Building management systems and controls do not always control buildings as effectively and efficiently as they should. **Graham P Smith** looks at the underlying causes of this problem

TAKING CONTROL

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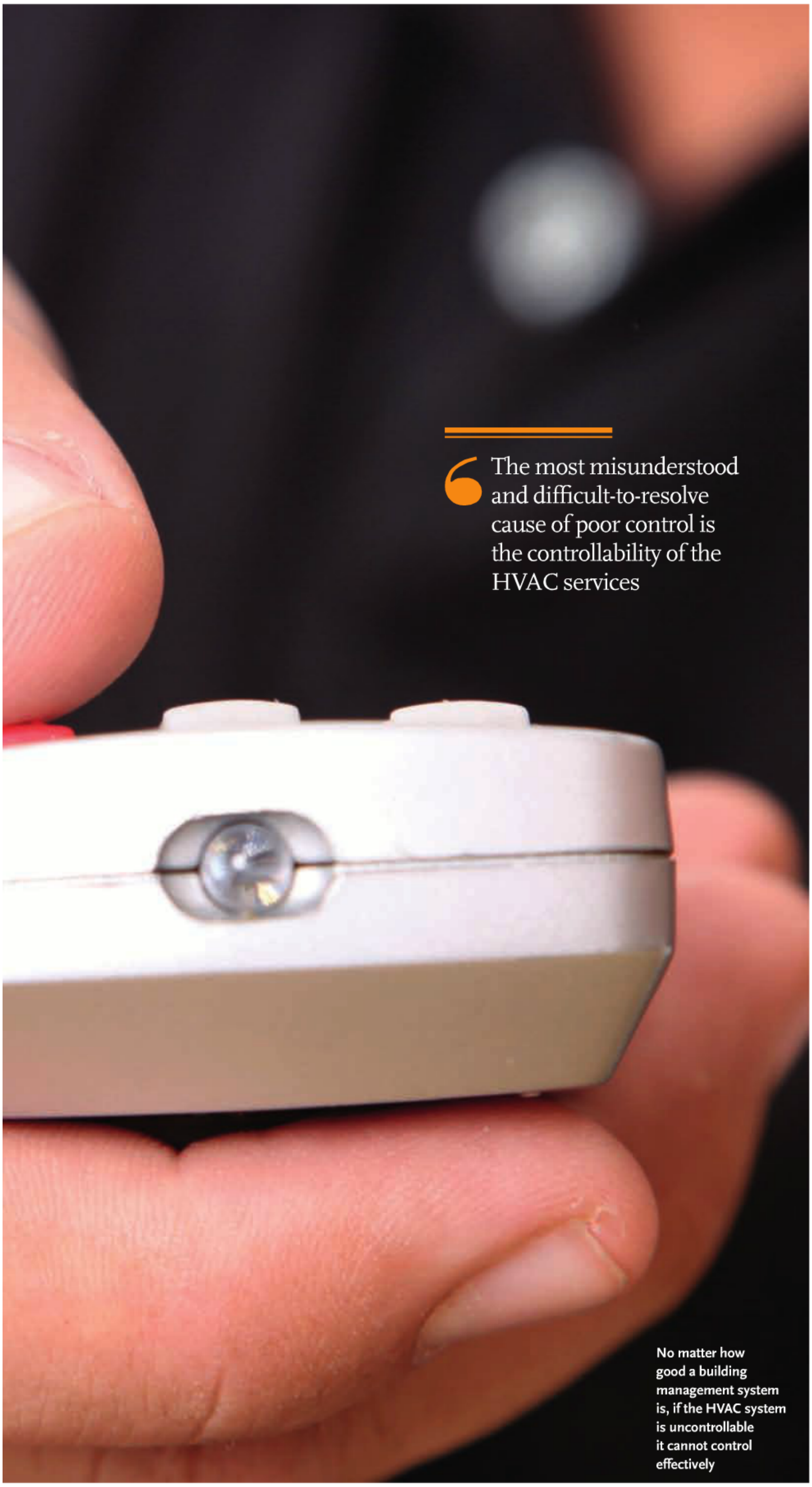
One of the most common causes of poorly performing buildings is inadequate or deficient control systems. About 90% of controls for heating, ventilating and air conditioning (HVAC) systems are inadequate in some way, costing industry and commerce more than £500m a year in additional energy costs, according to the Carbon Trust (see *Building Controls Technology Overview* – CVT032, 2007). Controllability – or the lack of it – is a key issue when it comes to saving energy and cutting carbon emissions from buildings.

There are a number of definitions of controllability. For the purposes of this article, the term is used to mean the ability for the system to be controlled within acceptable limits for both occupancy comfort and energy efficiency/carbon emissions. Despite advances in control technology, poor control outcomes are still common. Controls can be inadequate or deficient for a number of reasons, but the most common are:

- Inadequately specified control systems/ building management systems (BMS);
- Deficient commissioning and maintenance of control systems/BMS;
- Poorly understood, or ineffectual use of, control systems/BMS; and
- Poor controllability and uncontrollable HVAC services.

All these factors are important, but the most misunderstood and difficult-to-resolve



The most misunderstood and difficult-to-resolve cause of poor control is the controllability of the HVAC services

No matter how good a building management system is, if the HVAC system is uncontrollable it cannot control effectively

cause of poor control is the controllability of the HVAC services: no matter how good the control system or BMS is, lack of controllability means lack of effectiveness for all load conditions. A very simple example of an uncontrollable system is an oversized DX Cassette Unit with on/off control. This will never achieve a stable room temperature, and can result in cold draughts, dissatisfied occupants and poor efficiency of operation.

Changes to system design or plant selection may be required to achieve acceptable controllability – but such changes can be expensive and disruptive, and are avoidable by designing controllable systems. Alternative control strategies can sometimes be used, although not normally without some compromise of efficiency or operation.

Heating

Many controllability issues are associated with multiple boiler and chiller systems, which are normally less noticeable to the building user but are of increasing importance to reduce energy consumption and carbon emissions (and can be expensive and disruptive to rectify). CVT032 states that inadequate or incorrect application of boiler control can easily add 15% to 30% to fuel consumption, compared with a well-controlled system. Here are some of the most common heating-system controllability issues.

Poor header design (see Figure 1): Headers should be designed with flows at one end and returns at the other. If one circuit returns prior to the take-off for another circuit, the second circuit flow temperature will be affected – in this case the hot water supply (HWS) primary, which could affect HWS temperature. This should be obvious, but I've seen it on a major project within the last couple of years.

Split headers (see Figure 2): Individual flow and return headers will cause interaction between primary and secondary pumps, varying flows and potentially affecting stability of boiler control. It can be relatively easy to resolve by making the split header into a common header. A combined header/de-aerator/dirt separator can be very useful for this purpose.

Individual boiler pumps (see Figure 3): Individual boiler pumps and a common header are desirable to eliminate dilution of flow through off-line boilers, but can be the source of controllability issues. The most common issue is that boiler sequence cannot be controlled from return

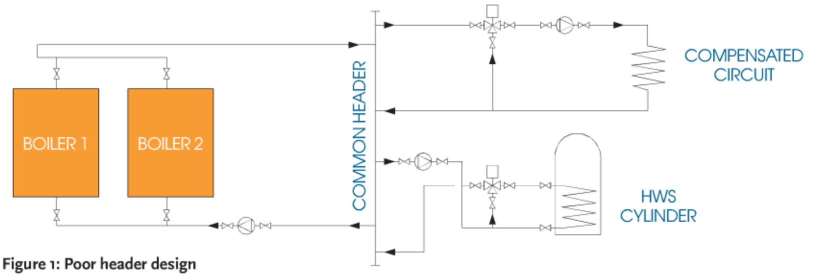


Figure 1: Poor header design

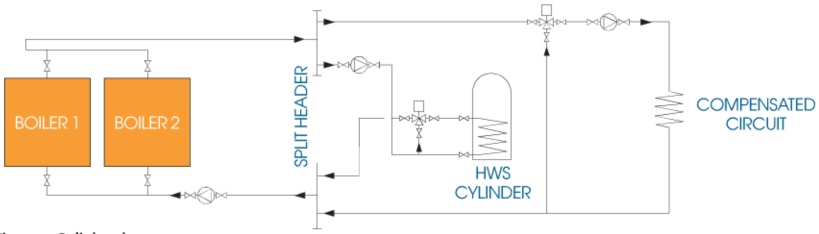


Figure 2: Split headers

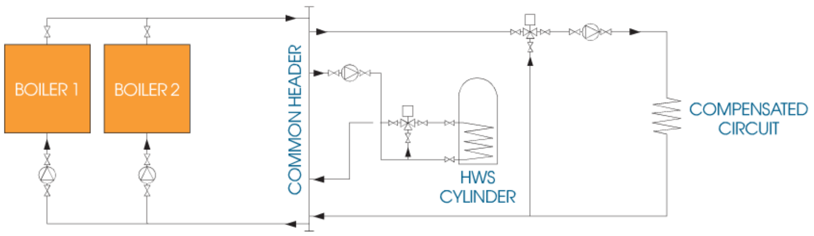


Figure 3: Individual boiler pumps and a common header

Note: The above diagrams incorporate corrections made since the publication of the print version of this article in December CIBSE Journal. The print version contained some directional arrows that were the wrong way around. We apologise to the author for these printed errors.

temperature as the temperature will not be representative of the system load, due to the change in flow rate. Flow temperature control can be used, but is only normally stable where it is correctly integrated to control boilers with modulating burners. Flow temperature control of boilers with on/off or high/low burners can be unstable and can interact with the boiler thermostats, unless particular care is taken with operating temperatures, which must conform with Health and Safety Executive guidance note PM5 (**www.hse.gov.uk**).

Boilers with individual pumps can be very effectively controlled with heat load control, which also allows the boilers to be controlled for their most efficient range of operation.

Condensing boilers: Many condensing boiler installations rarely work in condensing mode as, apart from start-up, the return water temperature is often above 54C, due to the system design. Direct compensation of boilers can achieve significantly increased condensing operation, but can only be used where a quick response to increase temperature is possible for HWS demand, where required.

System differential temperatures: Modern boilers are normally designed for higher differential temperatures, and consequently have lower flow rates. Whilst substitution of modern boilers with packaged pumps is normally successful at a domestic level, the effect on hydraulics must be considered for larger retrofit installations; reverse flows in common headers causing dilution of secondary flow temperatures is the most common problem.

Boilers with variable flow pumps: Pumps that vary boiler flow in unison with burner firing to maintain constant differential temperatures can cause significant hydraulic and controllability issues in multiple boiler applications, particularly where system differential temperatures have also not been carefully considered.

HWS segregation: Many systems combine heating and HWS heat sources to reduce capital costs. Segregation of HWS can often reduce standing losses in summer, and can permit far greater flexibility for boiler control, enabling more effective condensing operation.

Two-stage burners: These are very rarely correctly commissioned; only a few months ago I saw new boilers with both high and low burner stages set to the same temperature, working as single stage burners. Where controlled by the individual boiler thermostat, the second stage must be set to a lower temperature than the first stage; consequently, significant flow temperature variations will occur. Control can be integrated with sequence controls on multiple boilers to work effectively, but care must be taken to ensure compliance with HSE guidance note PM5.

There is little to justify two-stage burners as the theoretical gains over single stage burners are very rarely achieved. Modulating burners should always be used for good control and energy efficient operation.

Biomass boilers: These are increasingly used as a low carbon solution, but require a number of additional factors to be considered for successful operation. Purely adding a biomass boiler to an existing system without considering overall system integration – hydraulics and control – can be a recipe for problems. There are too many factors to consider here, but controllability is a major factor in successful biomass boiler system design.

Component pressure loss: Modern boilers can have significant pressure losses, which should be considered in their selection, as this will add to overall energy consumption. System components should also be

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Settings should be appropriate for the stable and economic operation of systems

carefully selected, and individual items with significantly higher pressure losses avoided, as these can dictate the maximum pump operating head. I have encountered systems where the majority of the loads had losses of 15 to 30 kPa, but a couple of loads were around 100 kPa.

To minimise energy use on variable flow systems, additional differential pressure sensors can be installed to control the individual parts of the circuits, to meet the required differential pressure only when these items of plant are operating. However, care needs to be taken to ensure stable operation of all items of plant when the system differential pressure changes. Selecting components with similar (low) pressure losses on each circuit is by far the most effective method for energy efficient controllable operation.

Chillers

One problem with chilled water (CHW) systems that I have identified on a couple of sites recently is parallel connection of a pair of chillers with a common pump-set (see Figure 4). In both cases the chillers were modern, large energy efficient chillers, but had flow temperature sequence control observed at low load, with one on-line chiller having an evaporator discharge temperature of 4.5C, mixing with the flow through the off-line chiller to achieve a mixed flow temperature of 6C.

An evaporator flow temperature of 4.5C will only satisfy a 25% load, assuming a constant flow system and 6C to 12C system temperatures. 3C would be necessary for 50% load with only one chiller operating to provide a mixed temperature of 6C, although chillers are typically set for a minimum control temperature of 4C to avoid the possibility of freeze-up. Running a chiller at lower CHW temperatures will typically have a reduction in coefficienct of performance (CoP) of around 3% to 6% at 4.5C instead of 6C, and 6% to 12% at 3C. The overall reduction in seasonal efficiency could be significantly greater, dependent upon the selected chillers and load profiles, plus there will be additional pumping losses compared with individually pumped chillers. I understand in both cases the chiller manufacturers had recommended the hydraulic layout and control system!

It is normally more efficient to run modern multiple chillers together down to loads of around 20% to 25%, dependent upon chiller selection. However, individual chiller turndown is limited and stability of operation has to be considered at low loads. Significant energy savings and stable, reliable operation can normally be achieved with a controllable system design incorporating individual chiller primary pumps, a common header or buffer vessel, heat load control and variable flow secondary circuits. Reset of evaporator flow temperature at low loads can also save further energy in many applications.

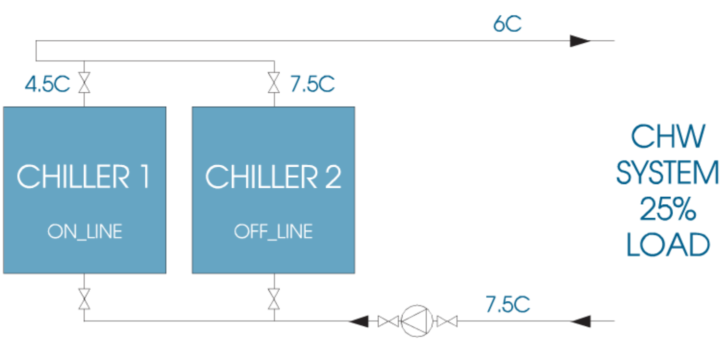

Figure 4: A pair of chillers connected to a common pump set

Conclusion

The above is a selection of common controllability issues, most of which are easily avoided with suitable input to system design, resulting in controllable, energy-efficient operation. Robust control strategies are necessary to achieve optimum energy efficient, low carbon operation. Simple solutions are preferable, wherever possible, although modern plant with direct communication via BACnet, for example, offers further opportunities for more efficient operation. **CJ**

GRAHAM P SMITH is director of Birling Consulting. He was a technical adviser for and a principal author of CIBSE Guide F: *Energy Efficiency in Buildings* -1998.
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