Energy efficient district heating in practice – the importance of achieving low return temperatures.

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The paper quantifies the benefits of low return temperature to reduce both the capital and operating cost of district heating (DH) schemes. The key benefits are reduction in network heat losses, smaller pipe sizing and improved boiler and CHP efficiency. The paper uses energy centre and HIU data from a number of operating DH schemes in London that serve newly built flats. The data presented includes flow duration curves that indicate the long duration of periods with very low load and return temperature data that shows the impact of incomplete commissioning. The paper discusses how designs can be improved to lower the DH return temperature at all operating conditions. The issues considered include, impact of over estimating peak load, impact of additional heat exchangers in system, pump selection and control, HIU and secondary system selection.

Keywords: District heating, return temperatures, HIU, heat losses.

Introduction
This paper focuses on district heating (DH) installations in new build high density residential developments, typically developed in response to the planning requirements for DH in London. Commonly these are variable volume, fixed flow temperature schemes based around gas engine CHP with an indirect HIU (Heating or Hydraulic Interface Unit) with instantaneous DHW heating in each flat.

This paper focuses solely on the benefits from reducing the return temperature, there also can be benefits in reducing the flow temperature, which is the thrust of the ‘4th Generation DH’ concept as described in ‘Towards 4th Generation District Heating’ (Dalla Rosa A, 2014).

Main content

Heat delivered by a district heating scheme is

\[ Q = m \times dT \times 4.2 \]

With \( Q \) = heat supply capacity (kW)

\( m \) = mass flow rate (kg/s)

\( dT \) = the difference in temperature between the district heating flow and return temperatures.

\( 4.2 \) = Specific heat capacity of water in kJ/kg C

The heat delivered is a function of the flow rate and the amount of cooling of that flow. The operating flow temperatures are usually below 90°C. The return temperatures are a function of the plant that uses the heat and the number of bypasses on the DH network. This paper explores why maximising the cooling (increasing the \( dT \)) of the DH flow which then reduces the flow rates is the key to cost effective DH. This is why minimising the DH return temperature is a common focus in countries where DH is more established.
The benefits of achieving low return temperature:
- Low return temperatures = larger $dT$ = lower flow rates (for same kW delivered) = small pumps and pipes
- Smaller pumps = lower capital costs and lower power consumption
- Smaller pipes = smaller surface area so lower heat loss
- Lower return temperature = cooler return pipe = lower heat losses
- Lower heat losses = less heat input into DH network and reduced unwanted heat gains in buildings
- Lower return temperatures = potentially improved boiler efficiency and extra CHP heat recovery
- Larger $dT$ = more thermal storage per unit volume of thermal store = smaller thermal store for same heat storage capacity

This paper will explore the above statements, which are set out at this point to explain the paper's focus on reducing DH return temperatures.

Factors determining DH network return temperatures
The DH return temperature is determined by individual return temperatures from five process:

1. DHW generation
2. Space heating system
3. By-passes on DH network
4. DHW / space heating plant operation when no load
5. Heat exchangers on the DH network e.g. at building entry

Domestic hot water generation
The production of DHW can be either using a cylinder or directly on demand in a heat exchanger. Instantaneous heat exchangers in HIUs have a number of benefits: unlimited DHW supply, small size, mains pressure DHW and DHW heat exchangers that can generate very low DH return temperatures. Figure 1 shows the performance of a well-designed HIU where the DH return temperature is consistently below 20°C for a range of DHW flow rates. The low volume in the DHW heat exchanger means the Legionella risk is viewed as being low and 55°C is a commonly accepted UK DHW supply temperature (Woods P., 2015).

Cylinders have a number of disadvantages such as: needing to be heated to 60°C to ensure no risk of Legionella, up to 2 kWh/day standing heat losses (Charlick, 2013 Page 35) and the return temperature from the coil in the cylinder is often higher than 60°C to achieve 60°C throughout the cylinder. CIBSE AM12 recommends: ‘Storage calorifiers should be avoided as the return temperature will be higher than the storage temperatures except at cold start-up’ (Woods P., Combined heat and power for buildings AM12:2014 Page 19 section 5.4.1, 2013). Göteborg Energi the DH supplier in Sweden’s second city Gothenburg state that in their view DHW demands in all building types can be delivered with heat exchangers rather than calorifiers. (Arvsell, 2016)
Space heating systems can be designed to achieve low return temperatures. The radiators can be oversized to allow lower average temperature operation and hence lower return temperatures. Then the radiators need to be correctly commissioned such that the flow rates through the radiator are low enough for the design dT to be achieved in practice. A reliable and quick way to ensure correct flow rates and balancing are to use ‘pre-settable’ valves for either the TRV or the lock shield valve. These can be set to allow a certain flow rate for each radiator, with the manufacture supplying a table from which the correct setting can be calculated.

How a radiator is connected up has an impact on the heat output. A radiator sized for 90/70°C operation lowered to half its output would operate at 70/52°C if connected BOE.
(bottom opposite end) or 70/45°C if connected TBOE (flow into top of radiator and return out of the bottom of the opposite end) (Ward, 1991, p. 92) so it is worth considering the location of the radiator connection points to keep radiator sizes and costs down. Some radiator design are configured internally to achieve the benefits of TBOE but with BOE connection. Clearly achieving lower return temperatures requires significant over sizing, but radiator sizes are all smaller now due to improved building thermal insulation. The current UK guidance eg CIBSE Heat Networks Code of Practice (Woods P., 2015) suggests that space heating circuits should be designed to achieve 40°C return temperatures. Other heating systems such as fan coils and air handling units can similarly have their heat exchanger area increase to lower the return temperatures.

**HIU performance in practice**

![Graph showing HIU performance](image)

**Figure 2** Example of poor HIU and setup. One year of data for over 100 flats.

Figure 2 shows one year of 15 minute data from the heat meter in each HIU of a development of approximately 100 flats. (Guru Systems Ltd, 2015). Note the large flow rates at zero dT and the relatively limited flows at 50°C dT. The 50°C dT flows are DHW generation but the bulk of the return flow is at 10°C dT or less, and if you volume weight the return temperature – the high flows at zero dT mean the dT at the energy centre is virtually zero.
Figure 3 Example of better HIU and setup, one year of data approx. 30 flats

Figure 3 shows a different site with better HIU and set up, the flow rates are all lower and the average dT around 30°C. The difference in performance between these two sites is due to both poorer HIU design and poorer commissioning for the site shown in Figure 2. The performance of the site in Figure 3 could have been improved with better commissioning.

**HIU standby flow and bypasses to maintain DH temperature.**

Most HIUs will act to maintain the warmth in the DH network potentially making such concerns and installation of thermostatically controlled bypasses unnecessary. The keep warm temperature the HIU maintains is balance between higher temperatures potentially giving more rapid DHW delivery and lower temperatures which reduce the DH return temperatures and the standing heat losses on the DH network. It is important to fully understand the standby operation of the HIUs – there are a range of ways that different HIU designs maintain temperatures at standby. HIU's don't necessarily need a keep warm function, if the DH local to the HIU is kept warm instead thought the use of a thermostatically controlled bypass at the end of the DH pipe run that serves a number of HIUs, or a single HIU with a keep warm function could be installed at the end of the pipe run. The system does not need to be maintained at the full DH flow temperature. The DH will only cool at low loads and so if there is a load during this period that load will see the full system dP and hence the HIU can potentially draw more than the design peak flow and so give sufficient output at lower DH flow temperatures. For space heating lower DH temperatures will still deliver a heat output for the short period it takes for the DH to get up to temperature.
<table>
<thead>
<tr>
<th></th>
<th>Heat demand (kWh /yr)</th>
<th>Flow temperature (°C)</th>
<th>Return temperature (°C)</th>
<th>DH volume to deliver this load (m³/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual heat demand</td>
<td>3000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space heat</td>
<td>1800</td>
<td>80</td>
<td>50</td>
<td>51</td>
</tr>
<tr>
<td>DHW</td>
<td>900</td>
<td>80</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>keep warm flow @5 litre/hour</td>
<td>300</td>
<td>55</td>
<td>45</td>
<td>52</td>
</tr>
</tbody>
</table>

Table 1 Estimate of annual DH volumes for the different HIU demands

Table 1 is a simplification of what the DH flow supplies over the year. 3000kWh is a typical annual billed heat consumption for a new build London flat, which breaks down into flows to meet space heating and DHW demands (Burzynski R, 2011). The keep warm return temperatures and flow rates are drawn from the lower flow rates in Figure 5. During the standby periods all the HIU at this site act to keep the DHW heat exchanger near the 50°C DHW set point as shown in by the return temperatures in Figure 5. The table demonstrates that the standby flow is a significant element of the overall system demands and return temperature.

**Other Bypasses on DH networks**

Bypasses may be installed on DH networks, to maintain minimum pump flows, system temperature and water treatment. Bypasses installed for flushing sometimes don’t get closed once flushing is completed.

![Figure 4](image.png)

**Figure 4** DH flowrates and return temperatures after connection of new building with open bypasses (SSE, BMS data Royal Arsenal Riveside Woolwich, Feb - April 2011)

Figure 4 shows the connection of a new building to an existing operating DH network serving 460 flats. The new building of over 200 flats has flushing bypasses left open and the flow
rate jumps from 10-20 m³/hour to 60 m³/hr and the DH dT reduces from 25-30°C to less than 5°C. Between time periods 2000 and 2500 the new building is periodically isolated and at these times the flow rate drops to below 10 m³/hr (lower than before as April has lower space heating demands and as a small bypass at the new building connection has also been closed). Now (later than the period in the graph) that all bypasses are closed the DH return temperature is consistently below 50°C. It’s common to install flushing bypasses above each HIU. These can be designed out by flushing before the HIU is installed.

Figure 5 Flow duration curve Impacts of bypass flow on return temperature (SSE, April 2013 - 2014)

Often bypasses are put in at the tops of risers to maintain minimum pump flows. Figure 5 attempts to demonstrate the impact of these ‘small’ minimum flows, they may be small at peak loads but a very significant at low DH loads.

Figure 5 shows measured flow and return temperature data at 15 minute intervals for a 5 month period August to end of December. The x axis has the highest flow rates on the left hand side of graph and the lowest on the right hand side. The return temperature plot is the temperature for the flow rate at that point on the flow duration curve. 10% of design peak flow has been added to the measured flow data. The peak flow used is the measured peak during the preceding 2 years. The combined temperature of the 10% fixed flow at 85°C added to the measured flow rate and temperature is calculated. The graph clearly shows the very significant impact such flows have on the annual average return temperatures.

The measured peak flow averaged 2.5 kW per flat. So this graph alternatively represents a 5% bypass flow on a system designed to deliver 5 kW peak to each flat or 3% bypass for system based on 8 kW peak per flat. In the authors experience most systems are designed on a significantly higher peak than 5 kW per new build flat.

To prevent the increase in return temperature as shown in Figure 5 there needs to be no bypasses installed between DH flow and return to maintain minimum pump flows. The pump set installed needs to have sufficiently large turndown to operate at the minimum system.
flows. The minimum flow are dictated by the standby flows of the installed HIUs. For example 3 pumps each at 50% of peak load would be better than 2 pumps both sized for 100% of peak load, or smaller jockey pumps could be installed. Operational experience indicates that pumps do reliably operate below their design minimum flow in many instances without issue, the scheme a presented in Figure 4 operates with no bypasses on system except the HIU standby flows which can be as low as 2 m³/hr, the pump has, an oversized, peak flow of more than 110m³/hr at the operating dP. Pump manufactures can supply information on the absolute minimum flow rate that must be maintained

*Block heat exchangers substations*

Heat exchangers are commonly used to provide separation between circuits. Separation can be required to contain the static pressure arising from tall buildings and at ownership boundaries to limit the impacts of the operation and maintenance of parts of the heat network with different ownership. From a performance and efficiency perspective heat exchanger substations are detrimental, as they act to reduce the DH flow temperature on the secondary system and will raise the return temperature on the primary and hence all the pipework operates at smaller dT. There are other disadvantages too; a heat exchanger requires distributions pumps, pressurisation and expansion systems, water treatment and controls/alarms. All this plant needs full redundancy. So there is more complexity in the system controls and operation, there is more to commission, more to maintain and more to go wrong. In the author's experience substations and are commonly oversized leading to problems at low load. In addition to the pump minimum flow issues commented on earlier there are potential issues of the substation's control valve working effectively at the very low loads required. In the author's opinion building substations should be avoided whenever possible, for example in blocks where there are indirect HIUs, as they add considerable capital and lifecycle costs to the DH operation. Operation of the system at higher pressures should be considered to allow removal of block substations. The increase in maximum system pressure can be small – as this is dictated by the height of the highest building irrespective of if this building has a heat exchanger or not. The increase in pressure seen at the base of a tall block by excluding a block heat exchanger is that of the DH pumps dP and this could be controlled through the use of differential pressure control valves across the block. Most steel underground DH pipe is rated to 25bar – so the element that sees the pressure increase is more than capable of handling it. Boilers, CHP, thermal stores and pump call all be designed for higher pressures. It is often suggested that substations ease the commissioning of the systems within the block, but should simplification of commissioning be a valid reason to increase DH operating costs for the 50+year life of the building?

In the UK individual HIUs per flat / house seem the accepted norm for new DH build, but HIUs too have similar drawbacks as block substations and in some countries it is common for their just to be a substation for the block and no further hydraulic separation within the building, to quote Frederiksen and Werner 'It (apartment substations) is a rather expensive solution that has not gained general acceptance in Scandinavia' (Werner, 2013, p. 323). The typical Scandinavian configuration for a block of flats is a basement substation and then a circulating DHW supply and a space heating circuit that serves radiators in all flats. The drawbacks of this approach are two pair of hot pipes to each flat, space heating is much more communally controlled – e.g. when is it on and off and the temperature of the radiators and the need metering on both the space heating and the DHW.

In Denmark most individual house connections are direct - i.e. there is no heat exchanger between DH and dwelling heating systems. A number of town schemes moved to require
indirect connection but then changed back to just requiring direct connection, (Landstrom, 2015) which is simpler cheaper and more efficient.

**Benefits of achieving low return temperatures – pipework**

**Pipe sizing**

If the whole system design ensures large temperature differences at the design peak load then the pipework can be sized accordingly.

The heat transfer capacity of pipe is dependent upon the; cross sectional area, the fluid velocity, the specific heat of the fluid and the temperature difference between the flow and return as follows:

\[ Q = \pi r^2 v \Delta T C_p \text{[kW]} \]

Where \( r \) = pipe internal radius

\( v \) = fluid velocity

\( \Delta T \) = temperature difference

\( C_p \) = specific heat of fluid = 4.2 for water.

This is tabulated in Table 2 below for pipe sizes 16-150mm diameter and 10-60°C temperature difference.

<table>
<thead>
<tr>
<th>Pipe size (mm)</th>
<th>16</th>
<th>20</th>
<th>25</th>
<th>32</th>
<th>40</th>
<th>50</th>
<th>65</th>
<th>80</th>
<th>100</th>
<th>125</th>
<th>150</th>
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<tbody>
<tr>
<td>kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10</td>
<td>15</td>
<td>24</td>
<td>37</td>
<td>61</td>
<td>95</td>
<td>148</td>
<td>251</td>
<td>380</td>
<td>594</td>
<td>928</td>
<td>1336</td>
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<tr>
<td>20</td>
<td>30</td>
<td>48</td>
<td>74</td>
<td>122</td>
<td>190</td>
<td>297</td>
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<td>1856</td>
<td>2672</td>
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<tr>
<td>30</td>
<td>46</td>
<td>71</td>
<td>111</td>
<td>182</td>
<td>285</td>
<td>445</td>
<td>753</td>
<td>1140</td>
<td>1782</td>
<td>2784</td>
<td>4008</td>
</tr>
<tr>
<td>40</td>
<td>61</td>
<td>95</td>
<td>148</td>
<td>243</td>
<td>380</td>
<td>594</td>
<td>1004</td>
<td>1520</td>
<td>2375</td>
<td>3711</td>
<td>5345</td>
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<tr>
<td>50</td>
<td>76</td>
<td>119</td>
<td>186</td>
<td>304</td>
<td>475</td>
<td>742</td>
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<td>6681</td>
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<tr>
<td>60</td>
<td>91</td>
<td>143</td>
<td>223</td>
<td>365</td>
<td>570</td>
<td>891</td>
<td>1505</td>
<td>2280</td>
<td>3563</td>
<td>5567</td>
<td>8017</td>
</tr>
</tbody>
</table>

Table 2 Pipe kW capacities at different dT based on flow of 1.8m/s

Moving down one pipe size reduces capacity by 36% and reducing by two pipe sizes reduces the capacity by 62%. So moving from a 20°C dT e.g. 80/60°C basis for sizing pipes to an 85/40°C basis for space heat (56% reduction in flowrate) and 85/25°C (67% reduction in flowrate) for DHW could potentially allow a reduction in 2 pipe sizes. The design margin could be a specification that allows operation at 90°C flow temperature.

**Reductions in heat loss**

Smaller pipe have reduced surface area and so the heat losses are reduced as per Table 3.
Pipe OD (mm) & Max heat loss at 75°C BS5422:2009 (W/m) & Reduction in heat loss with pipe one sizes smaller & Reduction in heat loss with pipe two sizes smaller \\ 17.2 & 8.9 & 5.1% & 11.5% \\ 21.3 & 9.38 & 6.8% & 15.3% \\ 26.9 & 10.06 & 9.1% & 18.2% \\ 33.7 & 11.07 & 10.0% & 14.5% \\ 42.4 & 12.3 & 4.9% & 14.9% \\ 48.3 & 12.94 & 10.4% & 20.9% \\ 60.3 & 14.45 & 11.6% & 19.3% \\ 76.1 & 16.35 & 8.7% & 21.3% \\ 88.9 & 17.91 & 13.8% & 24.5% \\ 114.3 & 20.77 & 12.4% & 22.8% \\ 139.7 & 23.71 & 11.8% & 27.1% \\ 168.3 & 26.89 & 17.4% & \ \\ 219.1 & 32.54 & & \\ \\ Average reduction & 10.2% & 19.1% \\ 

Table 3  Heat loss reductions at smaller pipe sizes

Summarising Table 3:

Reduce pipes by one sizes = average heat loss reduces by 10% (at original temperatures)
Reduce pipes by two sizes = average heat loss reduces by 19% (at original temperatures)

There are also heat loss reductions from reducing the return temperature from 75°C to 45°C which gives a 29% reduction in heat loss (pipe size unchanged)

A typical UK DH system may be designed on a 20°C dT basis – 80°C/60°C flow/return temperature and in the author’s experience would typically operate at 80/75°C due to poor commissioning. Reducing the pipe by 2 sizes and dropping the return temperature from 75°C to 45°C reduces the heat losses by 43%.

If this pipe size reduction proves to be too ambitious a 12% increase in network capacity can be achieved by lifting the DH flow temperature from 80 to 85°C. These heat losses have been calculated in 3E Plus v4.1 (Association, 2014) with the BS5422:2009 recommended thicknesses of mineral wool. Calculations undertaken for all pipe sizes between 15 and 200mm all with same insulation thickness for all temperatures. All percentages refer to the reduction in the total heat loss (the heat loss in both the flow and return pipes).

**Benefits of achieving low return temperatures – Energy centre.**

Lower return temperature have a number of benefits within the energy centre. These include:

- Potential for higher efficiency operation of condensing boilers
- Scope for increased heat recovery from CHP plant
- Higher COPs from heat pumps, and increased efficiency of solar thermal collectors

And increased dT also has the following benefits:
Lower flowrates reduces pump sizes.
Increased heat storage in thermal store of the same volume.

**Boiler efficiency**

Providing the boiler is installed in a configuration that ensures the flow to the boiler is at the DH return temperature, then lowering this temperature increases the boiler efficiency. It is very common that condensing boilers are installed with headers that lift the return temperature to the boiler. Some boiler designs have no minimum flow rates and this allow the header to be removed and hence the boiler return to always be at the lowest possible temperature.

**Condensing boiler efficiency characteristics**

![Image showing condensing boiler efficiency curves](image)

Figure 6 Typical condensing boiler gross efficiency curves for range of return temperatures and outputs *(J Cockroft, 2007).*

Figure 6 shows that there is an approximate 5% efficiency improvement by lowering the return temperature from 70°C to 45°C, at part boiler load. The efficiency benefits from lower return temperatures at temperatures below 55°C as at this point condensation of the water vapour in flues gases starts and recovers the latent heat of vaporisation.

**Additional heat recovery from gas CHP**

With lower return temperature to CHP extra heat can be recovered from condensing the exhaust gases and though increased heat recovery from the engine intercooler. Figure 7 details the potential extra heat that can be recovered from engines up to 4.4MWe for the same gas input and electrical output.
Pumping electricity

There are significant reductions in pumping energy with increased dT. The power consumption for the pumps at the SSE scheme as per Figure 4 and Figure 5 has been calculated for a range of average flow rates at the operating differential pressure of 0.9 bar (Grundfoss, 2014).

The 10m³/hr 35°C dT is the current long term operating condition, the 55m³/hr flow represents the open bypasses situation as in Figure 4.

<table>
<thead>
<tr>
<th>System operating dT (°C)</th>
<th>Average flow (m³/hr)</th>
<th>Pump power (kW)</th>
<th>Annual energy use (MWh/yr)</th>
<th>Pump energy cost (£/yr)</th>
<th>Annual cost per flat (£/yr)</th>
<th>CO2 from pump electricity (tonnes/yr)</th>
<th>CO2 per flat (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>10</td>
<td>1</td>
<td>9</td>
<td>876</td>
<td>1.2</td>
<td>5</td>
<td>6</td>
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<tr>
<td>5</td>
<td>55</td>
<td>7.6</td>
<td>67</td>
<td>6658</td>
<td>8.9</td>
<td>35</td>
<td>46</td>
</tr>
</tbody>
</table>

Figure 8 Electricity consumption of pumps for 5 and 35°C dT at same dP

The electricity costs are based on electricity costing 10p/kWh and the CO₂ emissions based on an emission factor of 0.522kgCO₂/kWh. The table shows leaving the bypasses open can increase pump electricity by more than a factor of seven. Larger saving could be possible as dP could be lowered for lower flowrates (Parsloe, 2006), but the controls at this site don’t allow this.

Clearly this is a very limited analysis of just one scheme with one set of pumps. The pumps are two pumps (duty/standby) each capable of a peak flow of 90m³/hr at the maximum head of over 2 bar. Under well commissioned operating conditions the peak flow is less that 40m³/hr and the system has always operated at a dP of 0.9bar at the pumps.
System oversizing

Over estimating of peak heat loads leads to larger plant and larger pipe sizing, both of which are detrimental to capital and operating costs as discussed earlier.

For DH schemes a common requirement is for 50-60kW of DHW for a 1 or 2 bedroom flat. Figure 2 and Figure 3 show the peak HIU loads for 2 DH networks and there is little demand over 35kW despite the DH and HIUs being designed to deliver over 50kW of DHW per HIU. More than 50% of all gas heated homes in the UK have combi boiler (DCLG, 2012) which are commonly between 30-35kW output. Why do DH customers need 50% more DHW than the millions of UK homes with combi boilers? These new build flats will have most probably have flow restrictors on many of the taps which makes the flow rates potentially lower than in the combi boiler houses. The HIU connection standard for the Arhus (Denmark’s second largest city where 95% of heat demand is supplied by DH (State of Green, 2015)) is for the HIU to deliver 32.5kW DHW (AffaldVarme Aarhus, Jan 2014).

Space heating demands are similarly over estimated. The 750 flat scheme as in Figure 4 and Figure 5, had a peak load of 1.8MW at the energy centre when it was minus 2°C outside. This peak occurred at 7 am on a weekday morning so covers space heating start up and morning DHW use and yet equates to a demand of approximately 2.5kW per flat.

Cost and CO2 savings

<table>
<thead>
<tr>
<th>Operating temperature</th>
<th>80/75°C</th>
<th>80/45°C</th>
<th>gas combi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boilers efficiency</td>
<td>87%</td>
<td>93%</td>
<td>0.8</td>
</tr>
<tr>
<td>Boiler heat cost</td>
<td>£/MWh</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>CHP *</td>
<td>£/MWh</td>
<td>32</td>
<td>26</td>
</tr>
<tr>
<td>DH losses per flat</td>
<td>kWh/yr</td>
<td>1800</td>
<td>774</td>
</tr>
<tr>
<td>DH losses</td>
<td>%</td>
<td>38%</td>
<td>21%</td>
</tr>
<tr>
<td>Total heat required</td>
<td>MWh/yr</td>
<td>3600</td>
<td>2831</td>
</tr>
<tr>
<td>Proportion of heat from CHP *</td>
<td></td>
<td>0.62</td>
<td>0.79</td>
</tr>
<tr>
<td>CHP heat</td>
<td>MWh/yr</td>
<td>2232</td>
<td>2236</td>
</tr>
<tr>
<td>Boiler heat</td>
<td>MWh/yr</td>
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<td>594</td>
</tr>
<tr>
<td>CHP heat cost</td>
<td>£/yr</td>
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<td>58138</td>
</tr>
<tr>
<td>Boiler heat cost</td>
<td>£/yr</td>
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<td>17896</td>
</tr>
<tr>
<td>Average cost of heat generated</td>
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<td>£/MWh</td>
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<tr>
<td>Average cost of heat sold</td>
<td></td>
<td>£/MWh</td>
<td>51</td>
</tr>
<tr>
<td>Cost of heat per customer</td>
<td></td>
<td>£/yr</td>
<td>154</td>
</tr>
<tr>
<td>CO2 from heat generation *</td>
<td></td>
<td>tonnes/yr</td>
<td>225</td>
</tr>
<tr>
<td>CO2 due to heat per customer</td>
<td></td>
<td>kg/yr</td>
<td>150</td>
</tr>
<tr>
<td>Pump electricity cost</td>
<td>£/flat /yr</td>
<td>9</td>
<td>4.6</td>
</tr>
<tr>
<td>Pump CO2</td>
<td>kg/yr</td>
<td>46</td>
<td>6.1</td>
</tr>
<tr>
<td>Total CO2 per flat</td>
<td>kg/yr</td>
<td>196</td>
<td>58</td>
</tr>
<tr>
<td>Total cost per flat</td>
<td>£/yr</td>
<td>163</td>
<td>106</td>
</tr>
<tr>
<td>CO2 saving</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost saving</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9 Summary of cost and CO2 savings for DH designed and operation at lower temperatures and comparison to gas boiler

Figure 9 summarises the overall benefits of achieving lower return temperatures. The comparison is between a system designed for 80/60°C operation which through poor
commissioning is only achieving 75°C return temperature. The heat losses are based on the actual losses for this 750 flat scheme which was sized for 80/60°C operation, but is now operating at 80/48°C, the loses have been factored up by 29% to account for the modelled operation at 80/75°C as calculated in E3Plus. The low return scenario then reduces these losses by 43% to model operation with a system using pipes all 2 sizes smaller and achieving a return temperature of 45°C. The table inputs marked with a * come from an energyPRO (EMD, 2014) CHP operating model for the site, which has the full site characterisation. To undertake this comparison the only variables that were changed in energyPRO were: boiler efficiency, CHP heat output, dT across the thermal store, and DH heat losses. The ‘CHP cost of heat’ is the annual average based on electricity export value (seasonal time of day tariff), CHP O+M costs, gas price and CHP efficiency. The marginal heat costs are lower from DH but this is not an analysis of the full cost of heating, from either and DH network or a combi boiler. Both of which have a range of fixed costs that also need to be accounted for e.g. billing, central plant and HIU maintenance and repair, gas and electricity standing charges.

The analysis shows there are considerable economic and CO₂ savings benefits from designing to achieve lower return temperatures. A comparison has been made against a gas combi boiler which shows the significant CO₂ savings of DH with CHP over gas boilers, the analysis is based on current emissions factors for gas and electricity. The combi boiler efficiency has been estimated from In-situ monitoring of condensing combi boilers report (GASTEC at CRE Ltd, 2009)

Capital cost savings
Reducing pipe size has significant reduction in cost of DH network cost. Based on an assessment using SPONS price guide reducing pipes by one size results in an 18% capital cost saving of steel riser and lateral pipe work and reducing pipe by two sizes results in 33% cost savings (SPONS, 2009).

According the CHP suppliers (Clarke Energy, 2014) the CHP will cost approximately 2-3% more for the version that recovers extra heat, which if the extra heat is valued at the cost of heat from boilers gives a pay back of around six months. The DH pumps will be smaller and therefore cheaper. A smaller thermal store could be used saving resulting in a cost and space saving. The radiators in the flats will be larger, and will need to be better controlled with flow limiting presettable TRV valves. Based on an analysis of radiator sizes and costs as in the Screwfix (Screwfix, 2016) catalogue 3kW of radiators sized for 50C dT will cost £149 and 3kW based on 30C dT would cost £177, and the presettable TRV which cost around an extra £10 per radiator. These additional cost are far smaller than the potential cost savings e.g. 18% cost reduction of the riser and lateral pipework – which in the author’s experience costs in the order of £1400 per flat. In summary this approach should reduce the capital cost or be cost neutral. Cost savings could also be achieved through improved confidence in designing for lower peak loads as this would reduce the sizes of all plant, and the space requirements.
Conclusions

There are clear financial and environmental benefits in reducing DH return temperatures and in not oversizing DH system.

In the author’s view:

- Many new UK DH schemes are designed for far higher peak loads than will ever occur
- Designers need to consider in much more detail how the system will operate at very low load
- Many DH designs are undertaken without consideration of the operating costs
- System designers need to understand how an HIU works and interacts with the DH network especially during the no load periods. Without this understanding it is hard to produce an efficient primary and secondary design and undertake effective commissioning
- Commissioning is universally poor - based on ESCO experience and working on other systems for DECC funded SBRI research. The common excuse is that a system cannot be expected to work at commissioning when there is no customer load. The author’s suggested response to this is ‘how much load is there at 3am on a summer morning on the fully built out DH system?’ – the answer is virtually zero load. So a correctly designed system should work efficiently at commissioning
- M+E designers are not given sufficient time post commissioning to understand and learn from their designs and hence the designs cannot improve
- Much of the industry has also misses the opportunity of learning from Scandinavia where there is vast experience of efficient and reliable DH
- There is large scope for more sophisticated improvements to DH design and operation, but in the author’s view we need to get the basics correct in the UK first.

Suggestions/solutions to address the issues raised:

- The CIBSE/ADE Heat Networks Code of Practice has been developed to address the issues highlighted in this paper (and many more) and will greatly help ensure the correct considerations are undertaken throughout the design, construction and operation of a DH scheme.
- To improve DH sizing more publically available data is required on peak heat loads,
- Clients need more knowledge of DH, need to understand the long term issues and be more demanding that the designers and contractors deliver DH which has lowest lifecycle cost. The Heat Networks Code of Practice will help here too.
- Heat meter data is a powerful, but commonly overlooked, tool for identification of system problems both during commissioning and in operation. Good tools to benefit from heat meter data are being developed through DECC’s SBRI research funding.
- The performance of an HIU during space heating, DHW generation and at standby is critical to overall system performance and many HIUs, in the author’s experience, return higher temperatures and volumes than the designer expects. The can be due to both HIU and secondary heating system design and commissioning. Detailed HIU performance data for five HIUs will be available in March 2016 when the DECC SBRI research work is published.
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