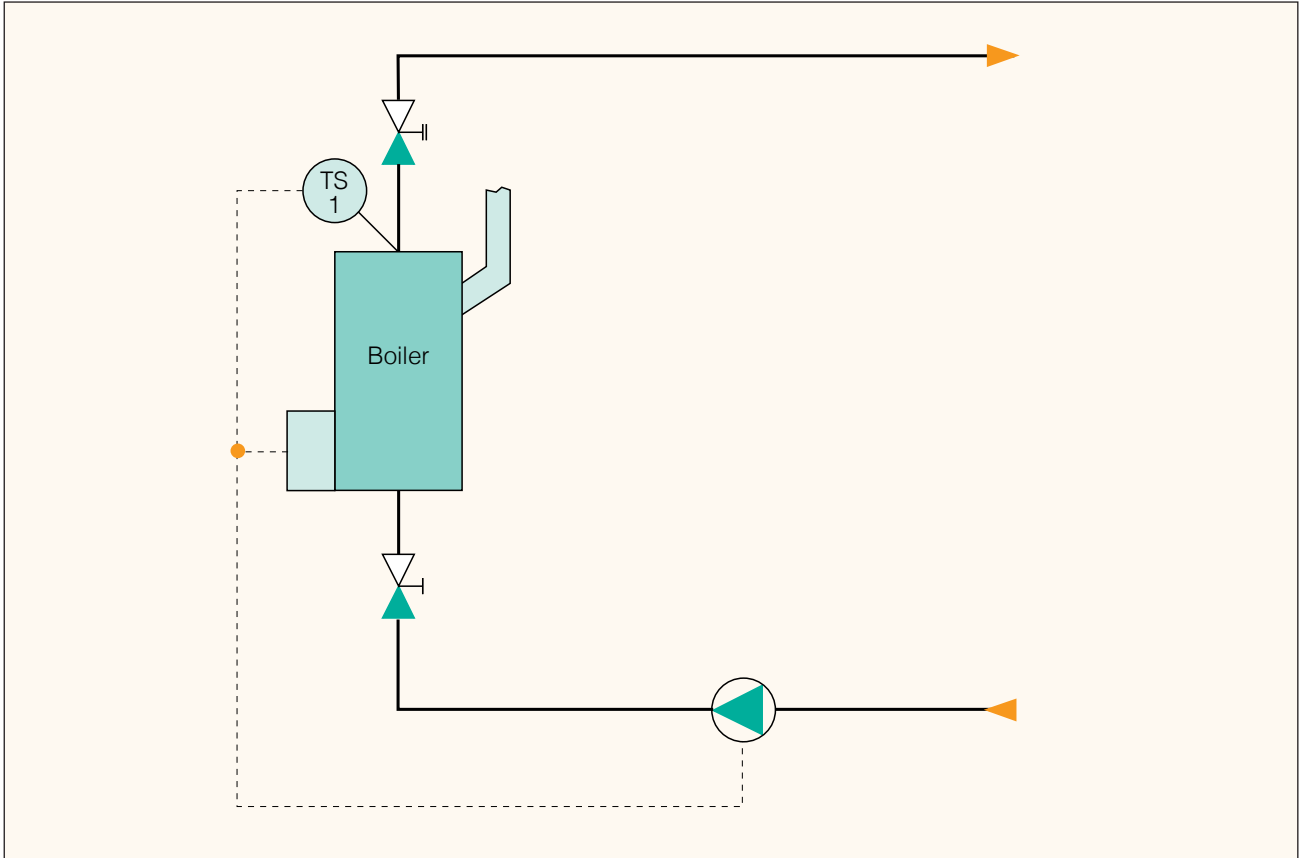


Figure 6 Problematic system

### 6.29 Control of Problematic Systems

- Outside temperature sequence control used where other methods not possible. 
- A minimum number of on-line boilers may be required for some loads.
- Possibly limit number of boilers for initial frost and fabric protection.
- Truly open loop with no feedback from the system demand.
- More effective than most currently installed sequence control systems.

### 6.30 Application Sheet B1 Single 'commercial' boiler



#### Legend

TS1 = burner control and high limit thermostat

#### Principle of Operation

Individual boiler firing is controlled by packaged boiler thermostat.

#### Application

- on/off
- high/low firing
- modulating

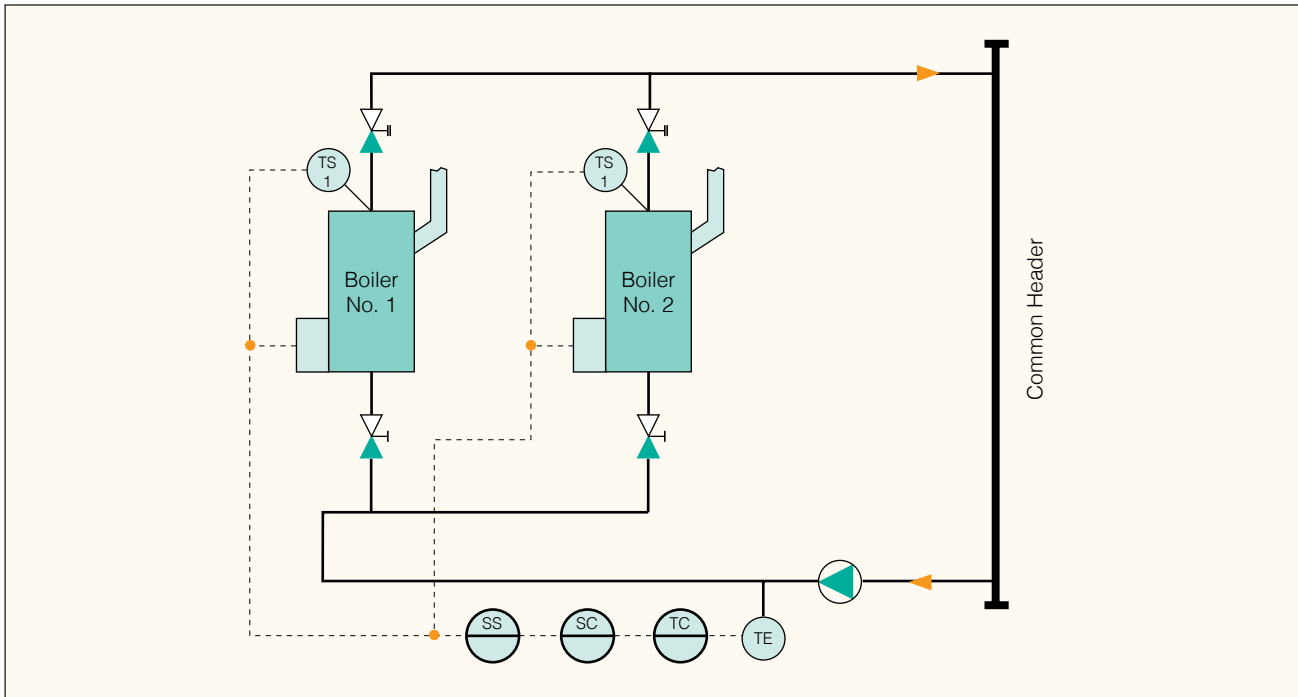


High/low firing and modulating boilers rarely have application as large single boilers are not frequently installed.

#### Notes

Constant flow through the boiler should be maintained at all times. Pump run-on on shutdown is recommended to dissipate heat and avoid high limit operation.

### 6.31 Application Sheet B2 Dual and multiple parallel connected low water content boilers



#### Legend

TS1 = burner control and high limit thermostat    TE = temperature sensor  
 TC = temperature controller    SS = sequence selector switch  
 SC = step controller

#### Principle of Operation

The lead boiler is enabled at all times heating is required. Subsequent boilers are enabled as the return water temperature drops in a manner proportional to temperature. Individual boiler firing is controlled by packaged boiler thermostats on boiler outlets.

#### Application

- on/off
- high/low firing
- modulating

Also see Application Sheet B3 for modulating boilers with flow temperature sequence control.

#### Notes

Constant flow in the primary circuit should be maintained at all times. The primary circuit pump has low power absorption due to the low resistance of the primary circuit. Some dilution of flow temperature occurs at low loads but is normally of little importance. Dilution increases the greater the number of boilers. Run on of primary pump on shutdown is recommended to dissipate heat and avoid high limit operation. Control via a proportional controller and step controller, or operation at specific temperatures with direct digital control (DDC), must be used. Where two boilers only are being controlled, an accurate thermostat or single stage controller may be used. P&I, PID or floating control must not be used.

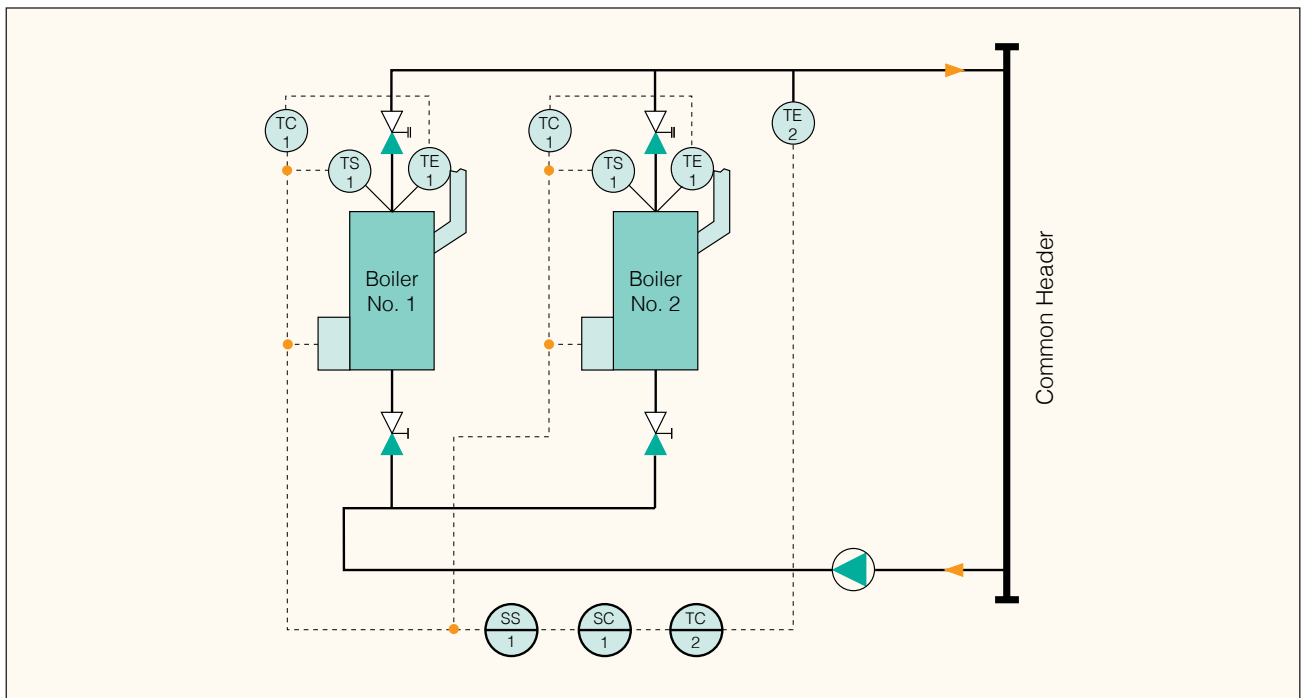
For 2 stage burners high fire should be controlled by sequence control provided maximum outlet temperature is controlled by boiler thermostat.

Reverse return connection of modules for equalising flows is recommended.

**Very highly recommended for simple effective and reliable control.**



### 6.32 Application Sheet B3 Multiple parallel connected low water content modulating boilers



#### Legend

- |  |                               |
|--|-------------------------------|
| TS1 = burner control and high limit thermostat | TE = temperature sensor       |
| TC = temperature controller                    | SS = sequence selector switch |
| SC = step controller                           |                               |

#### Principle of Operation

Simple control can be obtained via the systems described in Application Sheet B2. Improved control can be obtained with pressurised systems via control from flow temperature to give more constant temperature at low loads. Boilers are enabled and modulated in sequence with respect to flow temperature via a P&I controller. Maximum controlled flow temperatures from individual boilers are limited, in accordance with HSE PM5 regulations, via a limit sensor installed in place of original control sensor.

#### Application

- Modulating boilers only.

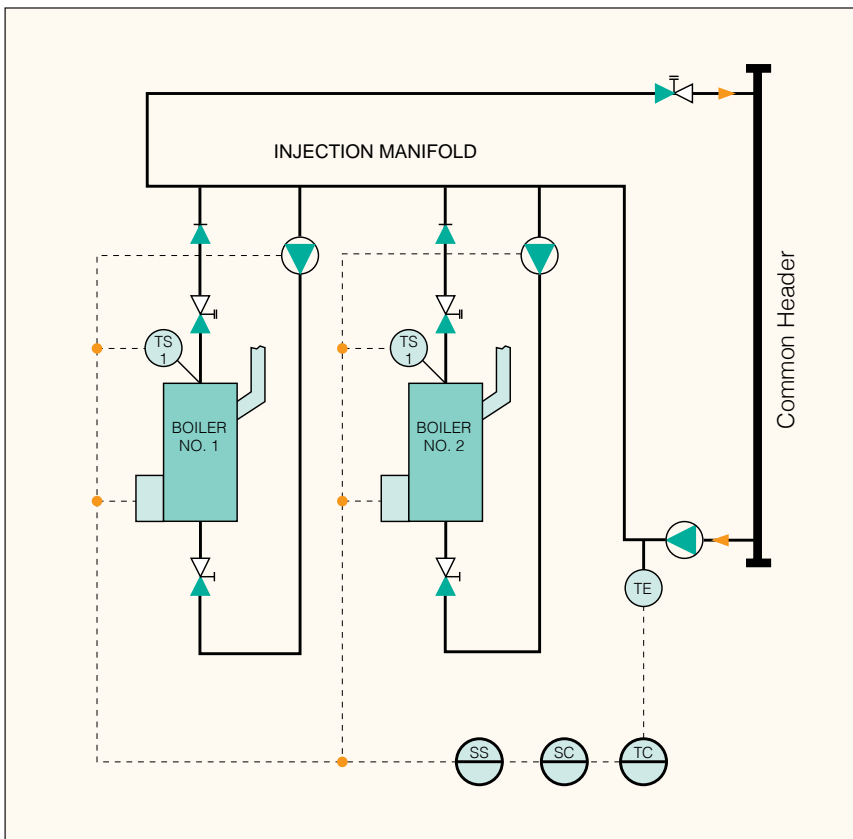
Constant flow in the primary circuit is preferable but not absolutely essential for control. Minimum boiler flows should be maintained at all times. The primary circuit pump has low power absorption due to the low resistance of the primary circuit. Run on of primary pump on shutdown is recommended to dissipate heat and avoid high limit operation.

P&I or floating control must be used for flow control: proportional control would give offset and defeat the object of as near constant flow temperature as possible. Signal splitting amplifiers may also be required. Boilers are enabled and modulated in sequence with a modulating high limit of output (17°C below boiling point maximum as per normal control setting) on each boiler. Separate hand reset high limit thermostats must be fitted as well. The flow temperature setting must be at or below the mixed flow temperature achievable with only one boiler on-line.

Control functions are probably more easily achieved with DDC. Analogue controllers must be of the variable voltage output type with matching voltage relays and amplifiers, etc.



### 6.33 Application Sheet B4 Multiple individually pumped boilers with injection manifold (single pipe manifold or high level header)



#### Legend

TS1 = burner control and high limit thermostat    TE = temperature sensor  
 TC = temperature controller    SS = sequence selector switch  
 SC = step controller

#### Principle of Operation

The lead boiler is enabled, with its individual pump, at all times heating is required. Subsequent boilers and pumps are enabled as the return water temperature drops in a manner proportional to the temperature. Individual boiler firing is controlled by packaged boiler thermostats on the boiler outlets. Run on of individual boiler pumps is normally essential for heat dissipation.

#### Application

- on/off
- high/low firing
- modulating

#### Notes

Constant flow in the primary circuit should be maintained at all times. The primary circuit pump has very low power absorption due to the low resistance of the primary circuit. Heat output of all boilers apart from the lead boiler is reduced due to the higher inlet temperatures. This does not apply if flows or temperature settings are increased and a fixed sequence of operation used. This can be complicated to commission and is unlikely to be maintained in accordance with the design intent. Individual boiler flow and returns must be located close together on the manifold to prevent flow when individual boiler pumps are not operating.

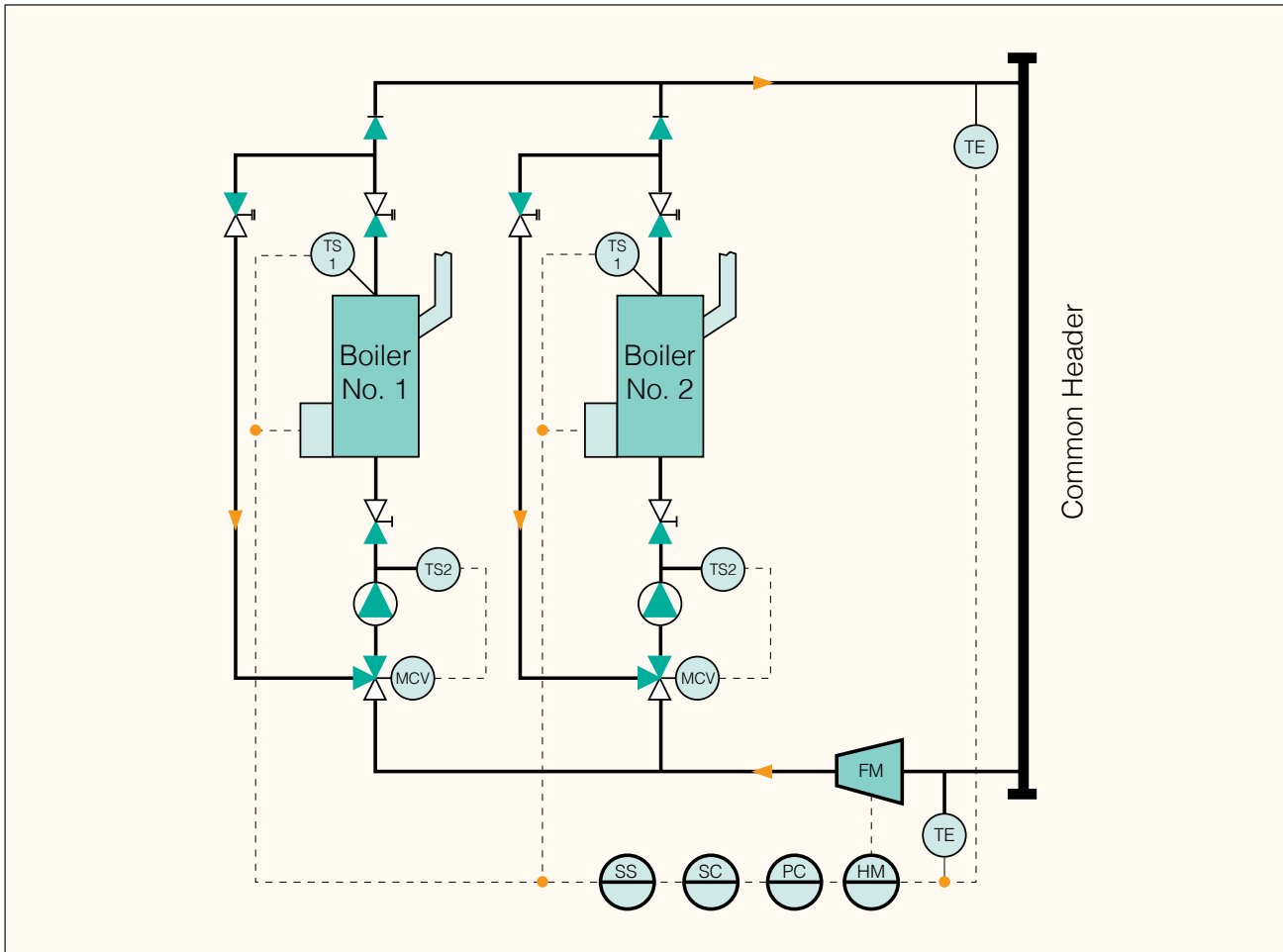


The additional cost of installation compared with the simpler system detailed in Application Sheet B2 will result in a very long payback period even if the system is set up and maintained correctly. However, the additional cost may be worthwhile where existing boiler system is being used with boilers with a high heat loss and the pipework is suitable for this configuration.

The additional sophistication provided by this control system is only justified where:

- Minimal heat losses from off-line boilers are required.
- Constant temperatures are required at low loads.
- There would be an unacceptable reduction in flow temperature at low loads due to flow through off-line boilers.

### 6.34 Application Sheet B5 Multiple parallel connected isolated large boilers



#### Legend

- TS1 = burner control and high limit thermostat
- TS2 = boiler warm up thermostat
- TE = temperature sensor
- FM = flow meter
- HM = heat meter
- PC = proportional controller
- SC = step controller
- SS = sequence selector switch

#### Principle of Operation

The lead boiler and pump is enabled at all times heating is required. Subsequent boilers and pumps are enabled with respect to the total heat load on the system. Boilers are enabled prior to actually being required in order to give time for warm up. During boiler warm up, the valve is in the recirculation position until the minimum temperature is reached to prevent corrosion and cold slugs in system.

Heat load control requires a temperature differential to operate, therefore, another form of control must be used on start up. Start up control can be with respect to outside air temperature which normally is a good indicator of the initial load on a system. Once the system has stabilised the control should change over to heat metering control for greater accuracy. This can be initiated as a time function or when the return temperature has stabilised. Individual boiler firing is controlled by packaged boiler thermostats on boiler outlets.

**Application**

- on/off
- high/low firing
- modulating

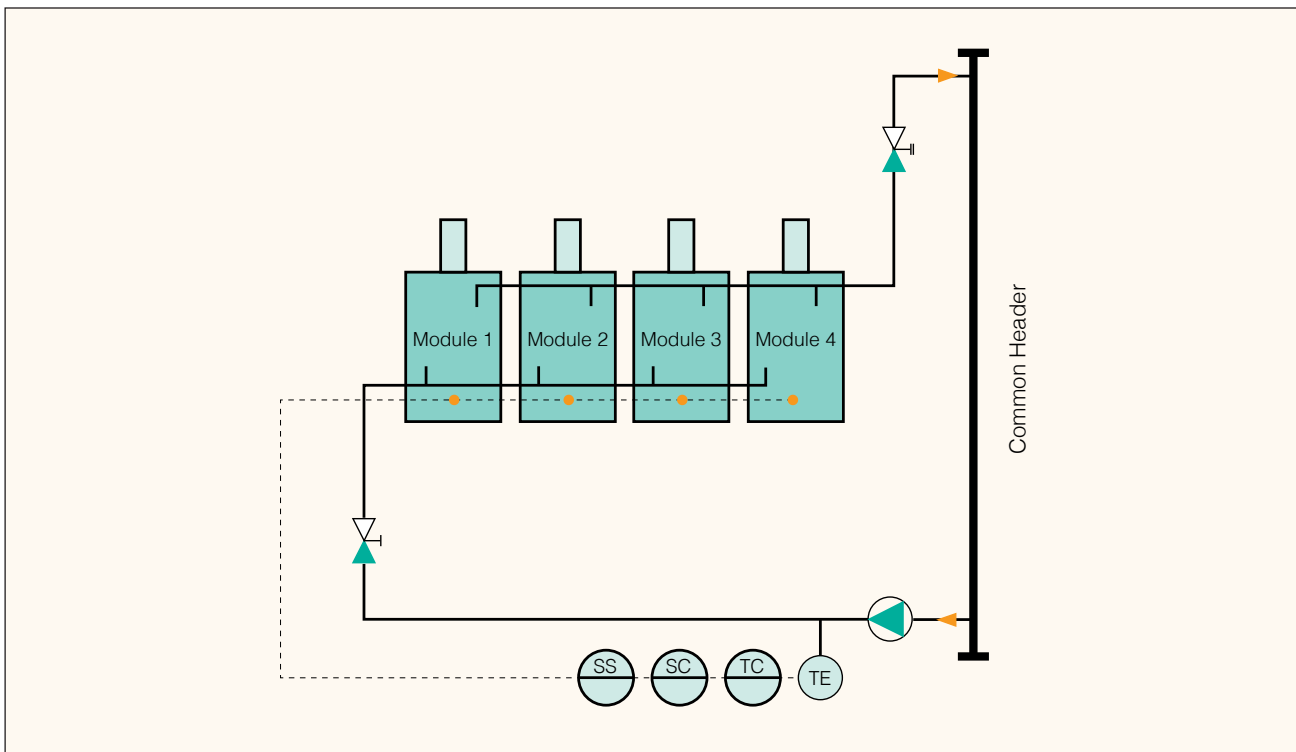
This method of control should only be applied in preference to that described in Application Sheet B2 where heat losses from the off-line boilers justify the additional expenditure.

**Notes**

A tight shut-off type valve may be required on the flow port to stop the boiler being heated when off-line. With a non return valve and without any flow interaction between circuits, a normal lift and lay valve may be adequate. A non return valve is required on the outlet of each boiler after the return connection.

Boiler pumps should be sized for flow through boilers at boiler pressure loss plus an allowance for primary circuit losses and valves only. Run on of individual boiler pumps on shutdown is recommended to dissipate heat and avoid high limit operation. Individual pump and valve arrangements are most suitable for this type of application, other arrangements being possible but not as effective. Control using a proprietary heat meter is possible although a method of switching at set heat loads with switching differential is required. DDC control, with heat load calculation in a programmable controller coupled with central facilities to assist setting up is recommended.

### 6.35 Application Sheet B6 Modular boilers with individual combustion chambers



#### Legend

- TE = temperature sensor
- TC = temperature controller
- SC = step controller
- SS = sequence selector switch

#### Principle of Operation

The lead module is enabled at all times. Subsequent boilers are enabled as the return water temperature drops in a manner proportional to temperature via the sequence control system. Individual boiler module firing is controlled by packaged boiler thermostats on the module outlets.

#### Application

- Modular boilers with on/off burners and individual combustion chambers.



#### Notes

These control methods can be applied to stacked modular boilers (with individual combustion chambers) or in-line assemblies of modular boilers.

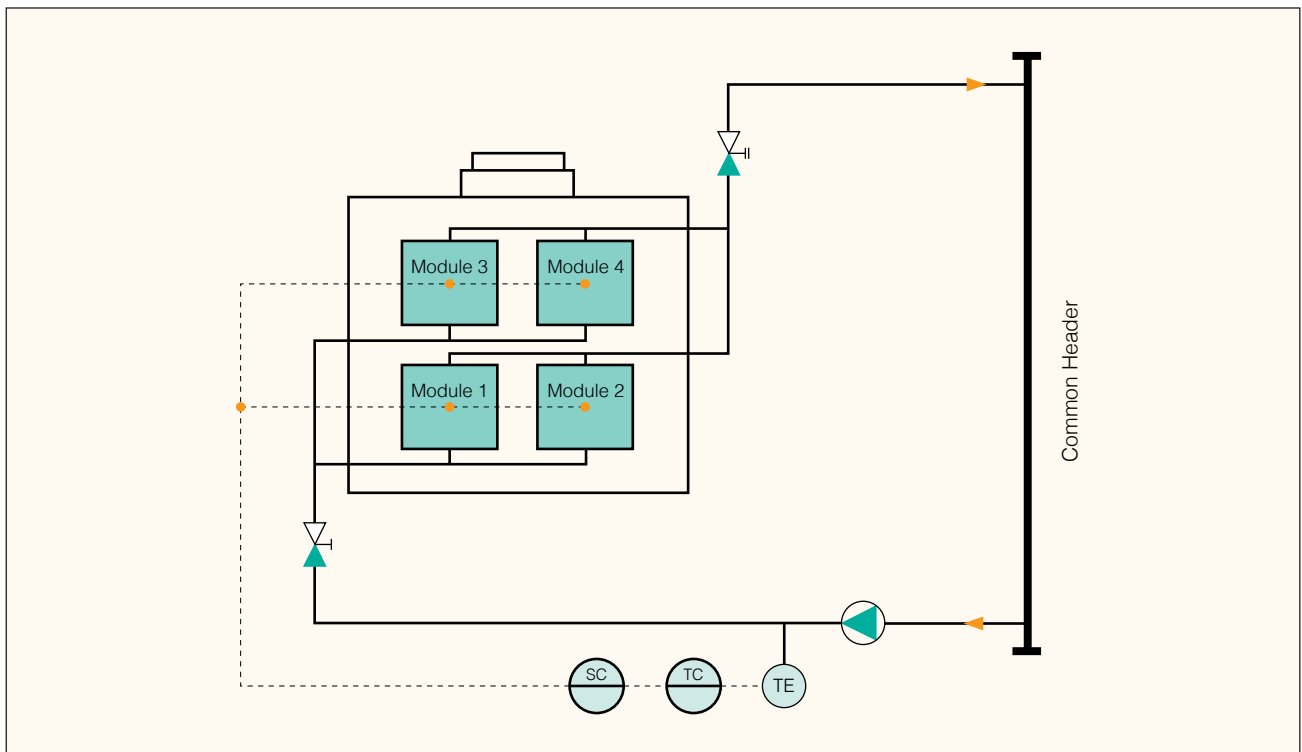
Constant flow in the primary circuit should be maintained at all times. The primary circuit pump has low power absorption due to the low resistance of the primary circuit. There is some dilution of flow temperature at low loads, although this is normally of little importance. Dilution increases the greater the number of boiler modules. Run on of primary pump on shutdown is recommended to avoid high limit operation.

Control via a proportional controller and step controller or operation at specific temperatures must be used. P&I, PID or floating control must not be used.

Low standing loss modules are recommended. Reverse return connection of modules for equalising flows is also recommended.

**Very highly recommended for simple, effective and reliable control.**

### 6.36 Application Sheet B7 Modular boilers with a common combustion chamber



#### Legend

TE = temperature sensor                      SC = step controller  
 TC = temperature controller

#### Principle of Operation

The number 1 module MUST be enabled first and then remain enabled at all times. Subsequent modules are enabled in a fixed sequence once the common combustion chamber purge cycle has been completed. Subsequent modules are enabled via a sequence control system as the return water temperature drops in a manner proportional to temperature. Individual boiler module firing is controlled by packaged boiler thermostats on module outlets.

Boilers with thermostats on the module inlets do not meet the requirements of HSE guidance notes and are not recommended. Sequence control must be used. Module thermostats on the inlet with staggered settings for sequence operation can be dangerous and MUST NOT be used.

#### Application

- Modular boilers with on/off burners and a common combustion chamber only.

#### Notes

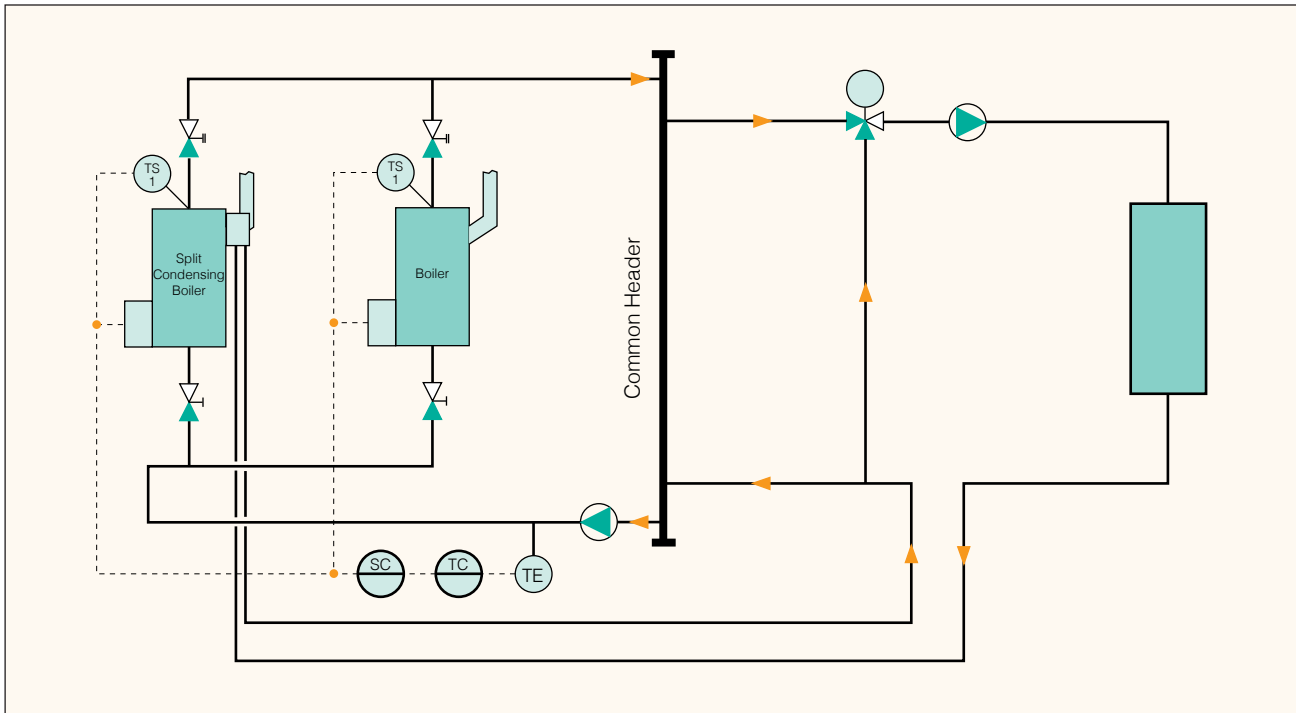
Constant flow in the primary circuit should be maintained at all times. The primary circuit pump has low power absorption due to the low resistance of the primary circuit. Some dilution of flow temperature occurs at low loads, but this is normally of little importance. Dilution increases with the greater the number of boiler modules. Dilution is counteracted by heat gain to off-line modules due to the common combustion chamber. Run on of the primary pump on shutdown is recommended to avoid high limit operation.

Control via a proportional controller and step controller, or operation at specific temperatures must be used. P&I, PID or floating control must not be used.

Reverse return connection of modules for equalising flows is recommended.

**This system is recommended for simple, effective and reliable control provided a sequence control system is used.**

## 6.37 Application Sheet B8 Combined split condensing and conventional boilers parallel connected



### Legend

- TS1 = burner control and high limit thermostat
- TE = temperature sensor
- TC = temperature controller
- SC = step controller

### Principle of Operation

The condensing boiler should always be the lead boiler. The lead boiler is enabled at all times when heating is required. Subsequent boilers are enabled as the return water temperature drops in a manner proportional to the temperature. Individual boiler firing is controlled by packaged boiler thermostats on boiler outlets.

### Application

This control system applies to systems in which a split condensing and a conventional boiler are connected in parallel. The condensing boiler secondary heat exchanger is connected to the return from a compensated circuit. Where there are multiple compensated circuits the one with the greatest load should normally be connected to the secondary heat exchanger.

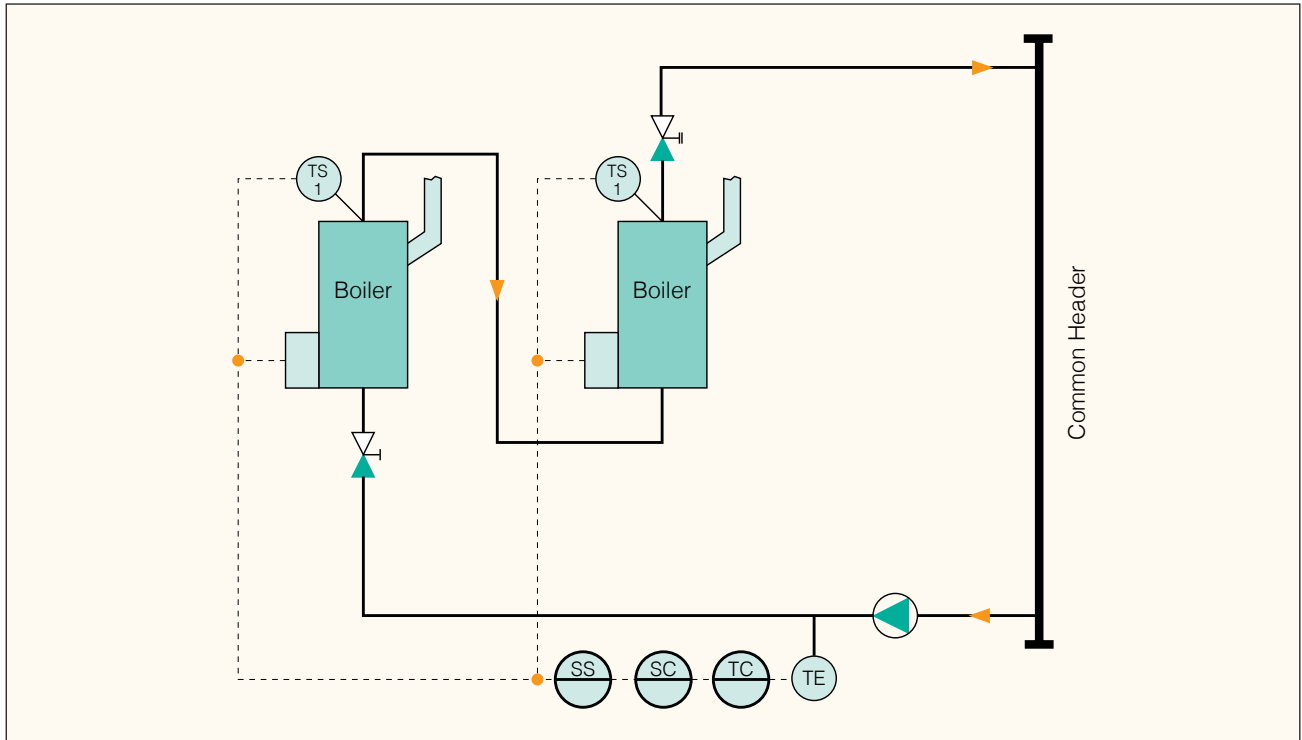
### Notes

Constant flow in the primary circuit should be maintained at all times. The primary circuit pump has low power absorption due to the low resistance of the primary circuit. Some dilution of flow temperature occurs at low loads, but is normally of little importance. Dilution increases with the greater number of boilers. Run on of the primary pump on shutdown is recommended to dissipate heat and avoid high limit operation. Control via a proportional controller and step controller or operation at specific temperatures (with DDC) must be used.

Where two boilers only are being controlled an accurate thermostat or single stage controller may be used. P&I, PID or floating control must not be used.

**Very highly recommended for simple, effective and reliable control although heat output of the split condensing boiler may be produced when it is not required by the compensated circuit.**

### 6.38 Application Sheet B9 Series connected boilers



#### Legend

- TS1 = burner control and high limit thermostat
- TE = temperature sensor
- TC = temperature controller
- SC = step controller
- SS = sequence selector switch

#### Principle of Operation

The lead boiler is enabled at all times heating is required. Subsequent boilers are enabled as the return water temperature drops in a manner proportional to temperature. Individual boiler firing is controlled by packaged boiler thermostats on boiler outlets.

#### Application

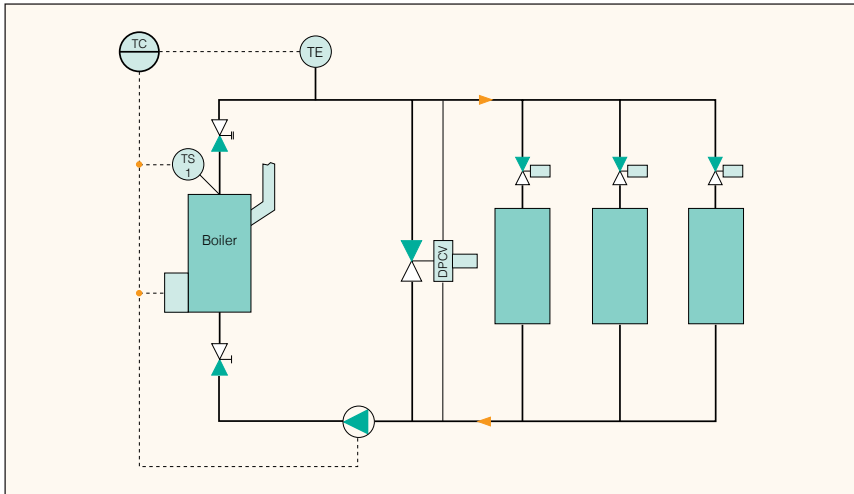
- on/off
- high/low firing
- modulating

#### Notes

Constant flow in the primary circuit should be maintained at all times. Run on of primary pump on shutdown is recommended to dissipate heat and avoid high limit operation. Control via a proportional controller and step controller, or operation at specific temperatures with DDC, must be used. Where two boilers only are being controlled, an accurate thermostat or single stage controller may be used. P&I, PID or floating control must not be used.

**Very highly recommended for simple effective and reliable control. No dilution of flow temperature. Additional pressure loss can be reduced if a high differential temperature system is used - normal maximum  $\Delta t = 17^{\circ}\text{C}$ .**

### 6.39 Application Sheet B10 Directly compensated single boiler



#### Legend

- TS1 = burner control and high limit thermostat
- TE = temperature sensor
- TC = compensator - step output
- DPCV = differential pressure control valve

#### Principle of Operation

The flow temperature of a compensated system reduces with an increase in outside temperature. It is normally desirable to have a directly compensated primary circuit where the condensing boiler is not of the split type and also compensation of the secondary circuit.

Compensators and compensated systems in general are dealt with in Section 7.

#### Application

- on/off
- high/low firing
- modulating

Conventional or condensing boilers may be used.

Compensation can be applied to multiple boilers but it is difficult to achieve stable operation unless boilers are modulating. Control would be similar to Application Sheet B3 with addition of compensator reset from outside temperature.

HWS should be provided by a separate system.

#### Notes

No separate primary circuit therefore provision must be made for maintaining minimum boiler flow where serving emitters with two port valve control (such as TRVs) or with user controlled isolation. A maximum differential pressure bypass is normally used. If variable speed pumps are used for economy of operation a separate secondary circuit must be used, connected via a common header or buffer vessel.

Run on of primary pump on shutdown is recommended to dissipate heat and avoid high limit operation.

Where high/low boilers are directly compensated, the high fire should preferably be enabled by the compensation system, with boiler firing controlled by the boiler control thermostat. Where modulating boilers are directly compensated control should be in a similar manner to that detailed in Application Sheet B3 except with a variable flow temperature - direct compensation of modulating boilers provides much more stable control.

**Recommended for small systems with separate HWS provision.**



## 7. COMPENSATED SYSTEMS

### 7.1 Introduction and Functions

- Required by the Building Regulations.
- The flow temperature is reduced on increasing outside temperature.
- Reduces distribution losses.
- Provides a basic control of space temperature.
- Improves stability of space temperature controls.
- Outside/flow temperature relationship is the compensator 'slope'.
- Straight line slopes - flow temperature is directly proportional to the change in outside temperature.
- Non-linear slopes - emitter output is more accurately related to outside temperature than with a straight line slope.
- Self adaptive slopes - the slope shape is based on previous resultant space temperatures.
- Improvement in control for other than linear slopes is generally small, especially if slope reset.

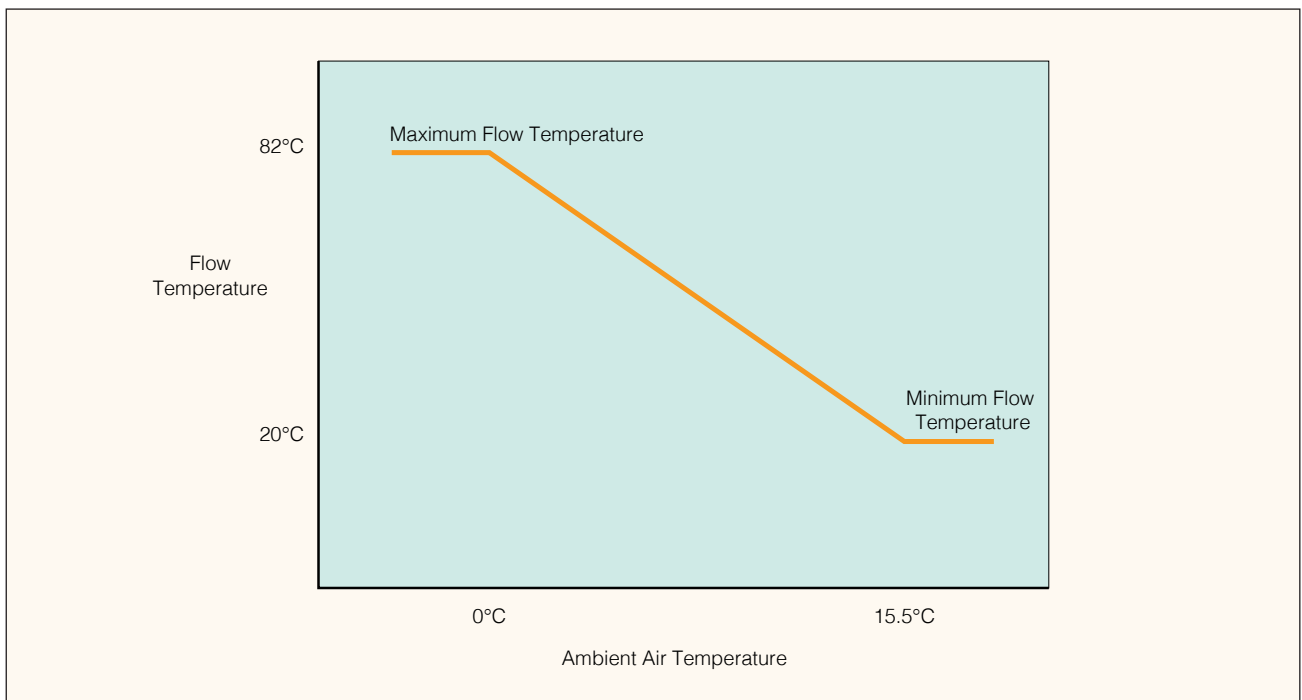


Figure 7 Compensator slope

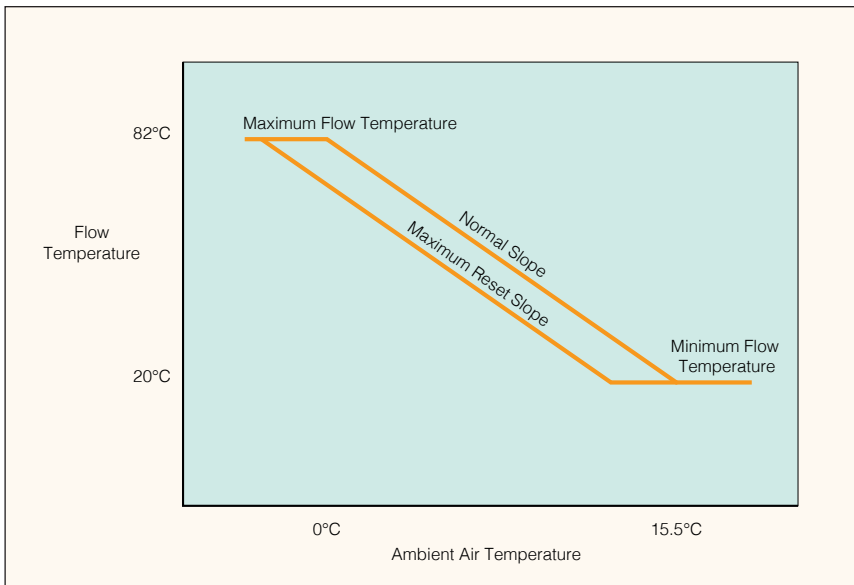
- Usually secondary circuits, fed from a boiler primary circuit.
- Boilers can be directly compensated.

### 7.2 Additional Influences on Compensated Circuits

- The primary influence should be the outside temperature.
- Additional influences - limited reset of the compensator slope.

#### 7.2.1 Solar Gain

- Large areas of glazing.
- Space temperature affected by solar gain.
- Compensator slope reset by solar sensors.
- Normally applies to individual zones not complete buildings.



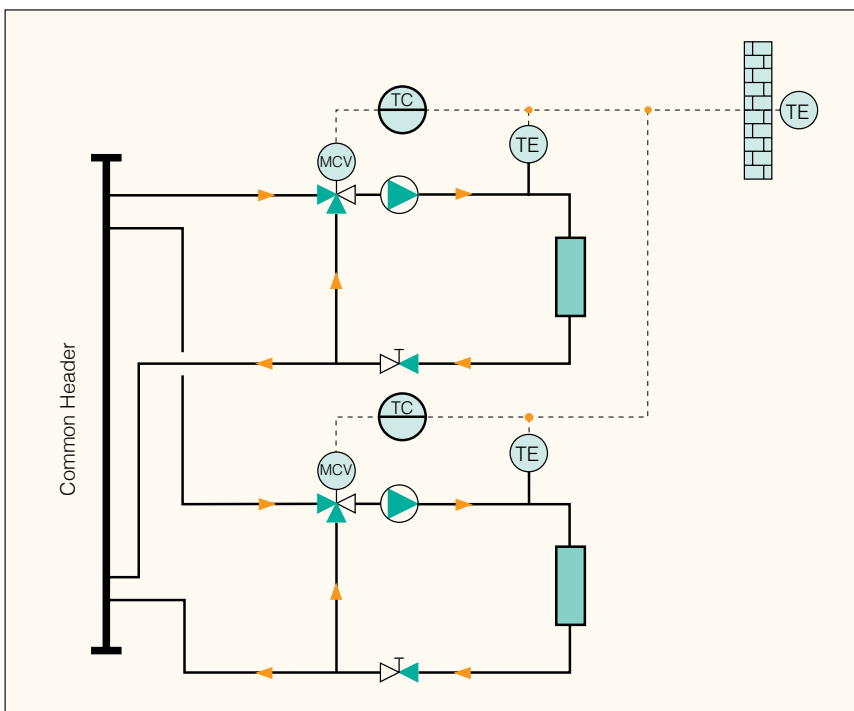
**Figure 8 Compensator slope with reset**

### 7.2.2 Wind Influence

- Not commonly used in the UK.
- Possibly required for high or particularly exposed locations.

### 7.2.3 Space Temperature Reset

- Slope reset from space temperature.
- Reset from high temperature only for energy efficiency.
- The space temperature sensors located in representative rooms.
- No space temperature control in space temperature sensor locations.
- Reset limited - 3°C reduction in flow temperature for a 1°C rise in average space temperature above the setpoint.
- Little benefit in more than four sensors.



**Figure 9 Multiple compensated circuits**

### **7.3 Multiple Compensated Circuits**

- Objective zoning can improve efficiency and comfort.
- Random zoning of buildings is of no benefit at all.
- Zones should be created if any of the following factors vary significantly.
  - Solar gain.
  - Occupancy patterns.
  - Building structure.
  - Emitter characteristics.

### **7.4 Circuit Temperatures and Limits**

- The surface temperature of emitters should be limited where there is the possibility of contact by the elderly or infirm.
- The DHSS guidance notes recommend an upper limit on surface temperatures of 43°C in nursing homes.
- Low surface temperature radiators are recommended rather than limiting compensated flow temperatures.
- Underfloor heating circuits normally require low maximum flow temperatures to prevent occupant discomfort.
- The minimum flow temperature for circuits serving fan convectors should be 40-50°C to prevent cold draughts from the fan.
- Circuits serving natural convectors, sill line and trench heating may also require a minimum flow temperature to provide emitter output.

### **7.5 Night Set-Back**

- Reduced compensator flow temperatures at night.
- Continuous occupancy such as old peoples homes and hospitals.
- Space temperature controls should also ideally be reset to prevent imbalance.
- Alternatively, circuits may be switched off until the space temperature reaches a minimum level dependent upon building and application.

#### ***7.5.1 Outside Temperature Shutdown/Daytime Economisation***

- Shut down above 16-19°C outside temperature.
- Considerably reduces energy usage during spring and autumn.
- Switching differential for stability of control.
- Fan convector interlock required.
- Possibly also boiler circuit if no HWS.
- Daytime economisation programs also applicable to buildings or zones.

## 8. SPACE TEMPERATURE CONTROL

### 8.1 Introduction and General Guidance

- Required by Building Regulations.
- Applied to compensated circuits.
- Except areas where compensator reset sensors are located.
- Ideally control of individual emitters.

### 8.2 Thermostatic Radiator Valves (TRVs)

- TRVs sense space temperature.
- Throttle flow to emitter - 2 port valves.
- Normally applied to radiators.
- Can also be fitted to convectors.
- Horizontal heads reduce heat transfer from pipes.
- Remote temperature sensors available.
- Prone to interference and vandalism.
- Susceptible to debris in the system.
- Debris effects minimised if TRV at the top of a radiator.
- Pressure and differential pressure ratings may be limited.
- European CEN Standard EN215.
- Dimensions to HD 1215-2 for UK use.
- Conventional valve sizing methods inappropriate.
- Normally sized to nominal pressure drop of 5 kPa.
- Restricted plug movement - 3°C Kv.
- Higher Kv values for single pipe systems.

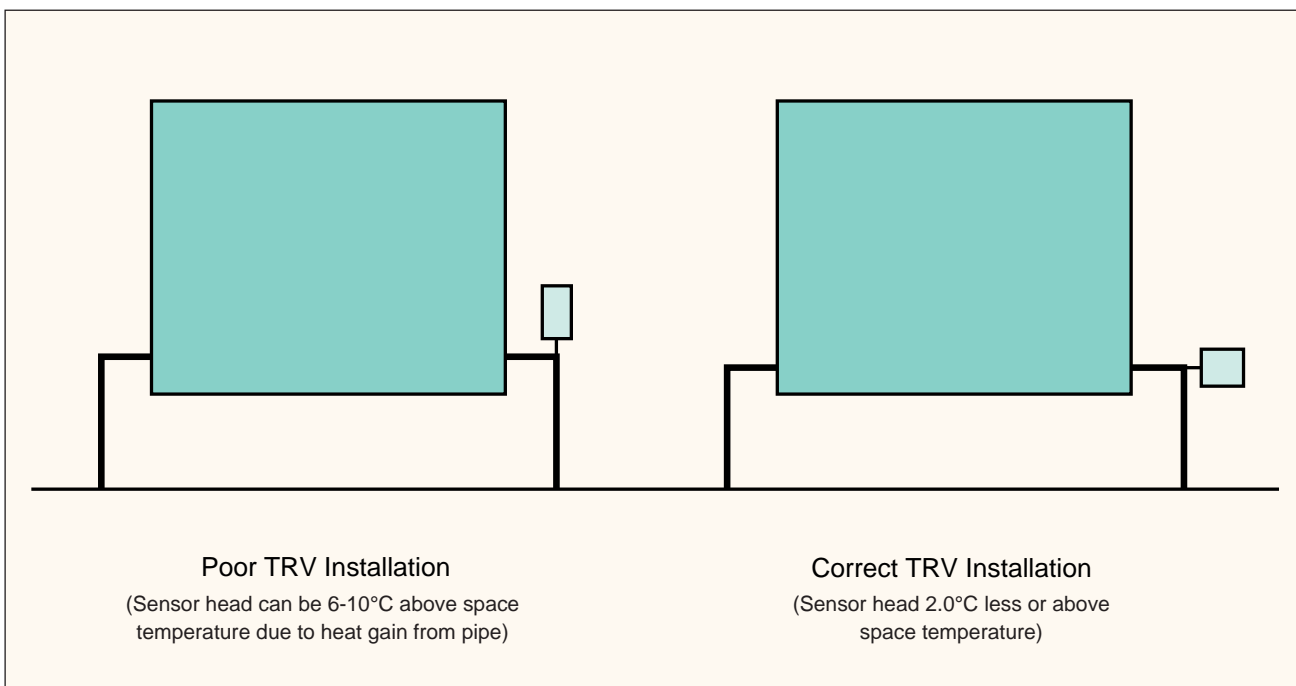
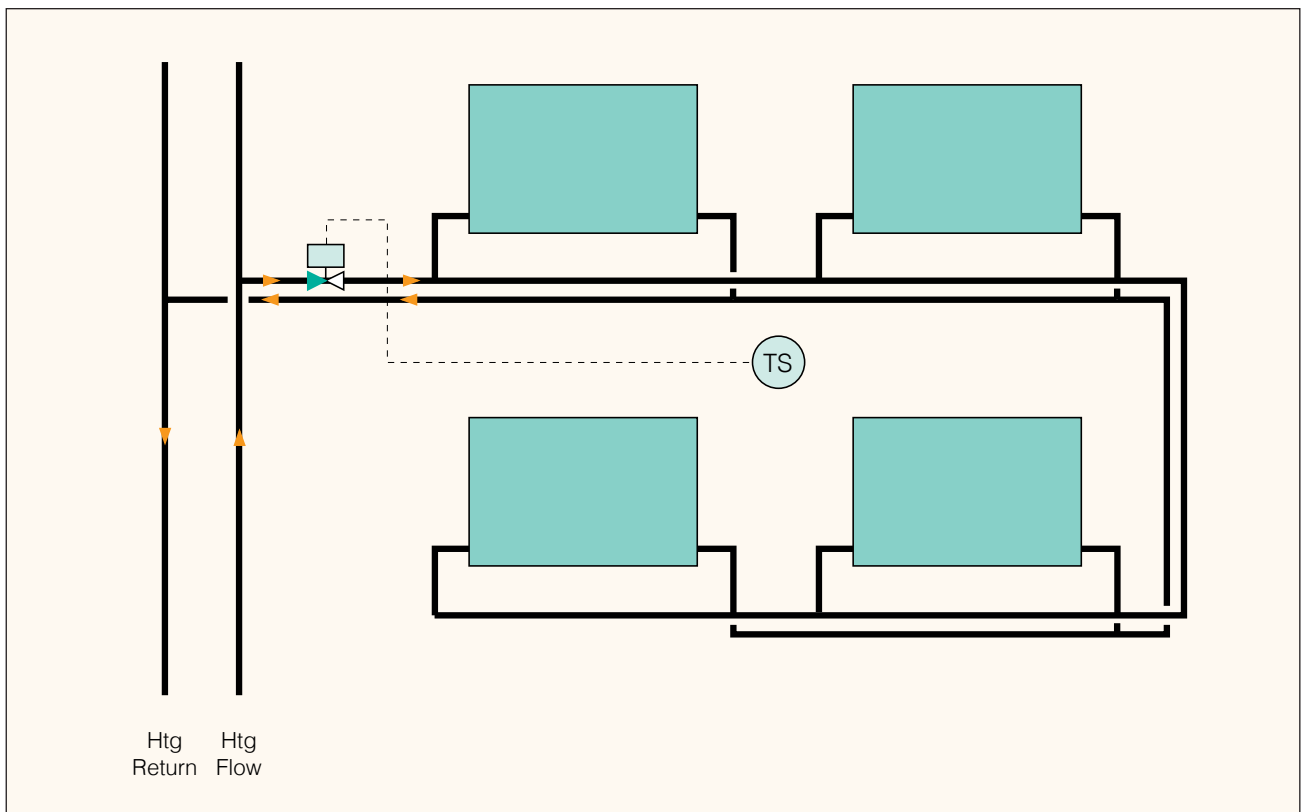


Figure 10 TRV installation



**Figure 11 Thermostat control of multiple emitters**

### 8.3 Room Thermostats

- Applications - radiators, natural and fan convectors.
- Zone on/off valve.
- Fan convector - fan interlock required.
- More representative locations than TRVs.
- Electronic thermostats more accurate and repeatable.
- Simple time control interface.
- Night set-back available.

### 8.4 Modulating Control

- Applications - radiators, natural and fan convectors.
- Modulating valve more expensive.
- Fan convector - fan interlock required.
- More representative locations than TRVs.
- Proportional control is normally adequate.
- P&I control not normally required for single stage.
- Proportional offset more economic than P&I.
- Communicating controls available.
- Multiple emitters separate pumped injection circuit.
- Limit multiple emitter quantities.

### 8.5 Time Proportioning Control

- More representative locations than TRVs.
- Individual or multiple emitters.
- On/off zone valves.
- Lower cost than modulating.

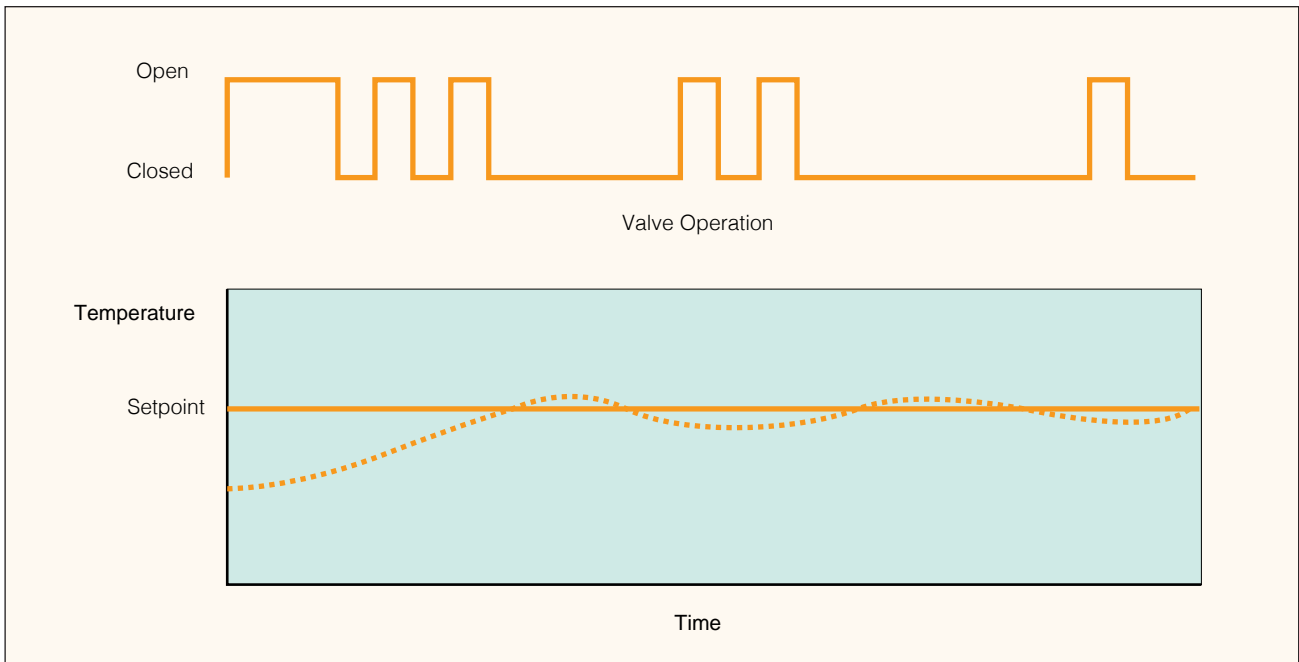


Figure 12 Time proportioning control

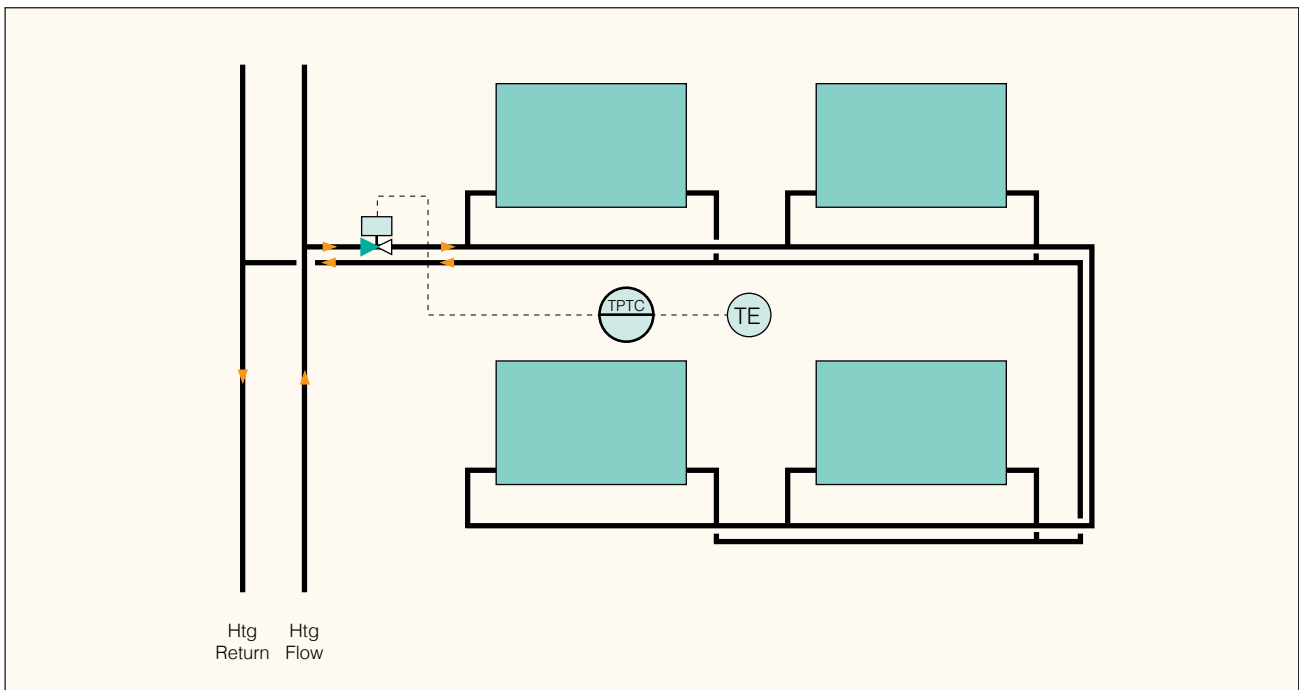


Figure 13 Time proportioning control of multiple emitters

### 8.6 Occupancy Sensing

- Ultrasonic movement.
- Infra-red detection.
- Microwave.
- Types and sensitivities to suit application.
- Intermittently occupied areas.
- Hotel bedrooms and commercial offices.
- Quick response heating systems required.
- Unoccupied settings for minimum temperatures.
- Considerable energy savings with random occupancies.

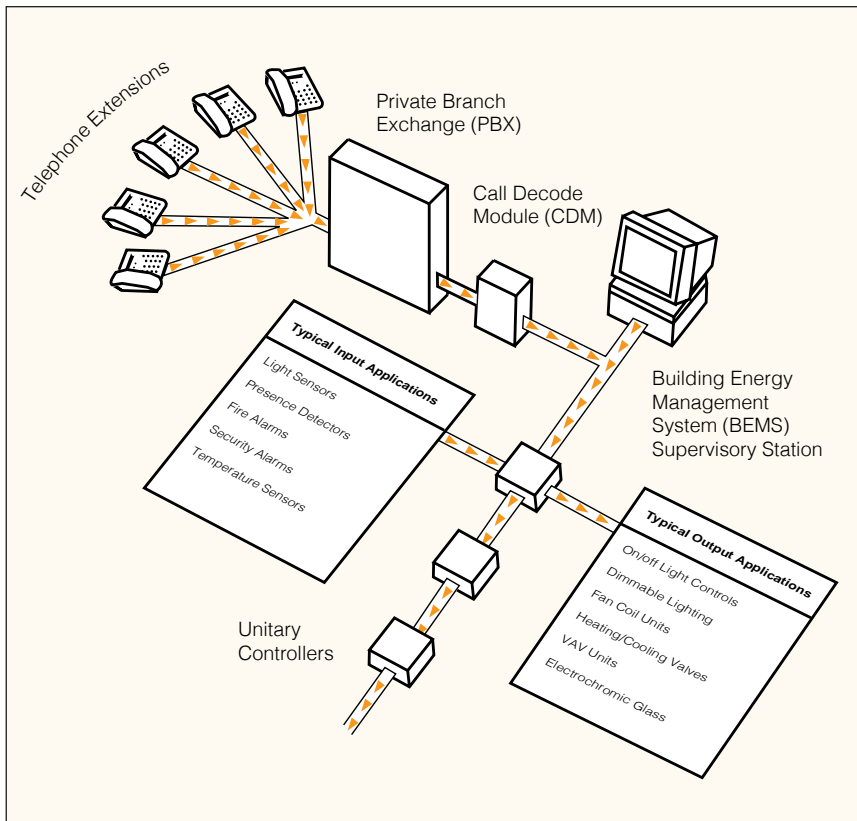


Figure 14 User interactive control

### 8.7 User Interactive Control Systems



- User local control of services.
- User feels in control.
- Telephone based systems.
- Code or voice instruction.
- Occupancy switches on temperature sensors.
- Security access system links.
- Overall time control links.
- Considerable energy savings with random occupancies.

## 9. HOT WATER SERVICES

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### 9.1 Introduction

- Often major source of energy wastage.
- Particularly where HWS not segregated.
- 90% summer energy savings possible with improved control.

### 9.2 Control to Avoid Legionnaires Disease

Detailed guidance:

- CIBSE Guide -TM13 - Minimising the Risk of Legionnaires Disease.
- DHSS Code of Practice - 'The Control of Legionella in Health Care Premises'.

The basic control premises for avoidance of legionella are:

- Maintenance of outflow temperature at 60°C +/- 2.5°C.
- Maintenance of return water temperature from circulation above 50°C.

### 9.3 Control to minimise standing losses

- Up to 90% energy wasted due to heat loss and inefficient generation.
- Considerable savings segregated and distributed HWS generation.

### 9.4 Time Control

- Intermittently occupation HWS time controlled.
- Required by current Building Regulations.

To avoid legionellae:

- Water temperature maintained at minimum of 60°C.
- Wasteful of energy if water recirculated.
- Water elevated to 70°C prior to occupancy.
- Cool to safe levels prior to occupancy.

### 9.5 Domestic Storage Cylinders

Traditional system:

- Thermostat one third up the cylinder.
- Only senses when draw-off.
- Outlet temperature not effectively controlled.
- Basic time control.
- Very inefficient.
- High limit or point of use mixing valve to prevent scalding.
- Domestic calorifiers should not generally be used in commercial and industrial premises.

The following measures can show returns in less than three months.

- Timeswitch with 15 minutes resolution.
- Multiple reheat periods.
- Typically four two hour periods per day.
- Thermostat 50% to 75% up the cylinder.
- Higher the better provided sufficient water remains to satisfy large draw offs.
- Wide differential thermostat - 11°C.



## 9.6 Commercial Storage Cylinders

- Immersion thermostats located in pockets.
- Improved temperature sensing.
- Control thermostat two thirds of the way up cylinder.
- High limit thermostat top of the cylinder or outlet.
- High limit thermostat manual reset.
- High limit control valve tight shut-off.
- High limit control valve spring return actuator.
- Cylinder recirculation pump to avoid stratification and stagnation.
- Distribution pumps to maintain minimum return temperatures and avoid stagnation.
- Horizontal cylinders controlled in a similar manner to vertical cylinders.

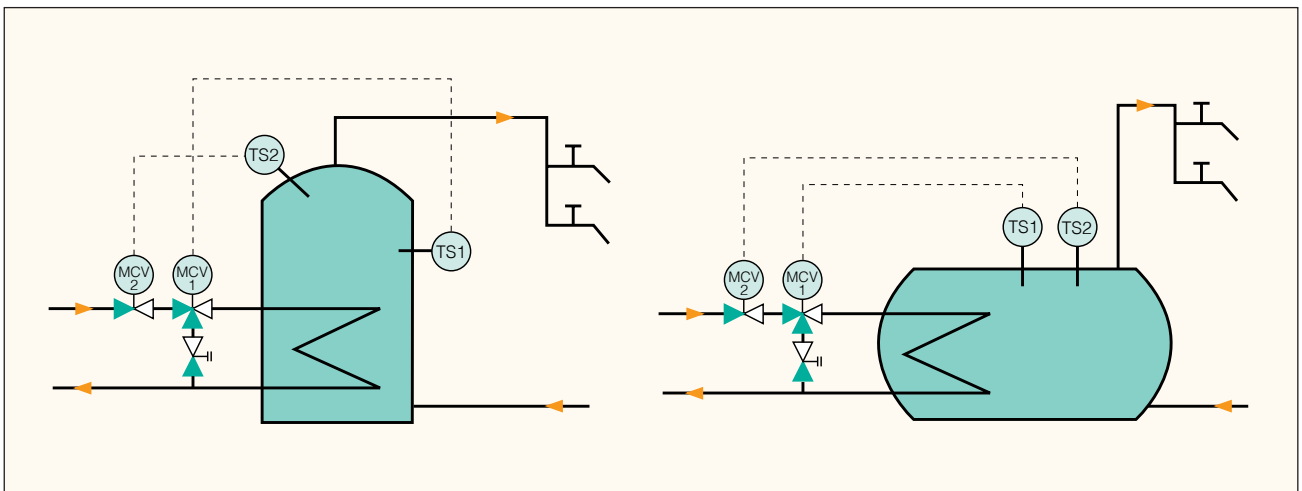


Figure 15 Commercial storage cylinders

## 9.7 High Temperature Storage

- Enables smaller quantities of water to be stored.
- Reduces the risk of legionellae.
- Local mixing with cold water.
- Mixing valves to BS1415.
- Increased scale build up.

## 9.8 Direct Fired Water Heaters



- Gas or oil-fired.
- Condensing versions
- Control and high limit thermostats top of the unit
- Recirculation pumps required for DHSS requirements.
- Some units have self powered controls.
- Flue dampers can provide up to 50% energy savings with intermittent use.

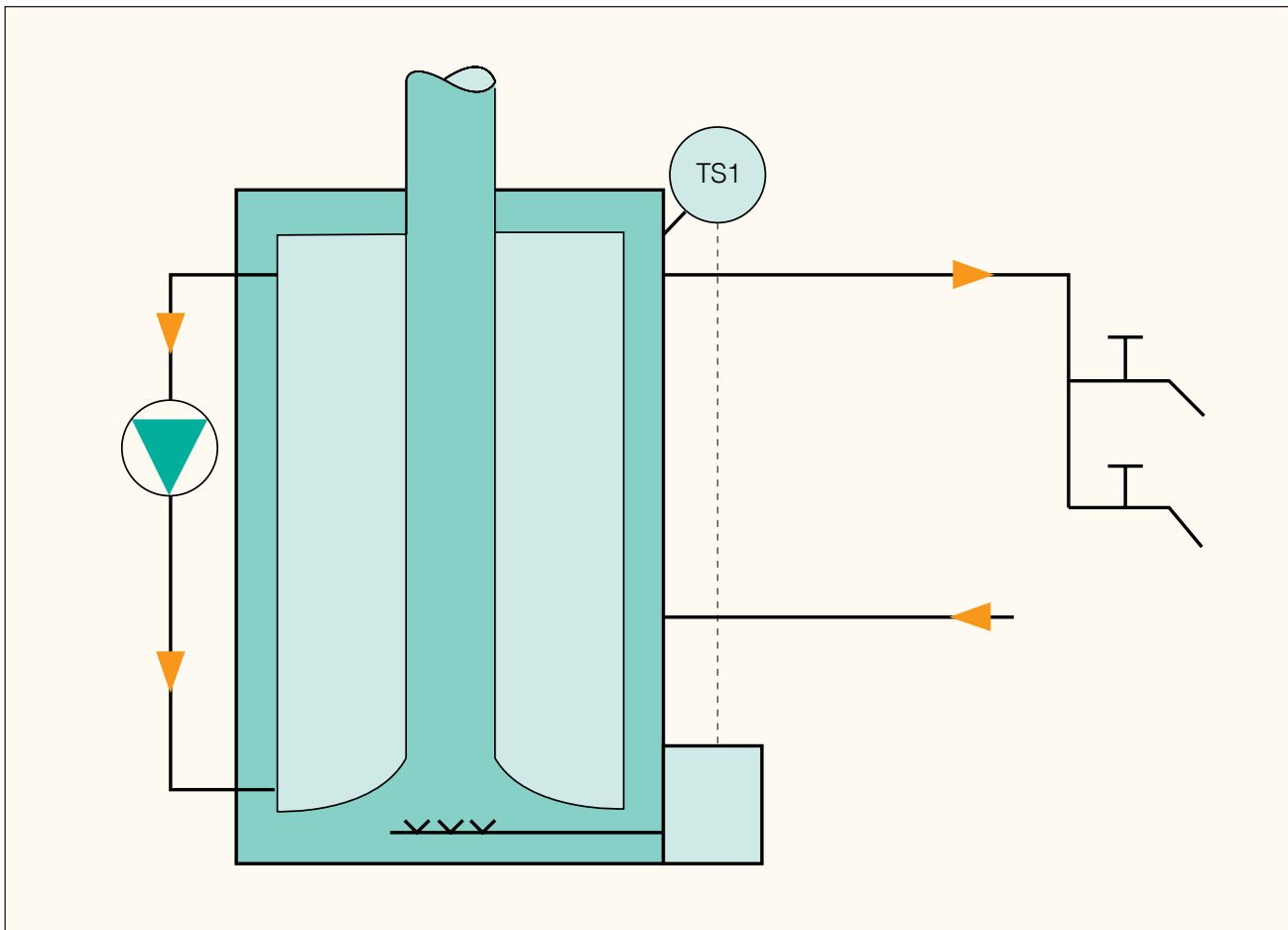


Figure 16 Gas-fired HWS generator

### 9.9 Electric Storage Cylinders

- Fitted with immersion heaters.
- Controlled via built in thermostats.
- Time control required.

To minimise the use of peak rate electricity:

- Cylinders sized for 90% of consumption on night rate electricity.
- Storage temperature 60°C.
- Timers for economic provision of peak rate top up.

### 9.10 Point of use Water Heaters and Showers



- In-built variable temperature control.
- No additional control is required.
- Very economic provision of HWS.

## 10. WARM AIR SPACE HEATING

### 10.1 Unit Heaters

- To heat large air volumes.
- Warehouses, factories, retail sheds, etc.
- Direct gas-fired units.
- Indirect gas or oil-fired units.
- Indirect units fitted with water or steam coils.
- Full fresh air units for minimum fresh air.
- Recirculation units to maintain space temperature.
- Direct gas-fired unit heaters fresh air to BS 6230.
- Often supplied with packaged controls.
- Optimisers - 5 to 7% savings.
- Optimiser savings less than wet heating systems.
- Summer/winter switch, or similar, for heating only in heating season.

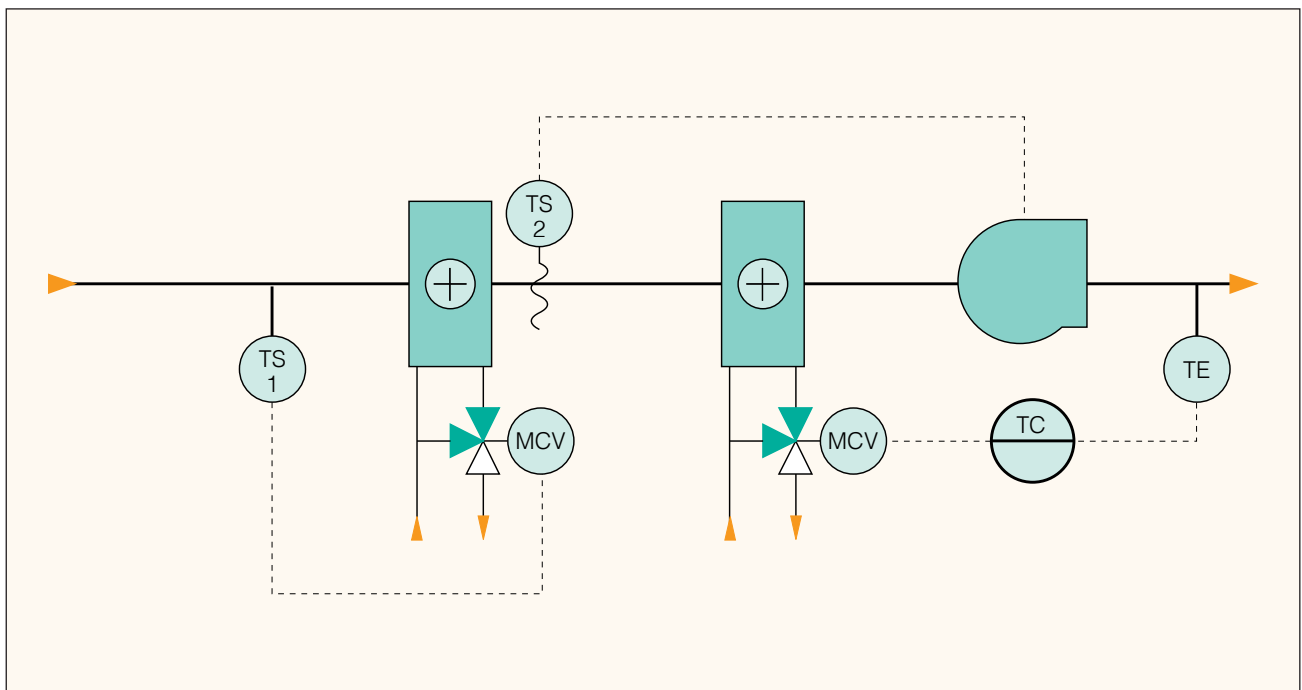


Figure 17 Water coil full fresh air unit heater

#### Legend

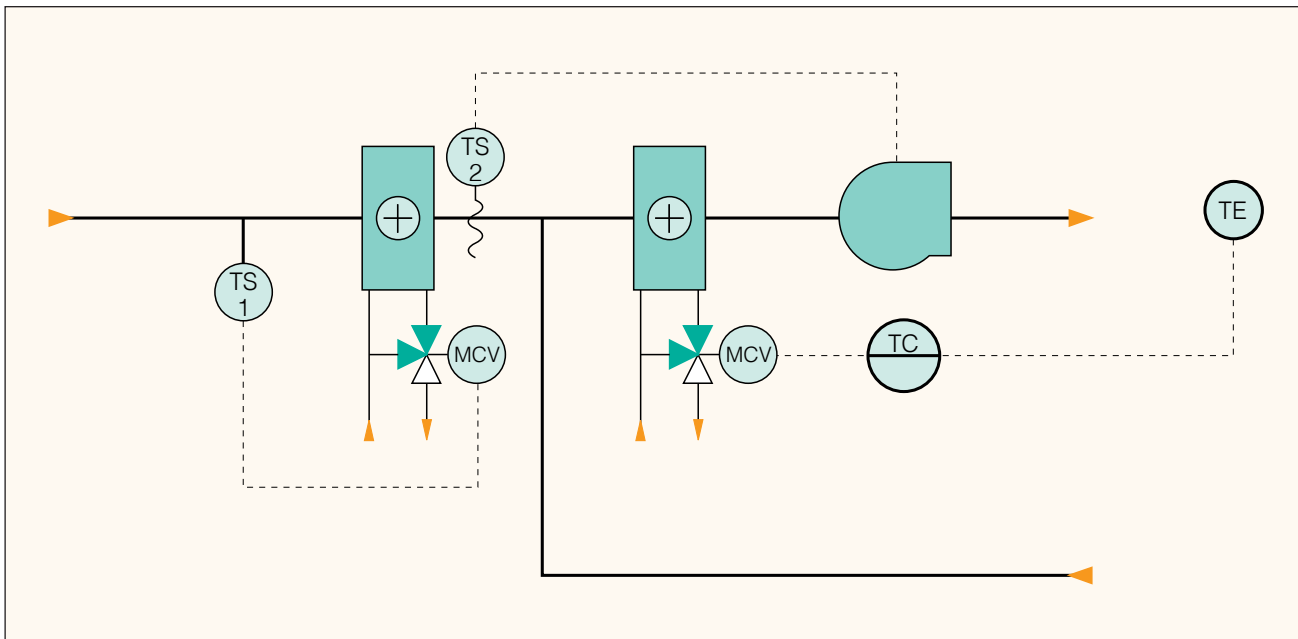
- TS1 = outside thermostat  
TS2 = frost thermostat  
TE = temperature sensor  
TC = temperature controller  
MCV = control valve

Full fresh air unit heaters:

- Fans must run continuously during specified operating hours.
- Where only source of heat high limit space thermostat required.

Direct gas-fired unit heaters:

- On/off switching differential 3°C minimum for stable control.



**Figure 18 Water coil recirculating air unit heater**

**Legend**

- TS1 = outside thermostat
- TS2 = frost thermostat
- TE = temperature sensor
- TC = temperature controller
- MCV = control valve

- Modulating burners preferable with proportional control.
- Supply air temperature is normally 25 - 30°C.
- Manual reset high limit supply air thermostat.
- Burner operation interlocked with fan.
- Supply cold air for 1-2 minutes initially each firing cycle.

Indirect, gas or oil-fired, unit heaters:

- Single stage, two stage or modulating.
- Modulating burners limited to 50% turndown to prevent condensation, except condensing units.
- Fan operation intermittent to avoid cold draughts.
- Heat exchanger up to temperature prior to operation.
- Firing cycle is initiated with respect to space temperature.
- Where a two stage burner is employed a two stage thermostat must be used.
- Automatic or non return fresh air dampers to prevent heat loss when not firing, if adequate minimum fresh air still available.

Water or steam unit heaters:

- Full fresh air control proportional or P&I with respect to supply air temperature.
- Recirculation units controlled from space temperature.
- Recirculation units - when space is up to temperature fan can stop.
- Fan run-on may be required for heat dissipation.
- Override valve fully open when outside below 2°C.
- Off-coil capillary frost thermostat to stop fan.

## 10.2 Destratification Fans

- Used in tall, large volume, spaces reduce heating requirement by destratifying the air.
- Operation continuous or intermittent.
- Intermittent operation prevents cold draughts and minimise energy consumption.
- Intermittent operation by high level thermostats just below roof to bring on fans when temperature high.

## 10.3 Tempered Air Systems

- Provide fresh air.
- Main heating load by other means.
- Time control.
- Automatic fresh air damper.
- Supply fan operation interlinked with extract.
- Extract fan differential pressure switch to prove air flow.
- Main heater battery controlled with respect to supply air temperature.
- Proportional or P&I mode.
- Electric frost heater air flow interlock.
- Electric frost heater high temperature cut-out.
- Water frost coil proportional control from outside fully open at 2°C.
- Off-coil manually reset capillary frost thermostat.

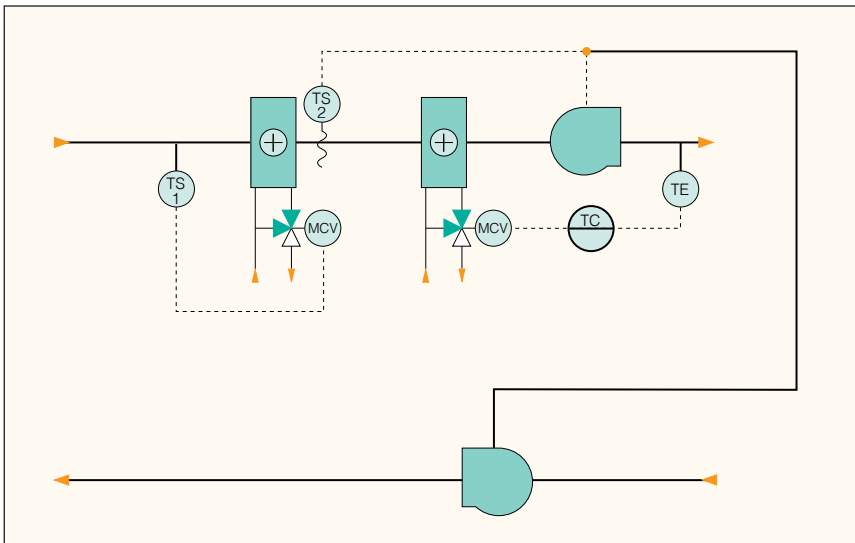


Figure 19 Tempered air system

## 10.4 Warm Air Plenum Systems

- Fixed percentage mixture of warm and fresh air.
- Time control.
- Above 30 kW an optimiser recommended.
- Supply fan operation interlinked with extract.
- Extract fan differential pressure switch to prove air flow.
- Main heater battery should be controlled with respect to space or return air temperature.
- Proportional mode.
- Separate zones should have an individual heater battery per zone.
- Frost heater control as tempered air.

## 11. RADIANT HEATING

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- Typically used in large volume buildings, low or intermittent occupation, such as factories and garages.
- Gas-fired, electric, steam or water heated radiant tube units.
- Gas or oil-fired air heated units.
- Gas-fired or electric quartz halogen plaque units.
- Temperature control is required for each heater unit.
- Time control for the overall system.
- Fully modulating control for steam and water radiant tube units.
- Radiant effect maintained above certain surface temperatures.
- Two stage gives closer control than on/off control.
- Black bulb sensors for temperature control sense radiant heat.
- Sensor locations - subject to radiant effect.
- Sometimes conventional sensors can give improve comfort by reducing switching frequency.
- Optimisers where warm up time is slow >30 minutes and as required by Building Regulations.

## 12. ELECTRIC HEATING



- Other than at off-peak tariff more than twice as expensive as gas-fired heating.
- Most electrical heating emitters have in-built thermostatic control which gives the advantage of local control at each emitter although sensing locations are poor.
- Restrict access to controls where appropriate.
- Timeswitch control of emitters can be difficult to achieve.
- Portable electric heaters should not be used to supplement a wet heating system as it can lead to control problems.
- Storage heaters should only be used where low cost off-peak electricity is available.
- Cost advantage of the off-peak electricity must not be eliminated by additional cost of day time electricity.
- Fan assisted storage heaters are more controllable than natural convection units.
- Fan controlled by a room thermostat stops overheating during the morning.
- More heat available during the day.
- Electric dry core boilers available.
- Work in a similar manner to storage heaters, heat is distributed via a conventional wet heating system.

### 12.1 Optimisation

- Special optimisers predict the charge required from the previous day and overnight temperatures.
- Economic over 10 kW storage heaters.

### 12.2 Underfloor Heating

- Special compensated controllers required.
- Maximum temperature limit to prevent overheating of floor.

## 13. HEATING SYSTEM DESIGN AND INTEGRATION

### 13.1 Introduction

- Essential that interaction between systems is considered at the design stage.
- Ensure that the total system is controllable and maintainable.
- Unwanted hydraulic interaction between systems is a major cause of energy wastage and operational problems.
- Control of the system should not cause any effect which upsets the stability of operation of any of the system component parts.
- Systems must be designed such that the effect of control on one circuit does not affect the other circuits.
- System design may be considered in component elements but the effect of each element upon the next must be considered for all system loads.
- Prime consideration is whether circuit is constant or variable flow.
- Any circuit with a variable flow element will affect other circuits unless precautions are taken.

#### 13.1.1 Single Directly Compensated Boiler with Variable Flow caused by TRVs

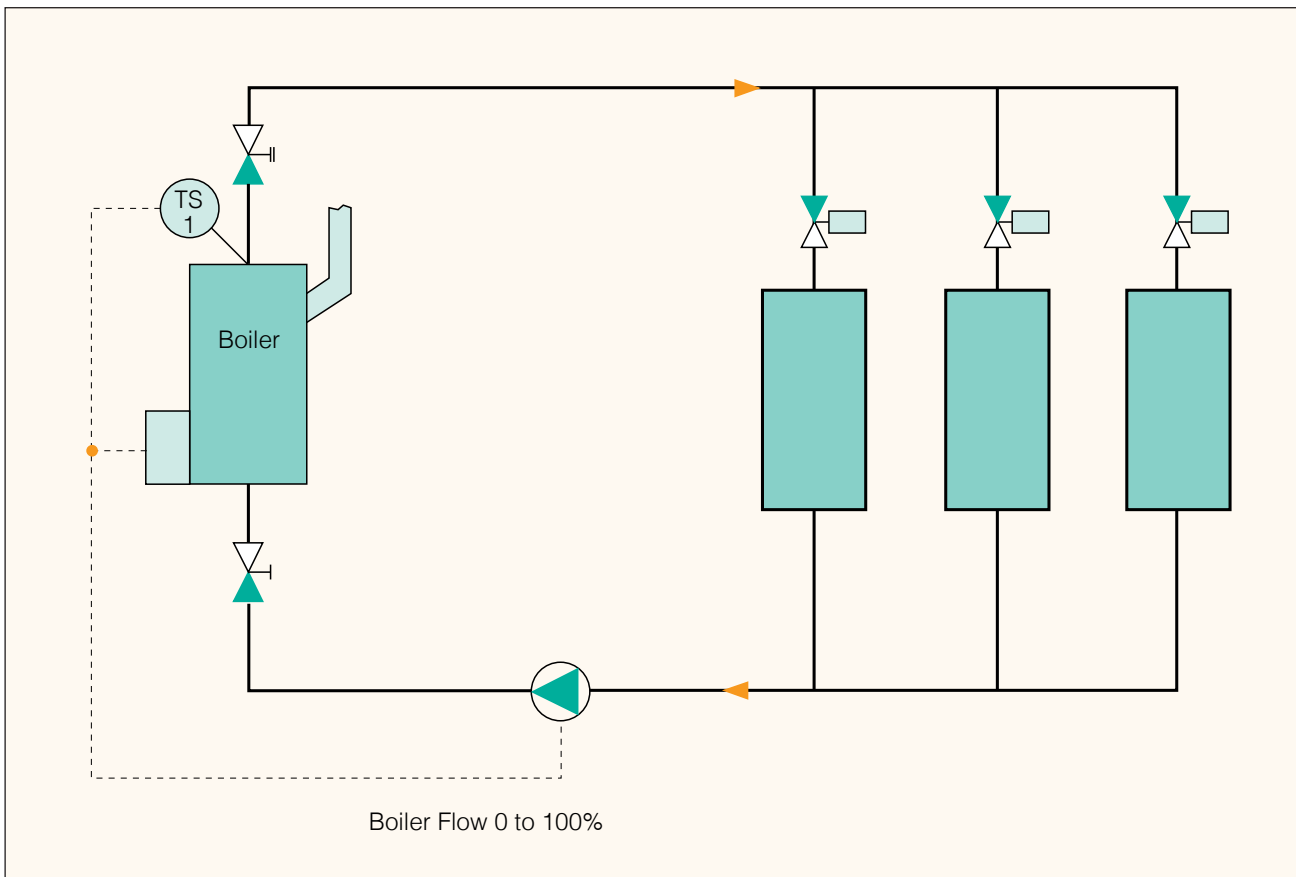


Figure 20 D&I 1

- Two port TRVs reduce flow through individual radiators.
- System flow also reduced.
- Minimum flow rates required by the boiler not achieved.
- Modern boilers higher relative minimum flow rates.
- Boiler trip.



### 13.1.2 Effect of a Compensated Circuit on a Non Pumped Boiler Circuit

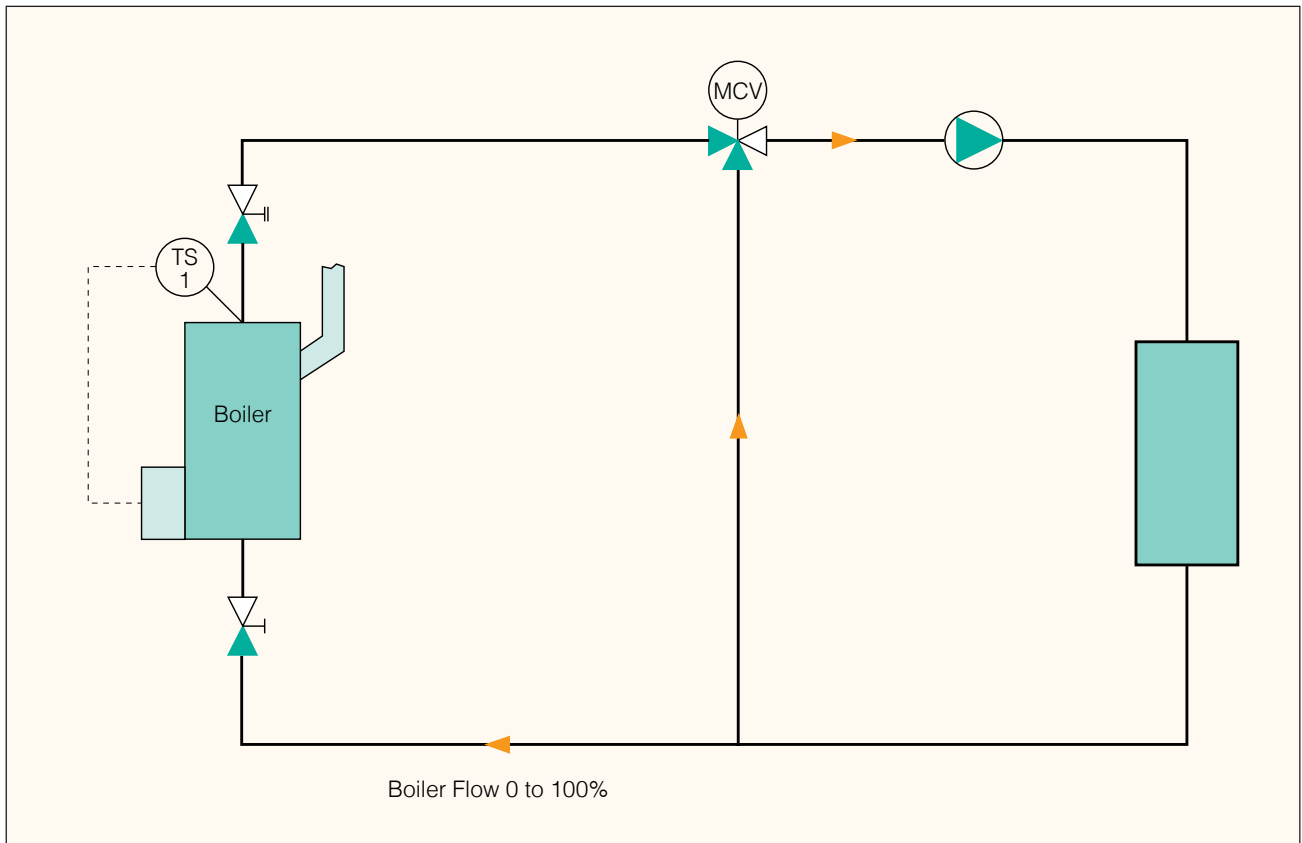


Figure 21 D&I 2

- Compensator valve causes variable flow in the legs connecting it with the heat source circuit.
- Even if compensated circuit constant flow.
- Minimum flow rates required by the boiler not achieved.
- Modern boilers higher relative minimum flow rates.
- Boiler trip.
- HWS system can ensure a small boiler flow at all times with older boilers.



### 13.1.3 Pumped Primary and Compensated Circuits Without Flow Interaction

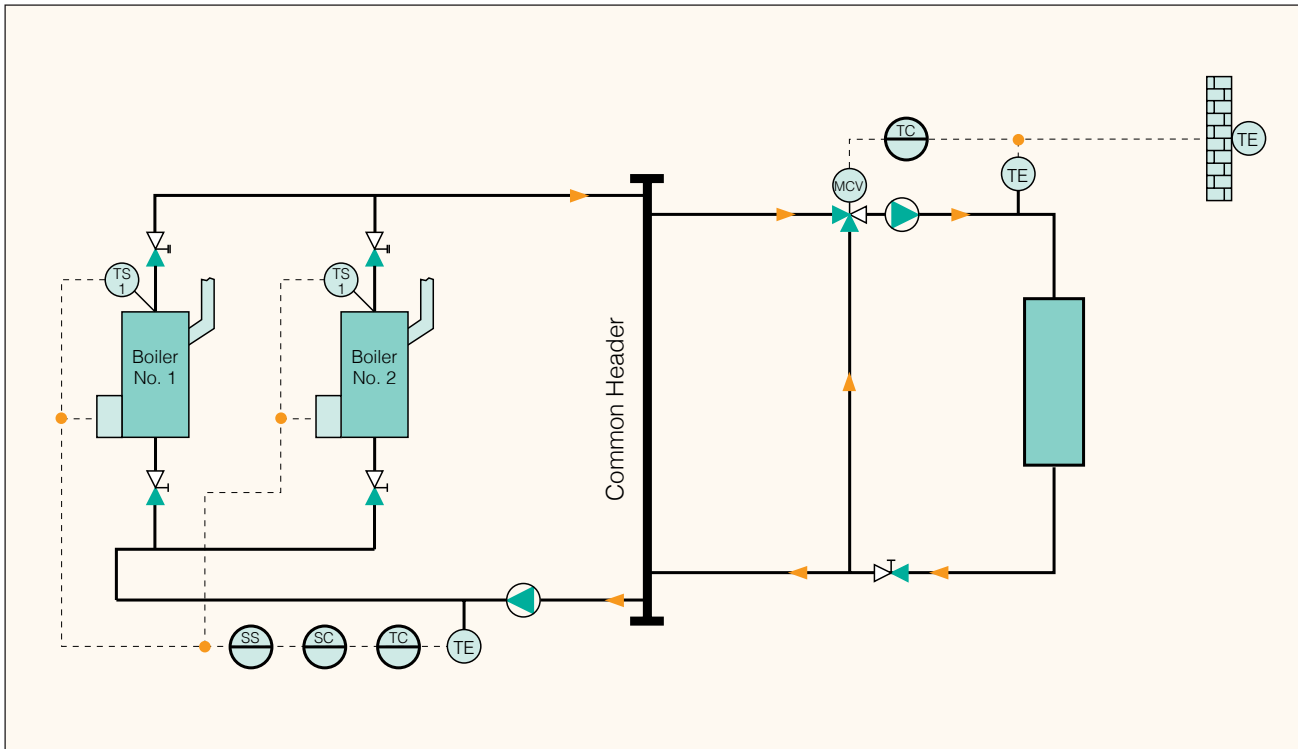
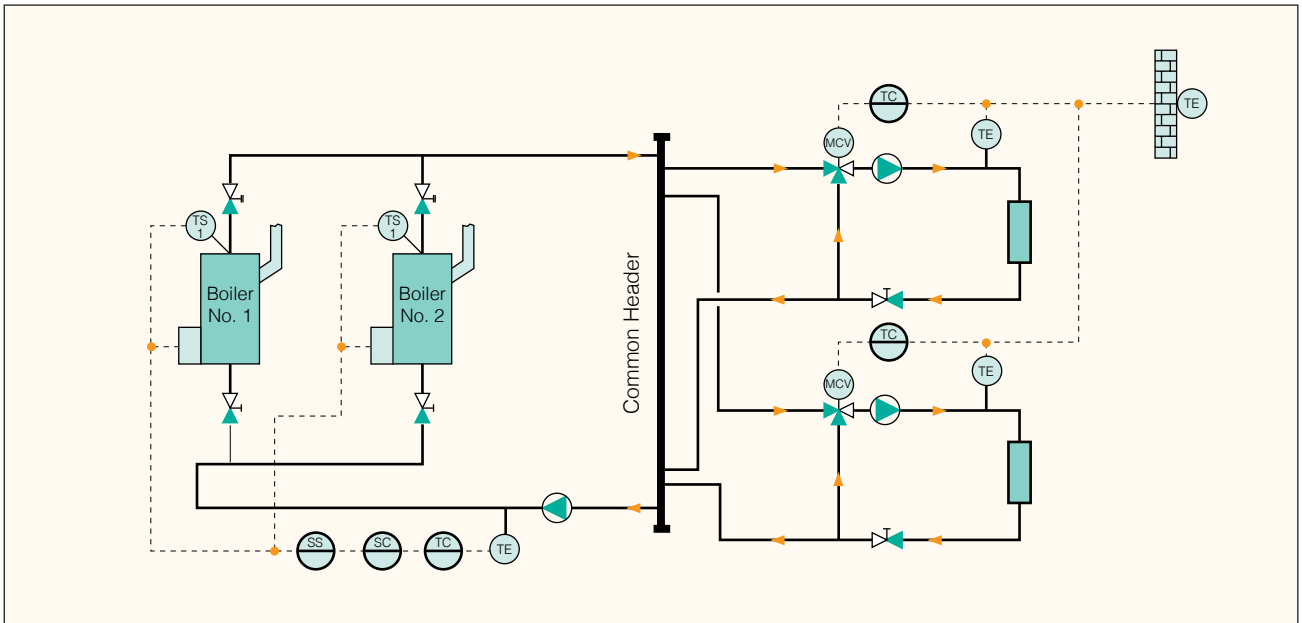


Figure 22 D&I 3

- Common primary pump.
- Non isolated modern low standing loss boilers.
- Minimum flow through boilers at all times.
- Header or buffer vessel to prevent interaction between primary & secondary circuits.
- Header (or buffer vessel) sized to ensure that there is minimal pressure drop with full flow through it.
- Primary circuit flow will not be affected whatever the position of the compensated circuit valve.
- Primary return temperature represents load for sequence control.
- Simple and easy to achieve with good long-term control.

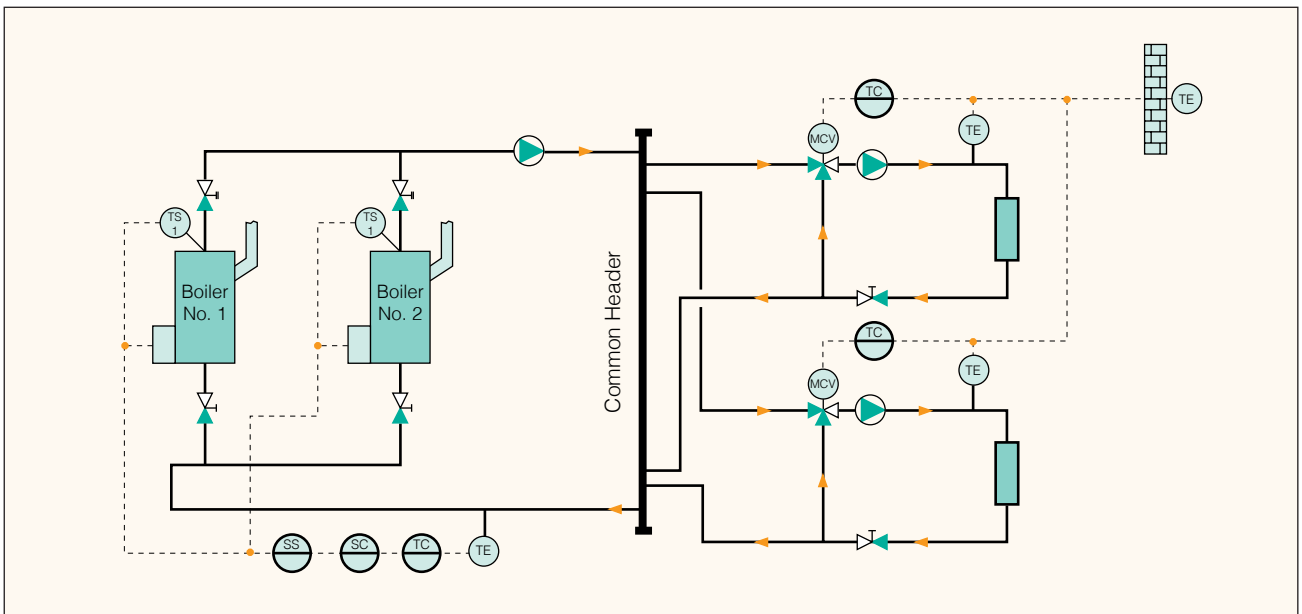
### 13.1.4 Pumped Primary Circuits with Multiple Secondary Circuits



**Figure 23 D&I 4**

- Advantages and precautions as per previous example.
- Multiple secondary circuits connected in parallel across the header so that each circuit has the full heat source available to it.

### 13.1.5 Pumped Primary Circuits with Multiple Secondary Circuits and Individual Boiler Feed and Expansion



**Figure 24 D&I 5**

- Advantages and precautions as per previous example.
- Individual boiler feed and expansion.
- Pump located in flow from boilers.
- Changes the zero point on the system.
- Boilers are at a lower pressure.
- Lower practical boiler safety margin for boiling.

### 13.1.6 Flow Interaction with Split Header System

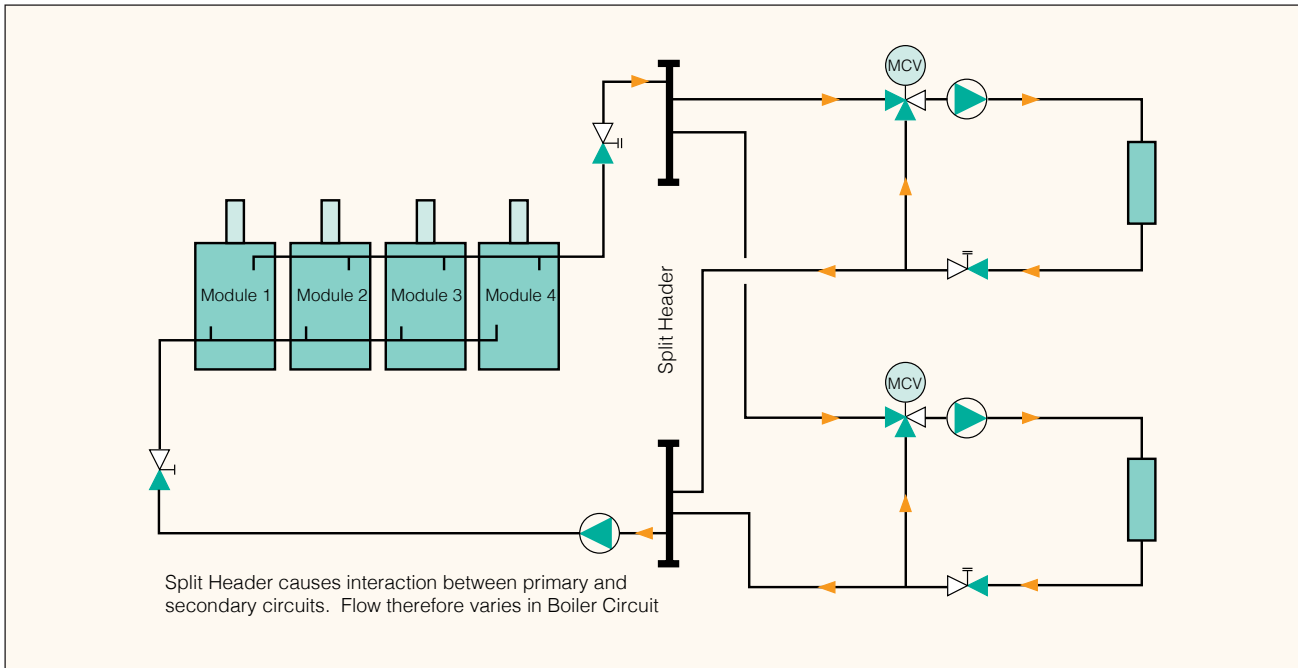


Figure 25 D&I 6

- Separate flow and return headers.
- Interaction between circuits.
- Variable flow created in primary circuit.
- Primary return temperature does not represent load for sequence control.

### 13.1.7 Constant Flow Main Circuit with Compensated Injection Circuit

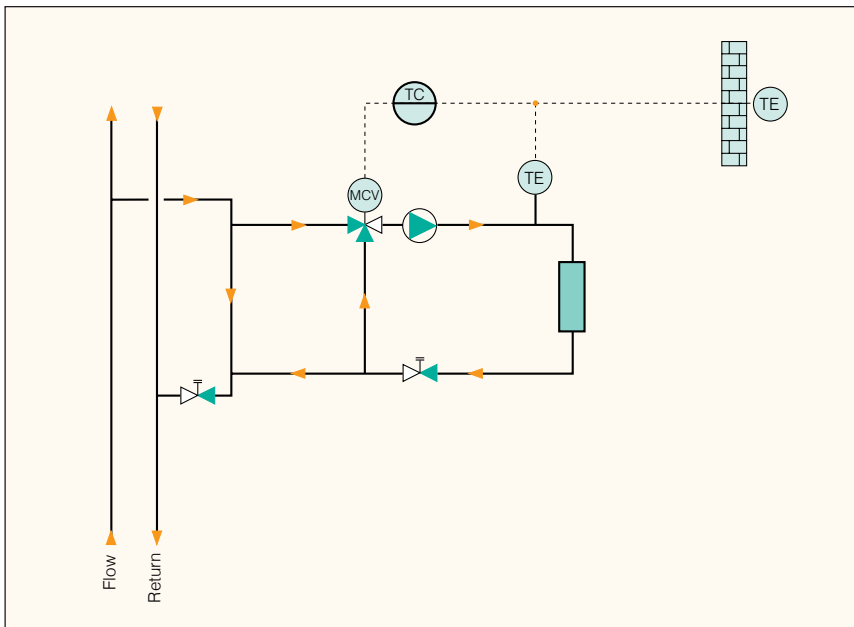


Figure 26 D&I 7

- Primary load constant temperature.
- Suitable local compensated zones.
- Injection circuit prevents interaction between circuits.
- Not normally applicable.

### 13.1.8 Large Boiler System

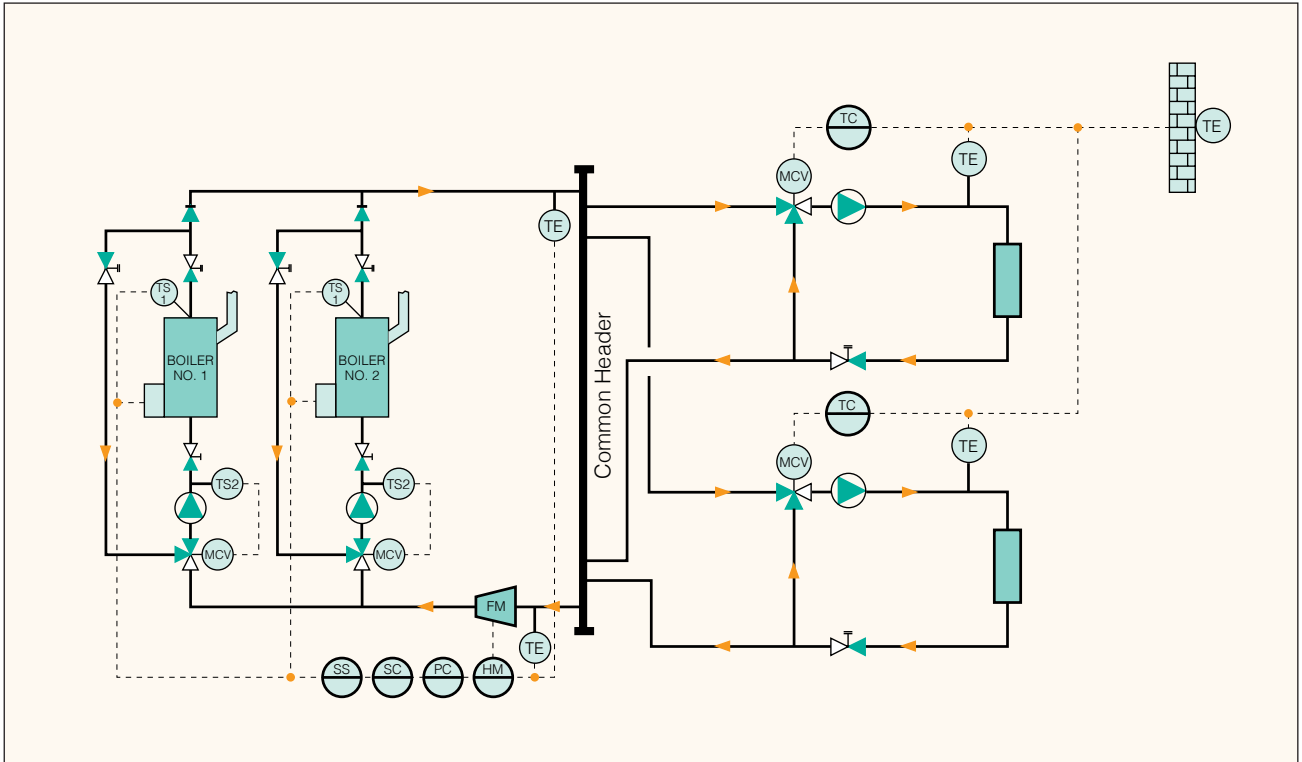


Figure 27 D&I 8

- Boilers automatic isolation.
- Variable flows in primary and secondary circuits.
- Common header or buffer vessel to prevent interaction between circuits.
- Heat metering sequence control.

## 14. SPECIFICATION, INSTALLATION AND COMMISSIONING

Whilst it is obviously not feasible to cover all types of specification necessary, it is the intention that the example will give guidance as to what is required.

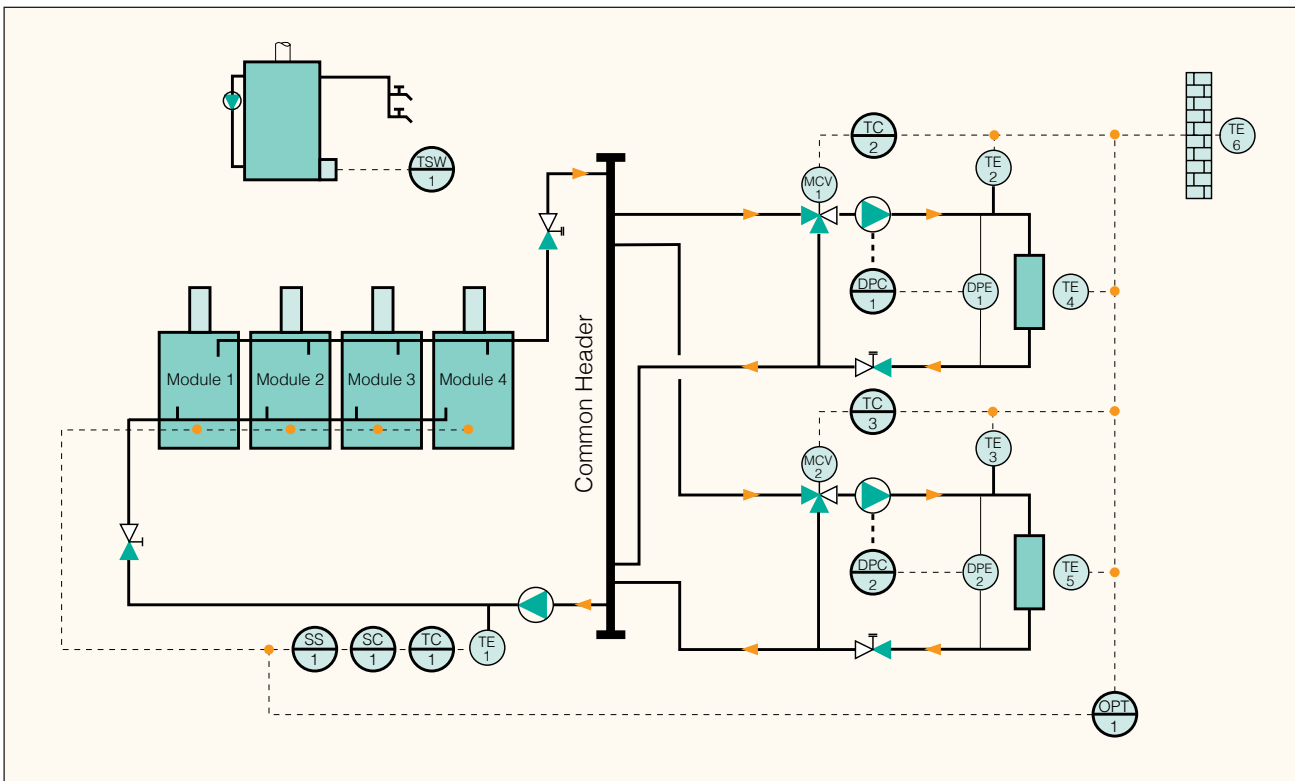


Figure 28 Typical modular boiler heating system with segregated HWS

### 14.1 Typical Specification for Heating and Hot Water System Controls

The specification should be read in conjunction with Figure 27.

#### Legend

- TE1 = boiler return water temperature sensor
- TE2 = zone 1 compensated flow temperature sensor
- TE3 = zone 2 compensated flow temperature sensor
- TE4 = zone 1 space temperature sensor
- TE5 = zone 2 space temperature sensor
- TE6 = outside temperature sensor
- TSW1 = HWS timeswitch
- OPT1 = heating optimiser
- TC1 = boiler sequence proportional temperature controller
- TC2 = zone 1 compensator
- TC3 = zone 2 compensator
- SC1 = boiler sequence control step controller
- SS1 = boiler sequence selector switch
- MCV1 = zone 1 compensator valve
- MCV2 = zone 2 compensator valve
- DPE 1 = zone 1 differential pressure sensor
- DPE 2 = zone 2 differential pressure sensor
- DPC 1 = zone 1 differential pressure controller
- DPC 2 = zone 2 differential pressure controller

- The heating system shall be non pressurised low temperature hot water (LTHW) comprising a primary circuit with four in-line parallel connected high efficiency modular boilers. The two secondary circuits are compensated and serve the east and west fascias of the building. The primary circuit shall be constant flow and the secondary circuits variable flow.
- The HWS is provided by locally mounted gas-fired water heaters.
- The heating system shall be started and stopped according to building occupancy by an optimiser with seven day program allowing different occupation times to be set for each day of the week. The optimum start function shall be in accordance with the latest issue of the BRESTART program. Optimum stop shall be provided with a user defined maximum off period. The optimiser shall be microprocessor based with default settings for a typical five day per week occupancy. The optimiser shall be self adaptive. The self adaption shall be limited so that it is not substantially altered on start-up after a system failure.
- The system shall be started during unoccupied periods in the event of low space temperature. Once the space is up to the required temperature for fabric protection the system shall be stopped. Exposed pipework shall have trace heating which shall be enabled in the event of low outside temperatures.
- On system start-up, the primary circuit shall run for an adjustable period of time prior to the secondary circuits being started. This shall enable fast boiler warm up and reduce boiler corrosion. Once the secondary circuits are started, the compensator control valves shall be held fully open until the end of the boost period. Boost shall be terminated at occupancy start time or earlier if the desired space temperature is reached.
- The complete heating system shall be stopped when the outside air temperature exceeds a user defined level.
- Each boiler module shall have its firing controlled by the packaged control thermostat located at the boiler outlet. A hand reset high limit function shall be incorporated in the control thermostat. Settings for control and high limit shall be in accordance with HSE PM5 for a non pressurised system.
- The sequence of boiler module operation shall be selected by the sequence selector switch to give the following combinations: 1,2,3,4 - 2,3,4,1 - 3,4,1,2 and 4,3,2,1.
- The lead boiler module, as selected via the sequence selector switch, shall be enabled at all times of system operation. The other modules shall be enabled in sequence with respect to reducing return water temperature via a proportional controller and three stage step controller. The proportional band of the controller shall be 11°C to match the design differential temperature of the system.
- Boiler operation shall be interlocked with the primary circuit direct drive pumps, so that the boilers are only enabled when the selected pump is running, via an auxiliary contact on the pump starter.
- The flow temperature of each compensated circuit shall be compensated with respect to north face outside air temperature. The compensator slopes shall be reset with respect to space temperature from the average of two rooms in each zone, to reduce the flow temperature by 3°C for every 1°C increase in space temperature above the desired space temperature. The rooms in which the reset temperature sensors are located shall not be fitted with any form of space temperature control.
- Space temperature shall be controlled in all rooms, apart from those with compensator reset sensors, by TRVs on the appropriate radiators.
- The pumps for the compensated circuits shall have their speed controlled by PWM inverter speed controllers. These shall be controlled with respect to the differential pressure at the ends of the index legs of each circuit.

- The local gas-fired HWS cylinders shall be controlled by their in-built packaged controls to maintain a minimum storage temperature of 60°C during the occupied period and for a minimum of 30 minutes prior to occupancy. Each cylinder shall have a recirculation pump to circulate water around the cylinder and avoid stagnant areas. A manual reset high limit thermostat shall also be provided on each cylinder.

## 14.2 Contractual Arrangements

Contractual arrangements are extremely important to the successful installation and commissioning of a control system. A single point of responsibility that can provide effective control of all the elements involved is ideal but in practice, rarely obtainable.

Many of the problems on installation of control systems arise due to:

- indistinct apportioning of responsibility between the mechanical and electrical contractors.
- poor communication between the electrical and mechanical contractors.

In contracts in which the controls and services wiring are part of the main electrical contract, problems can occur due to the above reasons.

The most successful contractual arrangement for installation of controls in a new build, or major refurbishment, is for the controls and services wiring to be part of the mechanical contract. The mechanical contractor should have a specialist sub contractor to supply, wire, test and commission the controls and control panels. This should either be a controls manufacturer or a systems company. The main electrical contractor should provide power to, and earth, the control panels, but all other services wiring should be carried out by the specialist sub contractor

For very small simple installations, electrical installation by the main electrical contractor may be acceptable and in some cases alternative or hybrid arrangements may be appropriate. Extreme care should be taken to ensure allocation of responsibility and attendance during commissioning by all parties.

## 14.3 Consultants

Limits of responsibilities of consultants are normally governed by the terms of their appointment which is often according to The Association of Consulting Engineers (ACE) terms and conditions.

## 14.4 Sensor Location

**Outside air temperature sensors** used for frost protection and compensation should be located on the north face of the building out of direct sunlight, away from sources of heat such as opening windows, vents, fans, flues, etc.

**Solar sensors** for compensated circuits should be located on the faces of the building being served by the circuit.

**Space temperature sensors** and room thermostats should be located on a wall, or column, at a height of 1.7 m above the finished floor level, away from heat sources and out of direct sunlight.

**Black bulb temperature sensors** for radiant heating systems should be located on a wall, or column, at a height of 1.7 m above the finished floor level. They should be positioned away from heat sources, out of direct sunlight and within the area served by the heater being controlled.

**Immersion temperature sensors** should be located in a pocket to allow removal without draining down. The sensor should be a close fit in the pocket. Where this is not possible, or where control is particularly sensitive, heat transfer compound should be used.

**Immersion temperature sensors** for mixed flows, such as compensated system flow temperature sensors, should be located at least ten pipe diameters from the point of mixing.



**Sensors positioned in ducts/air handling units (AHUs)** should be at least as long as half the width of the duct. If this is not possible averaging element capillary sensors should be used.

**Duct mounted frost thermostats** should be of the capillary type located within 100 mm of the heater battery surface and so arranged as to sense the temperature across the full width and height of the duct.

**Off-coil temperature sensors** in air handling units should be mounted at least 2 m from the coil and should not be subject to any radiation.

**Calorifier sensors and thermostats** should be located as described in the hot water services section.

#### **14.5 Mechanical Installation**

The following list of points detail good practice for controls related items of mechanical installation. The list is not intended to be exhaustive, but covers the main points.

**All control devices** should be installed in accordance with the manufacturer's instructions.

**Control valves** should be installed with the porting arrangement to suit the application, normally a mixing arrangement. Where diverting valves are required, suitable valves must be used. Most valves have common porting arrangements although some older valves had differing porting arrangements with the bypass and flow ports swapped. Where these are being replaced, the pipework will require modification to ensure the correct port characteristics are used.

**Control valves** should be installed within their pressure and differential pressure ratings.

**Differential pressure type flow measurement devices** should be installed in straight pipe 10 diameters upstream and 5 diameters downstream as a minimum. Other flow measurement devices should be installed as above, if possible, or in accordance with the manufacturers recommendations.

**All instruments, sensing elements, and test points, etc.** should be mounted in accessible locations from permanent walkways, ladders and platforms. Instruments should be located so they do not obstruct walkways or plant equipment access. Access should be left around instruments to enable maintenance to be carried out.

**Instrument impulse lines** should NOT be mounted on, or supported by railings, but should be mounted on cable tray or similar support. All holes cut in tray or trunking for the passage of impulse lines should be grommeted.

**All instrument connections** should be relieved of any strain and stress by suitable support.

**All supports, brackets and supporting channels** should be manufactured in mild steel and painted with a coat of red oxide primer before installation, except where corrosive conditions may occur. In this case they should all be hot galvanised.

**Weatherproof housing** should be provided for all outside mounted instruments.

**Damper actuators** should be fixed to brackets to prevent any movement of the actuator, other than designed movement, during operation.

**Pockets for temperature sensors or thermostats** should be screwed into 1/2 inch BSP bosses welded to the pipework. Pockets should be located on pipework bends where the pipe diameter is insufficient for the pocket length. Pockets should be located at a height of 1.0 to 2.0 m from the finished floor level where possible for ease of access. The pockets should be able to withstand 1.5 times the system working pressure. Pockets should be nickel plated copper, except where stainless steel is specified.

**Calorifier pockets** should be located so that the pocket does not interfere with the removal of the tube bundle.

**Surface temperature sensing elements** may be used on small diameter pipes where the insertion of a pocket would cause an unacceptable pressure drop, or for temporary installation. Good thermal contact must be ensured with positive clamping of the element via a jubilee clamp or similar. Spring clamps are not recommended. Heat transfer compound should be used between the surface and the sensor. Surface mounted elements should not be permitted for high limit functions and should be avoided where at all possible. It should be noted that surface temperature sensing elements normally provide a temperature reading a couple of degrees below the actual liquid temperature.

**The heads of rigid stem instruments** should be securely fixed to the pockets or ductwork. The heads of remote bulb capillary sensing instruments should preferably be securely fixed to a wall, or a supporting framework, or to a relevant air handling unit and ductwork where it is not subjected to vibration.

**Differential pressure switches** for an air handling unit installation should be piped with seamless copper or fire retardant polythene tubing of a minimum OD of 6 mm.

**Differential pressure switches** for hydraulic installation should be piped with seamless copper tubing to BS 2017 of a minimum OD of 6 mm. The tapping points should be fitted with isolation valves to allow removal of the differential pressure switch without draining down the system. The installation should be pressure tested to 1.5 times the system working pressure.

**AHU capillary sensors** should be mounted on a suitable framework with access for replacement.

**All control items** should be located so that they are readily accessible for adjustment, service and replacement.

## 14.6 Electrical Installation

The following list of points detail good practice for electrical installation related to controls. The list is not intended to be exhaustive, but covers the main points.

**All control equipment** should be wired in accordance with the current edition of the IEE regulations.

**All control items** should be installed and wired in accordance with the equipment manufacturers instructions but should, as a minimum, be installed in accordance with the following.

**Sensor wiring and data communication** should always be run in separate conduit or trunking from low and high voltage wiring whether the sensors are wired in screened cable or not. Where plastic conduit or trunking is used the sensor/data cable should be separated from low and high voltage cable as far as possible. Recommended distances are 0.5 m from low voltage and 1.5 m from high voltage. Sensor/data cable should never be run in parallel with power cables and should, where possible, cross at right angles.

**Valve or damper actuators** should be wired as per sensors above where the actuator is extra low voltage. For low voltage (240 V) actuators the wiring need not be segregated except where required by the control manufacturer.

**Analogue inputs (sensors), analogue outputs and data communication for micro processor based controllers and BMS** should be a minimum of 1.0 mm<sup>2</sup> twisted pair, multistranded copper conductors PVC sheathed, overall screened 440 V rated.

**Where steel wire armoured (SWA)** is used for data communications the cores should be individually screened twisted pairs, with an overall screen where there is more than one twisted pair.

**Screened or mineral insulated copper sheathed (MICS) cable** should be terminated at the controller/outstation/control panel in accordance with the instrument manufacturers instructions. The screening, or outer metal sheath of MICS, should be earthed at the controller/outstation/control panel only. Screening should be connected to the internal panel screened wiring via an adjacent terminal on the terminal strip.

### **14.7 Retrofit Installations**

A number of additional considerations need to be taken into account in order that installation of control equipment on a retrofit basis can run smoothly and commissioning problems be minimised. The main points are detailed below.

The contract documents must clearly state allowable working hours, limits on noise and dust creation during normal working hours, areas with special entry conditions, etc. Standards of installation must be defined. Where these exceed the standards of existing services it should be clearly pointed out that existing standards are not the basis for acceptance of workmanship.

A Clerk of Works, who is readily available on a daily basis, must be appointed to represent the client. He must be capable of management of the contractor and interpretation of the specification to enable the installation to proceed without unnecessary delays but maintain the intended standards of the specification. Where he requires more detailed technical backup this should be provided by the system specifier.

The Clerk of Works should be responsible for reporting progress to the overall project manager or supervising officer on a regular basis.

A supervisor must be appointed by the contractor who is also available on a day to day basis to control his staff and to liaise with the Clerk of Works.

Detailed daily worksheets should be kept and a weekly programme of work should be submitted to the Clerk of Works in advance each week.

Regular site meetings should be held chaired by the supervising officer or project manager. Reports should be submitted by both the Clerk of Works and the contractor. Accurate minutes should be recorded and distributed to all parties detailing the actions required.

Liaison with the building users is essential at all times. The purpose of the installation and how it will affect the users should be made clear at the start of the contract. Day to day liaison is normally the responsibility of the Clerk of Works who is often appointed by the end user.

### **14.8 Monitoring**

It is essential to fit adequate instrumentation during the installation phase to enable accurate commissioning of the systems and subsequent assessment to ensure efficient operation. The needs will vary greatly dependent upon the systems installed. Time and finance should be set aside at the outset of the installation phase to ensure that this area is adequately covered.

### **14.9 Pre-Commissioning**

When the controls installation is complete and has been inspected, the sequence of operation, valve and damper operation, and control setpoints should be set and checked.

### **14.10 Commissioning**

The main plant must be commissioned and operating prior to the controls being commissioned. This will involve the following actions.

- Circuit flow rates should be checked and balanced with control valves in the fully open, fully closed and mid positions. This ensures that flow is either within limits for constant flow systems, or operates between maximum and minimum flows for variable flow circuits. Control valve authorities should be checked against measured pressure drops. Where these are outside the required limits for good control, the valves, emitters or other items should be replaced with suitable components.
- The flow rate in primary circuits should be checked whilst the above checks are made on secondary circuits to ensure that there is no interaction between circuits.
- Where tight shut-off automatic isolation valves are used it should be ensured that there is no leakage under the full range of operating conditions.

When all services are set working the control should be calibrated and adjusted to provide stable design conditions and operate the plants in accordance with the design intent and specification.

### 14.11 Post Commissioning



Allowance should be made to check fully the stability of operation and operating temperatures under different climatic conditions. At least two visits should be allowed for during the Defects Liability Period.

### 14.12 Documentation

Prior to commencement of any works or installation of any materials, the contractor should submit the following data for approval by the engineer.



- Trunk wiring routes.
- Sensor and controlled device wiring routes.
- Sensor and controller locations.
- Plant interface and wiring details.

Within one month of completion of the contract, installed drawings, as listed in documentation above should be issued together with operation and maintenance manuals, software back-up and controller points schedules.

A fully comprehensive instruction manual should be supplied which covers operation of the controllers and details routine and breakdown maintenance of the control equipment which can be undertaken by the clients staff. Full details of fault diagnostic procedures should also be included.

The manual should include detailed schematic diagrams of all electronic components for the whole of the control system.

Where DDC controls are used detailed information on the software programs should also be provided so that an update of the programs can be carried out by the client's staff. This should include listings, details of software design, etc.

The manual should also show:

- how new software is added to the system
- how existing software may be altered
- how stored data may be altered or added
- how new points may be added to a controller
- how new controllers may be added to the system.

Two copies of the complete system software, either on disk or tape should be supplied.

Each DDC controller should be supplied with a points schedule in a rigid transparent plastic document holder.

For each point, the schedule should show as a minimum:


- the hardware address
- the associated software address
- point description
- the field or panel component reference and location of the monitored or controlled device
- the type of device including the manufacturers reference
- operating range and accuracy where applicable
- device accessories

Special interfacing or wiring requirements should be provided for approval. The schedule should be accompanied by manufacturers data sheets showing installation details, etc.

A set of basic operating instructions should be supplied in a transparent cover which can be screwed to the wall in the boilerhouse or whichever location is most suitable.

## 15. GENERAL GUIDANCE

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- Where heat load exceeds 30 kW, use an optimiser for start and stop on intermittently occupied buildings.
- Use high efficiency and/or condensing boilers.
- For multiple boiler installations, with modern low water content boilers, provide a constant flow pumped primary circuit to allow simple and reliable sequence control from return water temperature. Do not fit automatic isolation valves, or individual pumps on boilers, which would cause the primary circuit flow to vary. Ensure that the boiler circuit flow is not affected by variable flow from other circuits, which is often caused by compensator valves. 
- For existing systems without high efficiency or condensing boilers, or for large/high water content boilers, use effective measures to minimise standing losses.
- Where possible provide an entirely separate HWS system.
- Provide separate compensated zones according to building use, structure or solar gain.
- Provide space temperature reset of the compensator.
- Provide space temperature control from individual emitters where possible, except where space temperature reset sensors are fitted.
- Simple but well engineered systems are likely to be the most efficient over the life of the plant.

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