Controllability –The Achilles's Heel of Building Performance?

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Building Performance Gap

- Three times predicted energy consumption not uncommon – often causes unexplained
- Low carbon plant utilisation – Biomass 13% utilisation seen on several sites
- BRECSU GIR40 Heating systems and their control 1994:
  - 90% of HVAC systems were not properly controlled costing £500million in additional energy costs
  - Still reported as a fact in Carbon Trust Publications
  - Many issues in GIR40 survey were controllability, not just control

Building Performance - Factors

- Well Understood Factors:
  - Heat Loss/Gain
  - Thermal Mass
  - Infiltration
  - Solar Gain
- Less Well Understood Factors:
  - Plant Efficiency/Seasonal Efficiency
  - Controllability
  - Commissioning/Coordination of Commissioning
  - Parasitic Losses
  - Accurate Measurement

Controllability of Buildings

- Primarily the ability of the HVAC services to be effectively controlled for:
  - Comfort
  - Energy Efficiency
  - Effective utilisation of low carbon/energy efficient heating and cooling sources – Biomass, CHP, heat pumps, etc.
  - Fabric Protection
  - Safe Operation
- Controllability is Key to Performance of Modern Plant

Poor Controllability

- Poor Controllability Can Cause:
  - Poor Control
  - Unstable/Inconsistent Operation
  - Unreliable Operation
  - Reduced Plant Life
  - High Energy Consumption
  - High Maintenance Costs
  - Dissatisfied Building Occupants/Operators
  - Ongoing problems for the life of the building, or system
  - Contractual Disputes

Good Controllability

- Benefits:
  - Reduced Commissioning Time
  - Improved Control
  - Improved Energy Efficiency
  - Carbon Savings
  - More Satisfied Building Occupants & Operators
  - Reduced Maintenance Costs
  - Cost Savings throughout the life of the system
  - Reduced Chances of Contractual Disputes
- Costs:
  - Normally Little or No Capital Cost
  - Additional input to design and construction stages – but reduced commissioning issues
  - Very low cost compared to an uncontrollable system

Recent Factors

- Building Regulations/RHI
- Bivalent Systems/Low Carbon Heat Sources - Unique Characteristics - Different Solutions
- Modern Boilers – Greater Δt, Higher Turndowns, Variable Flows
- More Heat Networks/Community/District Heating
- Specialist Suppliers
- Packaged Control Systems
- Design & Build
- Value? Engineering
- Inadequate Project Management of More Complex Solutions

Controllability Guidance

- Poorly Documented
- GIR40 Heating systems and their control 1994 - Lead objective to ensure the services are controllable
- CIBSE Guides H & F – Boiler control primarily based on GIR40 and out of date
- AM15 Biomass Heating – requires a controllability review and considers thermal storage and plant response
- Most other guidance on system design and codes of practice - inadequate/no information on controllability – particularly important for bivalent systems/heat networks

Controllability Reviews

- Essential part of Design Process
- If system is not controllable – it won't work effectively
- Some guidance calls for system design reviews for commissioning – similar but not effectively defined

Controllability Reviews -Timing

- Early stages of design – Establish principles of operation & often hydraulic design
- Review again after final plant selection
- Existing Systems - Invaluable to identify true causes of poorly performing and resolve issues – often incorrect conclusions reached due to inadequate knowledge or ‘blinkered’ thinking

Controllability Review Requirements

- Reviewer requires thorough understanding of:
  - Typical and Actual Plant Characteristics
  - Hydraulic Design/Variable Flow/Heat Networks
  - Principles of Control
  - BMS/BACnet, etc.
  - Controls and System Commissioning
- Most individual disciplines - Building Services/Control/BMS/Energy Engineers - have inadequate experience of all relevant factors

Plant Characteristics

- Plant selection critical:
  - Max/Min Temperatures
  - Max/Min Flows
  - Differential Temperature/Flow
  - Max/Min Outputs
  - Modulating/staged/on-off outputs
  - Efficiency at different temperatures or outputs
  - Response rates/Mode changeover rates
  - Packaged controls
  - Communications/interfaces
  - Maintenance
- Critical information often difficult to find/understand
- Different sizes of same manufacturer's CHP can have different temperature limits

Hydraulic/Hydronic Design

- Must consider plant selection and characteristics
- Must consider different flows/temperatures for heating/cooling sources and loads
- Must enable stable operation
- Adequate straight lengths for flow measurement - particularly when required for control and billing
- PICVs, DPCVs, etc. selection/location – pressure losses can be high - parasitic loss

Control Strategies - Responsibility

Once system is controllable:

- Appropriate Control Strategies must be ***Specified***
- System Designer ***Responsible***
- Controls/BMS supplier/Systems Integrator ***Not Responsible for Fundamental Principles*** - cannot be expected to guess strategy for complex systems
- Strategies must be ***Detailed***
- 'Biomass/CHP shall always lead' without principles of how achieved ***Inadequate***

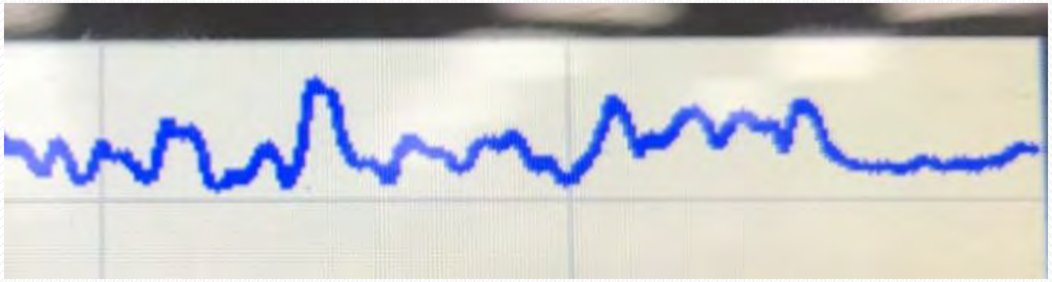
Control Strategies - Complexity

- Simple strategies where possible
- Bivalent/complex systems normally require more sophisticated strategies
- Heat Load based control strategies often more suitable for more complex/bivalent systems

Commissioning/Seasonal Commissioning

- Systems will not work properly unless effectively commissioned
- More complex systems require significant management and coordination of commissioning
- Recent experience - fundamental lack of understanding of basic control principles - some packaged equipment suppliers and some Systems Integrators
- Seasonal commissioning required for most systems
- Monitoring and data analysis recommended to ensure more complex systems working correctly

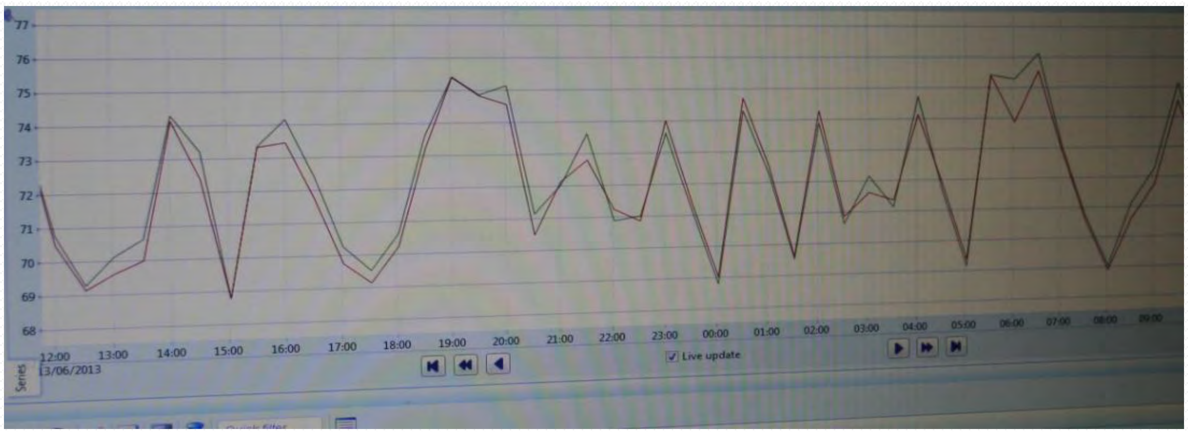
Controllability, or Control, Problem?



- Two recirculation upflow 'CRAC' type systems with proportion of untreated FA
- Close control applications – Both not accepted by clients, completion delayed
- Similar temperature and humidity control stability issues
- 1 **Composite Production Facility** – Set up by manufacturer with proportional control, small proportional bands and inadequate deadbands – reset with P&I control using empirical values - immediate improvement seen to right of above graph, all ten units reset, no further problems. **Inadequate Commissioning.**
- 2 **Laboratory** – Uncontrollable due to on/off reheat, reheat too small for high dehumidification load, inability to effectively set P&I control functions, incomprehensible control strategies, etc. All services replaced causing 8 month delay to project completion. **Uncontrollable system.**

Burner Controllability

- On/Off Burners – Old boilers - on/off thermostat control – switching differential 5K – up to 17°C variation in flow temperature has been recorded

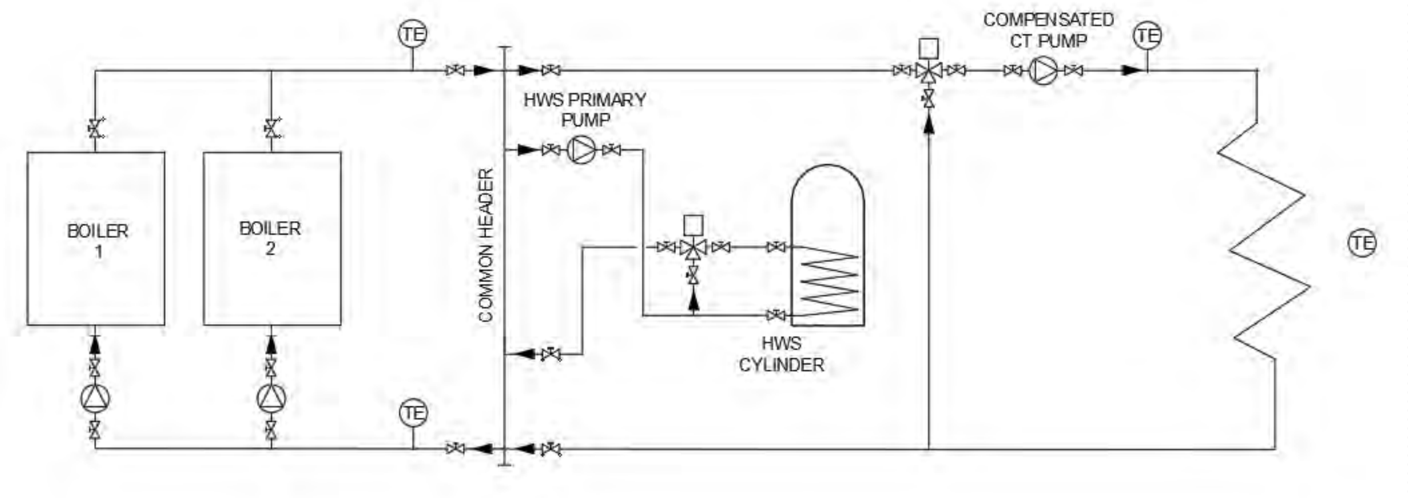


- High/Low Burners – High fire must be controlled at **lower** temperature if control from boiler thermostat – majority work as on/off – high fire control from sequence/heat load control possible
- Modulating Burners should always be specified
- Some modulating burners limited turndown due to boiler type – sometimes can be improved

Boiler Selection

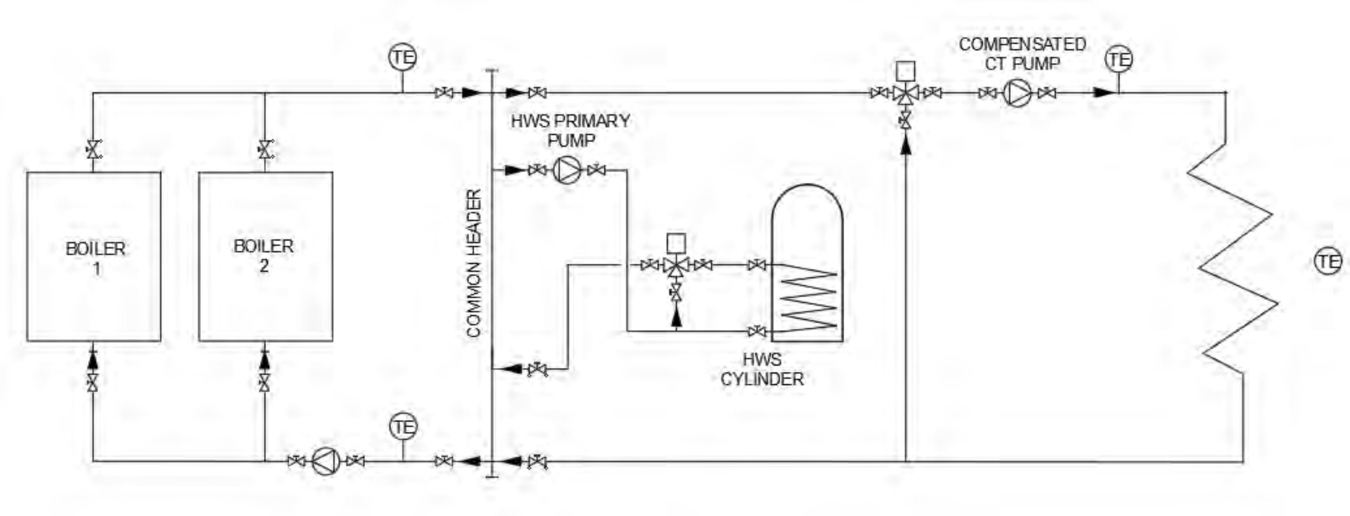
- Oversized boilers affect controllability
- Oversized boilers can affect efficiency of operation – condensing and start/stop
- Modern boilers more efficient at low loads – provided not stopping and starting
- Condensing boilers only condense when return below 54°C, maximum condensing down to 30-40 °C.
- Greater turndown with modern boilers
- Variable flow boilers can offer significant advantages in system design
- Most modern boilers Δt 20K – not direct replacement for older boilers with Δt 11K
- Segregate heating & HWS where practicable

Oversized Boilers



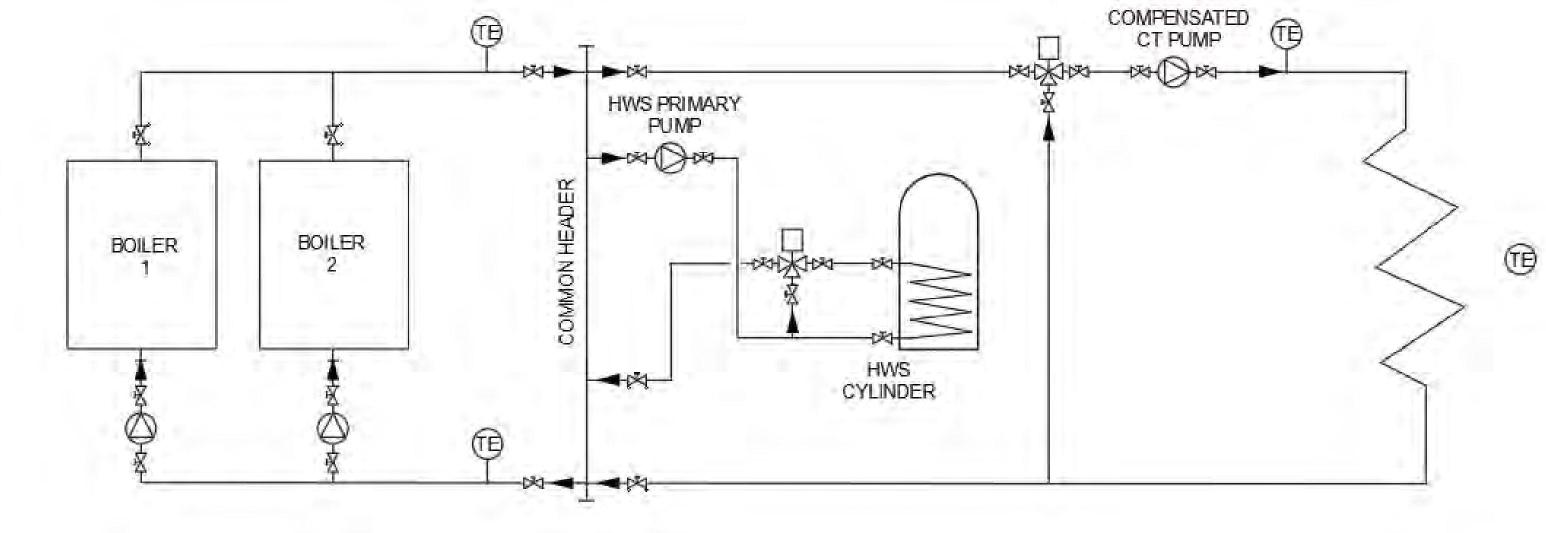
- Typically two boilers each 75% of load
- One boiler only required 90-95% of year
- Primary flow exceeds secondary flow from common header – causing primary recirculation - higher return temperature prevents condensing operation
- Low summer HWS loads - boiler stop/start reduces efficiency of operation further
- Do not use boiler cycling controllers – interlock operation with HWS demand and compensated valve operation
- Measures spent on high Δt heat networks are often wasted due to oversized boilers

Common Boiler Primary Pump



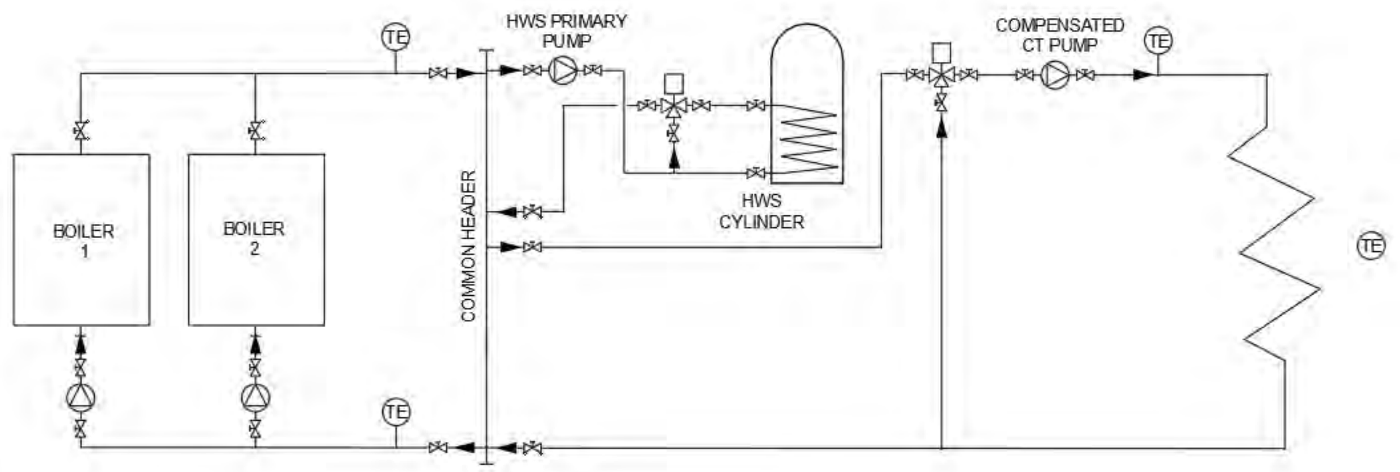
- Primary flow exceeds secondary flow from common header most of the time – causing primary recirculation - higher return temperature prevents condensing operation
- Flow temperature diluted through off line boiler
- Previously recommended for ease of control from return temperature – temperature differential proportional to load

New Boilers Retrofit Old Systems



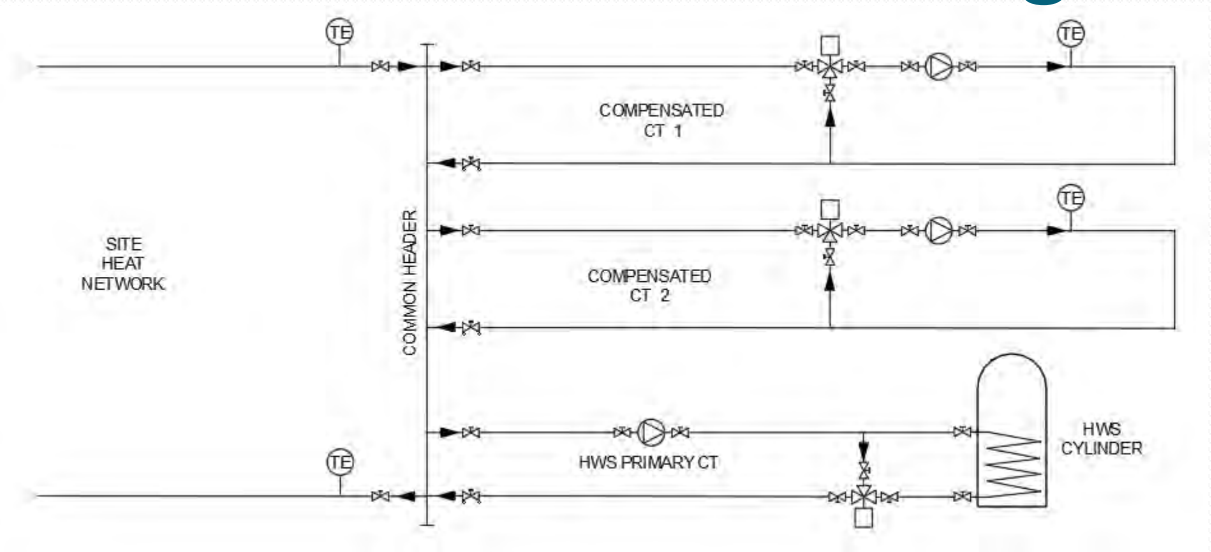
- Modern Boilers typical Δt 20K
- Old system typical Δt 11K
- Secondary flow exceeds primary flow at full load
- Maximum heat output compromised by dilution of secondary flow temperature

New Boilers Retrofit – Potential Solution



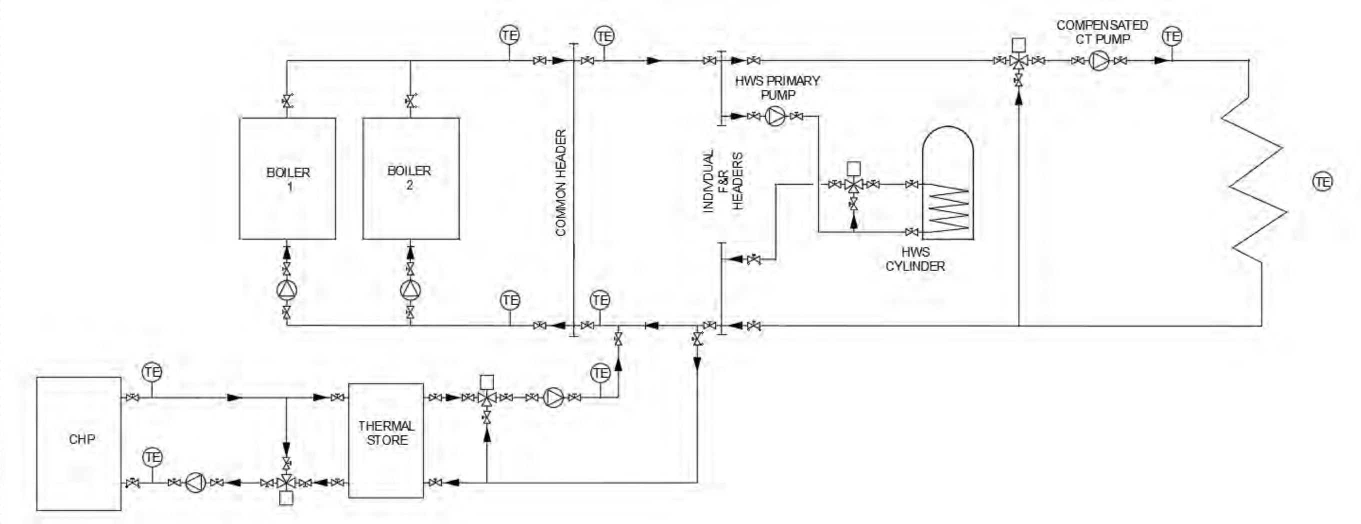
- Modern Boilers typical Δt 20K
- Old system typical Δt 11K
- Heating potentially lower temperature at high loads with HWS operation, but HWS less likely to be compromised
- Flows in many old radiator circuits can be reduced (oversized radiators)
- Only full draw from header when compensated valve fully open
- Direct compensation of condensing boilers when no HWS – improves condensing operation

Common Header – Poor Design



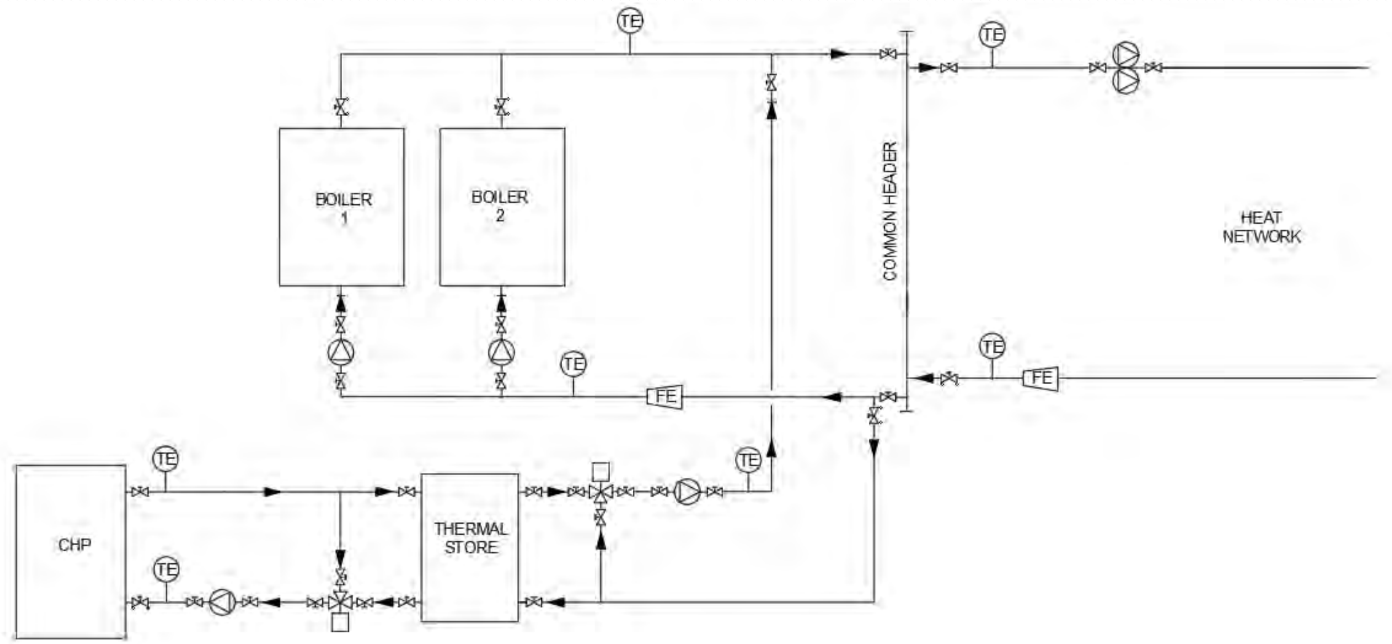
- BMS Inspection £240M Hospital Extension – Design Team, Contractor Team plus Review/Verification Team
- Me - Looking at schematic – Heating will compromise HWS primary temperature
- Contractor – Its only a schematic, we wouldn't have possibly built it that way
- Me – Lets Check – Guess What!
- One of several items that would have cost zero to get right during design

CHP – Return Injection Circuit



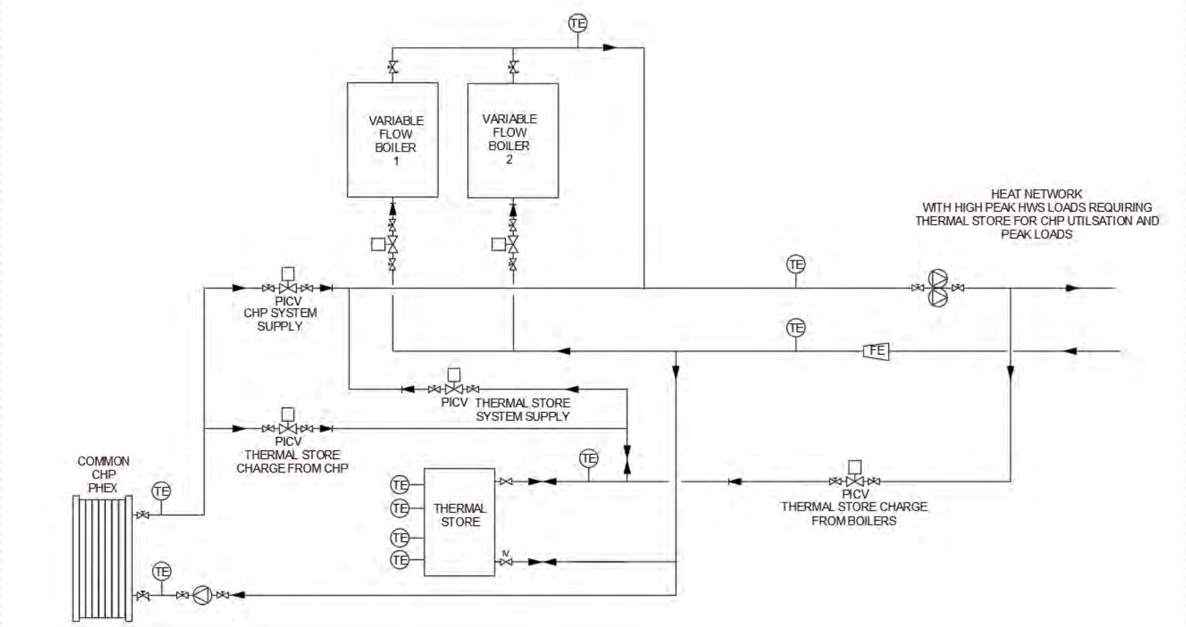
- Can provide effective CHP operation
- Boiler operation in condensing mode reduced
- Some packaged CHP/Thermal Store control good
- Other packaged CHP controls questionable

CHP – Parallel Connection with Boilers



- Does not compromise Boiler condensing operation
- Control more complex – thermal store pump variable flow – maximum dependent on thermal store charge

Thermal Store Peak Load & CHP Utilisation



- Variable Flow Boilers
- Controlled interaction CHP and System Pumps
- PICVs to control flows for each mode of operation
- Complex control

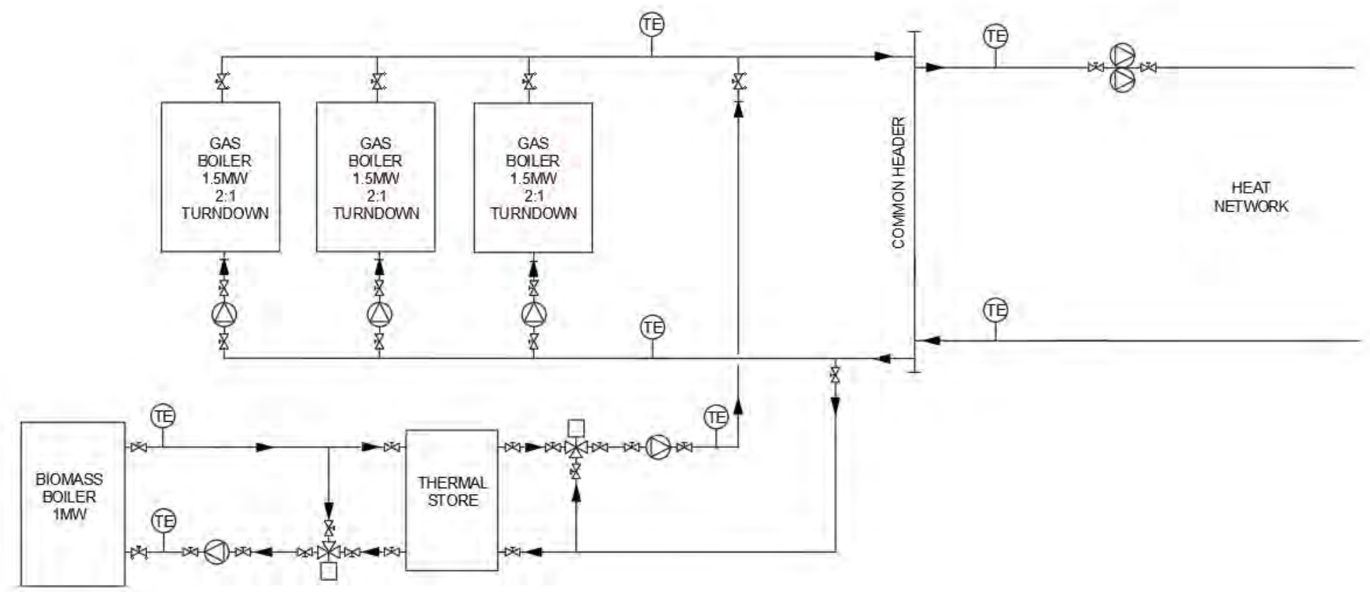
Controllability – Biomass Boilers

- Biomass boilers cannot just be added in the same way as a fossil fuel boiler
- Complete system must be considered
- Key factors:
  - Biomass Boiler Sizing
  - Biomass Boiler Response
  - Flow and return temperatures
  - Flow variation – variable flow loads essential for some schemes to work

Heat Load Control

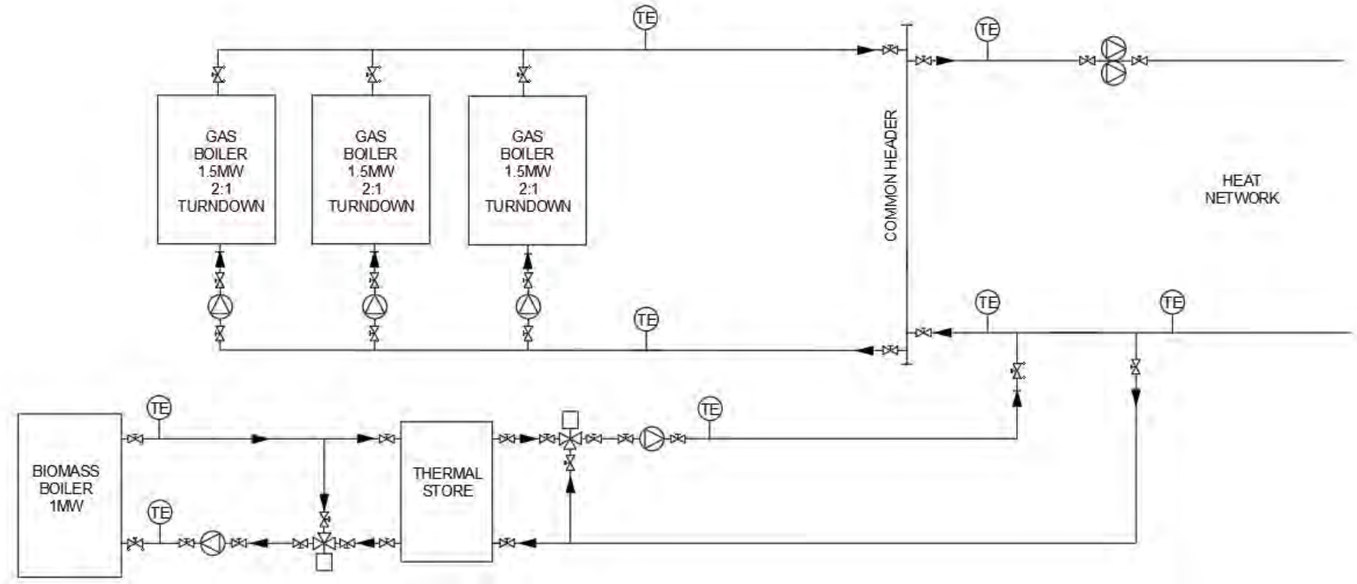
- Heat Load Control for optimum Biomass Boiler utilisation
- Heat Load Control stable and repeatable
- Now relatively low cost
- Heat Load Control can enable auxiliary boilers to supplement Biomass Boilers at different loads
  - When thermal store still has heat available
  - When thermal store discharged but Biomass Boiler heat still available
- Flow/Heat Meters must be correctly installed – 10D/5D straight pipe

Instable Biomass Boiler



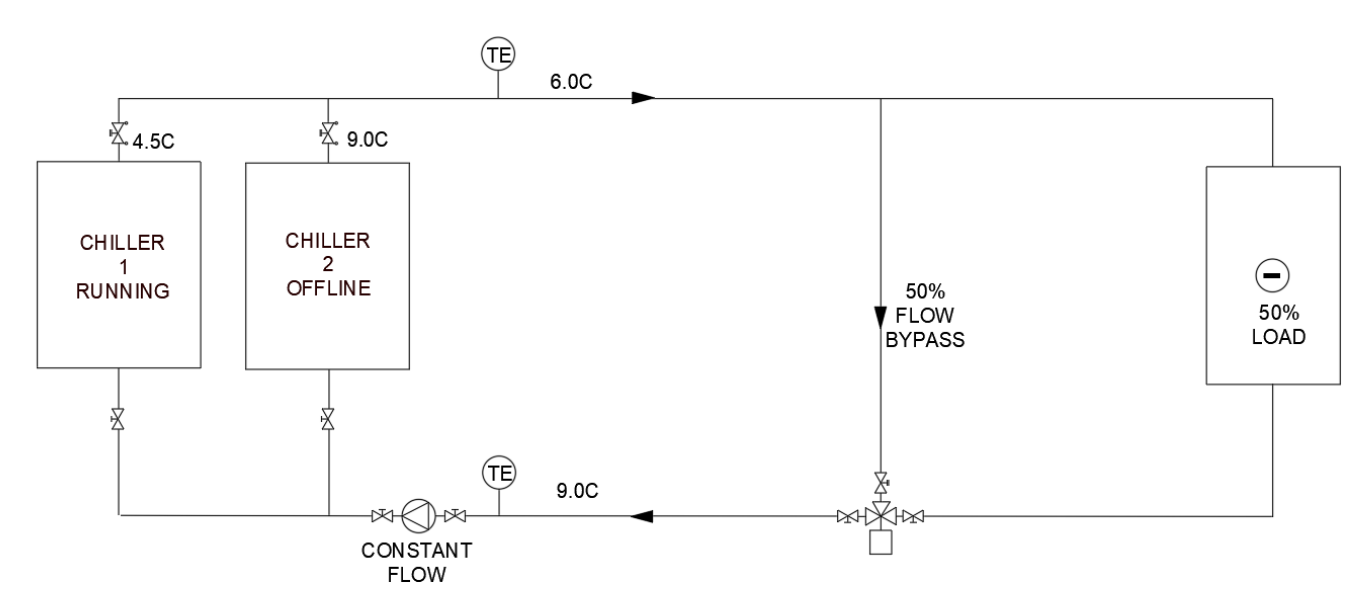
- Handover of £25M project delayed due to instable biomass boiler operation
- Biomass boiler and controls blamed
- Gas boilers initiated as soon as mixing valve fully opened
- Up to 750kW heating thermal store from lead gas boiler

Instable Biomass Boiler - Solution



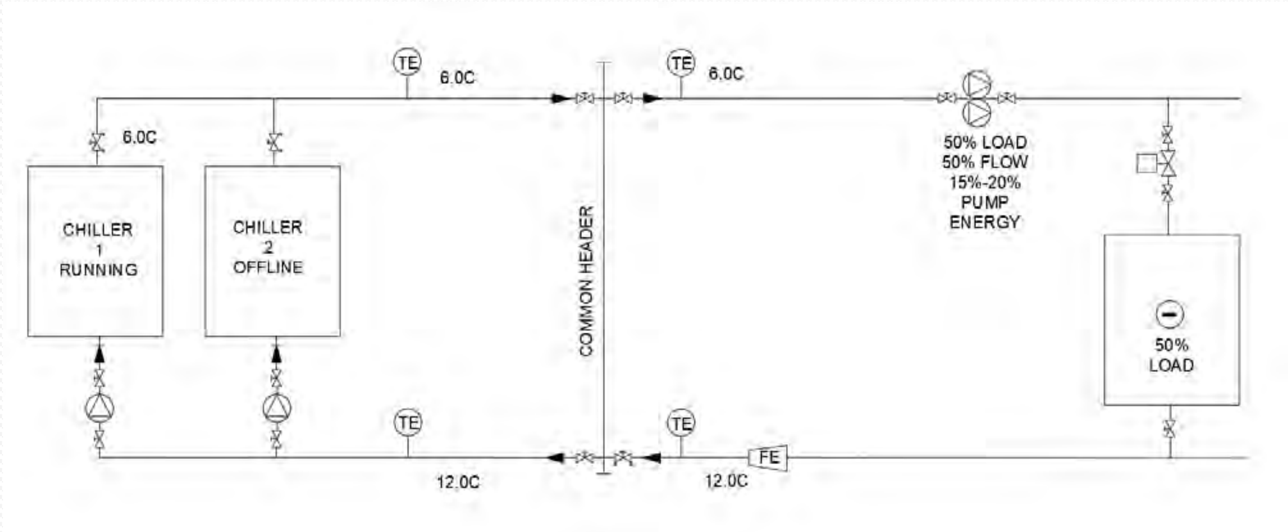
- Biomass heat injected into system return
- Gas boiler turndown improved
- Minimal interaction from gas boiler operation with 2km of heat network
- A number of control modifications suggested, but primarily a controllability issue

Common Chiller Design



- Lead Chiller must have a leaving temperature of 4.5C to achieve 6C at mixed point with only one chiller running
- Lead Chiller is operating less economically and nearer low limit temperature
- Common arrangement from some major chiller manufacturers
- If Lead Chiller at 6C then mixed flow temperature higher, can be problematic for dehumidification
- Sequence control from flow temperature unstable and/or both chillers run together limits turndown

Good Chiller Design



- Chillers packaged individual control 6C evaporator leaving temperature
- Individual chiller flows maintained by chiller primary pumps
- Secondary circuit variable flow – care needed in design to avoid parasitic losses
- Heat load based control of number of chillers on line can optimise energy performance by running more chillers at reduced output – but go to one chiller when load very low to provide turndown in capacity and stability of operation
- Reduced energy consumption pumps and chillers
- Improved stability of operation and reliability

Conclusions

- Many systems have poor controllability
- Controllability can often be improved for zero, or minimal, cost
- Ensure systems are controllable, or consequences can be significant
- Little guidance currently available
- Training/Specialist assistance available
- Lobby CIBSE and/or BSRIA to get guidance written and published

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