



Jones, Sean and Gillott, Mark C. and Boukhanouf, Rabah and Walker, Gavin S. and Tunzi, Michele and Tetlow, David and Rodrigues, Lucélia Taranto and Sumner, M. (2017) A system design for distributed energy generation in low temperature district heating (LTDH) networks. In: 16th International Conference on Sustainable Energy Technologies (SET2017), 17-20 July, 2017, Bologna, Italy.

**Access from the University of Nottingham repository:**

[http://eprints.nottingham.ac.uk/46466/1/SET2017%20Full%20manuscript%20-%20Jones\\_131\\_Update\\_v2.pdf](http://eprints.nottingham.ac.uk/46466/1/SET2017%20Full%20manuscript%20-%20Jones_131_Update_v2.pdf)

**Copyright and reuse:**

The Nottingham ePrints service makes this work by researchers of the University of Nottingham available open access under the following conditions.

This article is made available under the University of Nottingham End User licence and may be reused according to the conditions of the licence. For more details see: [http://eprints.nottingham.ac.uk/end\\_user\\_agreement.pdf](http://eprints.nottingham.ac.uk/end_user_agreement.pdf)

**A note on versions:**

The version presented here may differ from the published version or from the version of record. If you wish to cite this item you are advised to consult the publisher's version. Please see the repository url above for details on accessing the published version and note that access may require a subscription.

For more information, please contact [eprints@nottingham.ac.uk](mailto:eprints@nottingham.ac.uk)

---

# A system design for distributed energy generation in low-temperature district heating (LTDH) networks

---

Sean Rhys JONES<sup>1</sup>, Mark GILLOTT<sup>1</sup>, Rabah BOUKHANOUF<sup>1</sup>, Gavin WALKER<sup>2</sup>, Michele TUNZI<sup>3</sup>, David TETLOW<sup>1</sup>, Lucelia RODRIGUES<sup>1</sup>, Mark SUMNER<sup>4</sup>

<sup>1</sup> Department of Architecture and Built Environment, University Park, University of Nottingham, UK, sean.jones@nottingham.ac.uk

<sup>2</sup> Energy Technologies Building, Innovation Park, University of Nottingham, UK

<sup>3</sup> School of Civil and Building Engineering, Loughborough University, UK

<sup>4</sup> Department of Electrical and Electronic Engineering, University Park, University of Nottingham, UK

## Abstract

Project SCENIC (Smart Controlled Energy Networks Integrated in Communities) involves connecting properties at the University of Nottingham's Creative Energy Homes test site in a community scale, integrated heat and power network. Controls will be developed to allow for the most effective heat load allocation and power distribution scenarios. Furthermore, the system will develop the prosumer concept, where consumers are both buyers and sellers of energy in both heat and power systems.

This paper describes the initial phase of project SCENIC, achieving truly distributed generation within a heat network. The first of its kind, the system has a four pipe network configuration, consisting of a network flow loop to supply heat to homes, and a generation loop to collect energy from residential heating systems and supply it to a centralised thermal store.

To achieve the design, IES-VE steady state heat load and dynamic building modelling have been used. A pre-insulated Rehau Rauthermex piping diameter was sized using flow rate calculations. Pipe diameter is reduced in line with distance from the central pump and associated pressure losses. The diameter ranges from 40 to 25mm, with a heat loss as low as 7.0 W/m. In addition, flow rates will fluctuate below a maximum of 1.99 l/s.

Danfoss – 7 Series BS flatstations have been selected as the network-building heat interface units (HIU), to satisfy a calculated peak design heating loads of between 36.74 and 44.06 kW. Furthermore, to enable the prosumer concept and associated business models an adapted Danfoss Flatstations – 3 Series BS was selected to interface the distributed heat sources with the network.

This paper gives details of the novel system configuration and concept, energy flows, as well as calculation and modelling results for the heat network. A premise is given to maintaining low temperatures in the network to ensure system efficiency in line with the latest research thinking.

Keywords: Low-temperature district heating; smart heat networks; distributed generation; prosumer; community energy

## 1. INTRODUCTION

In the European Union, space heating (SH) and domestic hot water (DHW) account for 79% of energy use in households (192.4 Mtoe) (European Commission 2016). As around 84% of domestic heat is generated from fossil fuels, there is an urgent requirement to improve system efficiencies and support greater sustainable energy integration. Such improvements are necessary to align with the 2050 climate obligations for decarbonisation under the Kyoto Protocol (UN FCC 2014a) and more recently the UN-led Paris Agreement (UN FCC 2014b).

District heat network (DHN) research suggests that improving efficiencies and supporting sustainable energy technologies can be achieved through lowering building hot water supply and return temperatures (Lund, Werner et al. 2014) (Østergaard and Svendsen 2016) (Olsen, Lambertsen et al. 2008). Moreover, historically there has been a trend towards lower temperature heat medium within DHN (see *Table 1*), which has the following benefits:

- Improved heat load distribution as lower temperatures are more readily controlled
- Reduced distribution pipe heat losses of up to 75% when compared with high-temperature district heat networks (HTDH) (Dalla Rosa, Li et al. 2014, Yan, Lee et al. 2014). A lower temperature differential between heat medium and surrounding soil improves the heat transfer coefficient
- Utilisation of low-temperature heat such as heat pumps, solar thermal collectors, and waste heat
- Reduced system design margin. Building heat demand lies between 30-60°C. Therefore, supply from low-temperature district heating (LTDH) more closely matches demand (Wu, Wang et al. 2016), reducing the requirements of temperature-blending valves for DHW and enhanced building comfort levels for SH
- Reduced risk of scalding and high-pressure explosion
- Increased piping infrastructure lifetime due to reduced degradation from thermal stress on pipe

The aforementioned system benefits allow for increased energy efficiency, reduced greenhouse gas emissions, fuel and infrastructure cost reduction, resource optimisation, material utilisation, ease of control, increased system flexibility and improved user comfort levels.

*Table 1: Development of district heat networks over time*

Generation	Period	Heat carrier	Temperature (°C)
1 <sup>st</sup> Generation (1G)	Mid 1800s-1930s	Steam	>100
2 <sup>nd</sup> Generation (2G) ("High-temperature")	1930s-1970s	High temp. pressurised water	<100
3 <sup>rd</sup> Generations (3G) ("Medium-temperature")	1970s-2010s	High temp. pressurised water	80/40
4 <sup>th</sup> Generation (4G) ("Low-temperature")	2010s-present	Low-temperature water	50-55/25
5 <sup>th</sup> Generation (5G) ("Ultra low-temperature")	2015-present	Ultra-low temperature water	<49/<24

Currently, DHN are supplied predominantly by large-scale centralised fossil fuel heat stations. However, in future, a shift towards decentralised heat generation from low-temperature and sustainable heat sources should become a more feasible option. As a result, opportunities for prosumer participation, where homeowners can be both buyers and sellers of heat, will become more prevalent. For the prosumer concept to work, the discordance of low-temperature renewable energy supply and domestic demand must be balanced. One solution is thermal energy storage or a combination of thermal and battery storage in multi-vector energy systems (MES).

At the University of Nottingham's Creative Energy Homes test site, project SCENIC (Smart Energy Networks Integrated in Communities) is investigating how the enablement of renewable energy and the prosumer concept can be developed through the integration of community scale heat and power networks. The first phase of project SCENIC involved the design and installation of a heat network. The first of its kind in the world, SCENIC's heat network configuration has been designed and installed to facilitate a low-temperature heat medium, the uptake of sustainable energy generators, the integration of heat and power networks, smart controls, community level distributed generation, and prosumer participation. A concise site overview is presented in *Table 2*.

*Table 2 - Project overview*

Detail	
Occupants	Domestic 12; Office 35
Aim	To provide low-temperature heat and enable the prosumer concept
Heat source	Solar evacuated tube arrays, flat plate solar thermal arrays, solar PV arrays, biomass boiler, gas boilers
Adjoining buildings	7
Length of network	220 m

This paper presents the modelling, component sizing, system configuration, and proposed energy flows of this novel system.

## 2. BUILDING MODELLING

To enable the sizing of heat network components, steady state peak heat demand and annual heat consumption figures are required. Network pipe diameter, pump sizing, heat exchanger sizing, and hence the cost and capacity of the network can be projected based on the highest demand. Annual heat consumption figures are used for heating plant and buffer tank sizing, as well as defining the heat revenues of the system.

Options for modelling peak heat demand include those set out in *CIBSE TM54: Evaluating operational energy performance of buildings at the design stage* guidelines. However, in order to more accurately reflect the operation of the building in practice, IES-VE software was utilised in the modelling approach. IES-VE's advanced dynamic thermal simulation provides a higher level of heat demand modelling accuracy due to the added consideration of room occupancy, location and orientation, build material properties, energy system types and efficiencies, heat gains, and air flow (infiltration, mechanical and natural ventilation).

### 2.1. Peak heat loads

#### *Steady-state space heating (SH) load*

The steady state SH load represents a simplified IES-VE building model where certain assumptions remain constant. For example, the outdoor temperature value is assigned as -3.9 °C corresponding to the CIBSE guideline design winter temperature. Solar and casual heat gains are not considered so consequently the results are static (see *Table 3*).

*Table 3 - Steady-state heating load for each Creative Energy Home. IESVE model simulation data*

Building name	Instantaneous DHW heat load (kW)	Instantaneous DHW heat load (kW) x diversity factor (0.3)	Steady-state SH load (kW)	Total design peak heat load (kW)
David Wilson House	34.89	10.467	9.17	19.64
Mark Group House	34.89	10.467	8.22	18.69
EON House	34.89	10.467	6.94	17.41
BASF House	34.89	10.467	4.12	14.59
Tarmac House (No. 12)	34.89	10.467	3.50	13.97
Tarmac House (No. 10)	34.89	10.467	2.80	13.27
Saint-Gobain Nottingham H.O.U.S.E	34.89	10.467	1.85	12.32
	Total	73.27	36.6	109.89

#### *Instantaneous domestic hot water (DHW) peak heat load*

Instantaneous DHW peak demand was calculated separately using the assumptions represented in *Table 4*. The instantaneous DHW peak demand is assumed to deliver hot water to 2 showers and kitchen use for 4 people in each property. The calculated 34.89 kWp/house peak seen in *Table 3* is in line with the 37.5 kWp/house proposed in the Danish Standards included in CIBSE's *Heat networks: Code of Practice*.

*Table 4 - Instantaneous hot water peak demand calculation assumptions*

Parameter	Value	Reference
Peak hot water demand ( $\dot{m}$ )	25 L/person/hour (7am – 8am)	CIBSE part G – Table 2.10
Heated water temperature change ( $\Delta T$ )	50 °C (from 10 °C to 60 °C)	BS 8558:2015 Appendix B
Specific heat capacity of water ( $C_p$ )	4.187 kJ/kg.K	CIBSE part G – equation 2.2
Heat capacity equation	$Q = \dot{m} C_p \Delta T$	CIBSE part G – equation 2.2
Diversity factor	0.3	CIBSE – Heat networks: Code of Practice for the UK – Figure 9

Peak instantaneous DHW heat demand is unlikely to occur in all properties at the same time. Therefore, to ensure representative results, a diversity/coincidence factor is applied. The diversity factor is the ratio of the effective peak load used. The *Danish Standard DS 439*, recommended by *CIBSE AM12:2013* and *BS 8558/BS EB 806-3*, gives the coincidence factor as a function of the number of properties served by the heat network. In this case, a site with 7 properties has a coincidence factor of 0.3.

### 3. HEAT NETWORK CONFIGURATION

Network configuration is determined by the placement of infrastructure, as well as the network size and heat source location. Fortunately, the Creative Energy Homes test site can accommodate a largely soft-dig trenching system with a simple branched pipe network (see *Figure 1*). Branched networks allow for consumers to be connected to the main loops individually by a smaller service branch. Benefits of branched networks include flexible design, easy installation, and additional branches can be added to the network loop at later stages.

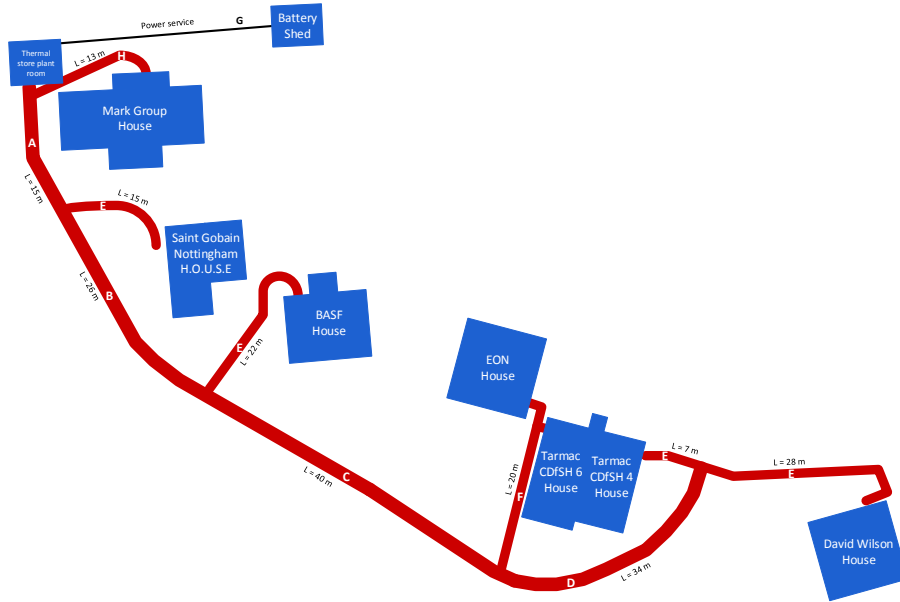


Figure 1 - Aerial view of the Creative Energy Homes test site with heat network trenching layout

As mentioned, project SCENIC is the first MES (Multi-vector Energy System) DHN with truly distributed energy generation. Consequently, a novel network configuration was required to facilitate prosumer and consumer participation at each property. A double loop system has been installed, where a network loop supplies heat to each property via a consumer HIU (heat interface unit) (see *Figure 2*), and a generation loop delivers heat generated at each property through a prosumer HIU to a CTS (central thermal store) (see *Figure 2*).

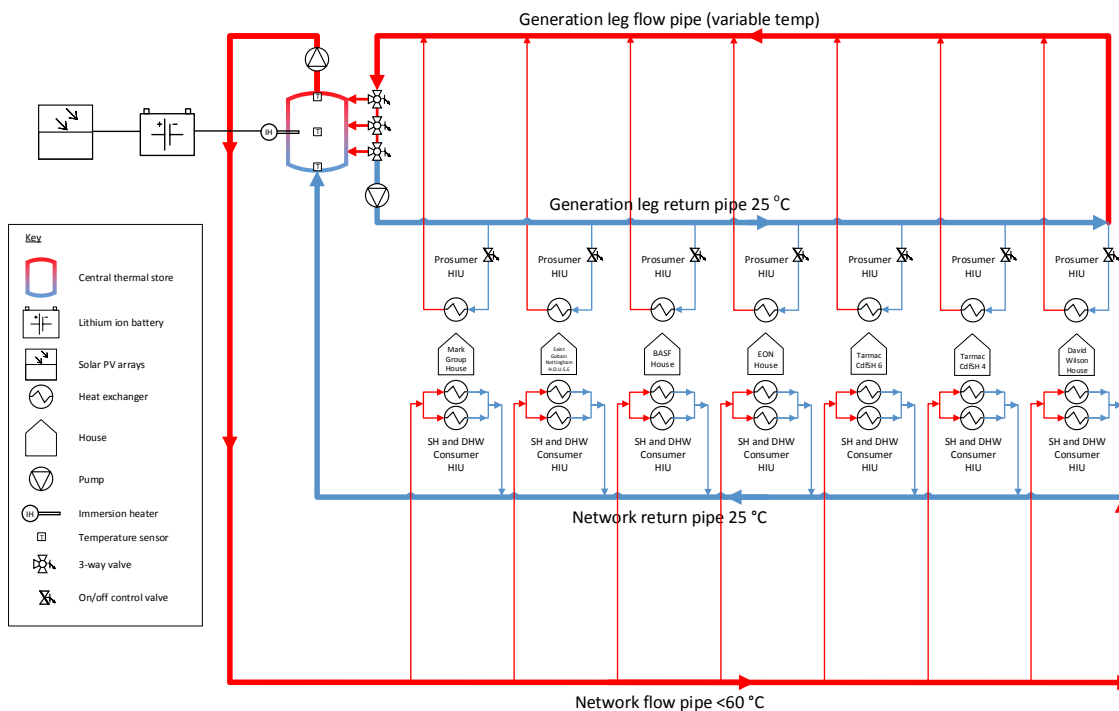


Figure 2 - SCENIC double loop heat network with system components. Generation loop (top) facilitates heat transfer from distributed sources to CTS. Network loop (bottom) facilitates heat supply to houses from CTS

## 4. NETWORK COMPONENT SIZING

Heat networks are designed on peak load in winter, yet year round efficiency needs to be considered. Despite peak load needing to be met, oversizing needs to be balanced against technically practical and economically feasible component selection. For most of the year the system will only operate at part load with peak output is only needed for a few hours.

Initially, network operating temperature needs to be selected. Following this, when sizing a heat network, three components are considered:

- Heat source
- Heat distribution / pipe system
- Heat exchanger / heat interface unit (HIU)

Within this section, we consider the sizing of the aforementioned heat network components using the modelled results. Once component sizes have been identified it is possible to present the overall heat network layout within *Section 4*. Unlike standard heat network component sizing and design, project SCENIC has to consider the integration of distributed generation on all 7 networked properties.

### 4.1. Operating temperatures

The transition to LTDH is widely understood to be the next step in heat network efficiency. Generally, LTDH has a supply temperatures below 55 °C and return temperatures of around 30 °C described in numerous papers (Olsen, Lambertsen et al. 2008, Paulsen, Fan et al. 2008, Torío and Schmidt 2010, Dalla Rosa and Christensen 2011, Li and Svendsen 2012, Østergaard and Svendsen 2016, Yang, Li et al. 2016). As a result, Project SCENIC aims to achieve a network supply temperature below 55 °C for most of the year and a return temperature of 30 °C.

Lund, Werner et al. (2014), the seminal work on the definition of LTDH (4th Generation) describes how future systems can achieve supply and return of 50 °C / 20 °C for most of the year without compromising comfort levels and hygiene requirements. It is understood that operating temperatures should be kept as low as possible to avoid unnecessary heat losses. Additionally, operating temperatures will also effect:

- Capital and running costs
- Heat losses
- Pump and pipe sizing requirement
- Efficiency of heat pumps
- Volume of thermal store required
- Heat exchanger capacity

The relationship between the aforementioned parameters is discussed more comprehensively alongside relevant system component information in the following sections.

### 4.2. Heat source

The generation technologies have been installed before the installation of the heat network except for an evacuated tube solar thermal array on oldest property (David Wilson House). *Table 5* specifies the capacity and location of each distributed generation technology. Energy flows are presented in *Section 5*.

*Table 5 – Heat source type and generation*

Building name	Energy generation technology	Peak installed capacity (kW)
David Wilson House	Evacuated tube solar thermal collector	4.42
	Gas boiler	24
Mark Group House	Evacuated tube solar thermal collector	4.42
EON House	Gas boiler	12
BASF House	Flat plate solar thermal collector	3.2
Tarmac House (No. 12)	Biomass boiler	15
	Flat plate solar collector	1
Tarmac House (No. 10)	Flat plate solar collector	1
Saint-Gobain Nottingham H.O.U.S.E	Evacuated tube solar thermal collector	1.28
Central thermal store	Immersion heater	12
Total		78.32

### Thermal store

In order to enable intermittent renewable generation, appropriate generation scheduling, and to satisfy peak loads energy storage is required. The tank is sized to match the peak flow rate of 1.99 l/s (based on formula 3) sustained over 10 minutes (600 seconds). Due to stratification, the required supply temperature is only available in one-quarter of the tank. Therefore the tank will need to accommodate 2400 seconds of flow. Hence, the required volume of the tank is:

$$S = 2400(F \cdot V) \quad (1)$$

where S is tank volume (l), F is diversity factor, and V is heat medium flow rate (l/s). With a heat network peak flow rate of 1.99 l/s, the hot water volume capacity required is 4,776 l.

The CTS selected for project SCENIC was a GALÚ Classic 10,000l accumulator tank with 100mm of polyurethane insulation with 0.23 W/mk thermal conductivity. The tank is capable of storing energy for days or even weeks with minimum heat losses. The tank can operate with a maximum supply temperature of 95 °C, and operating pressure of 3 bar, typically 1.5 bar. The tank was oversized to account for additional energy generation installation in later projects.



Figure 3 - SCENIC project central thermal store. 10,000 l GALÚ

The energy stored in the thermal tank is available as sensible heat in the raised water temperature. The capacity of the central thermal store is

$$E = c_p \cdot \Delta T \cdot m \quad (2)$$

where E is energy content (kJ),  $c_p$  is the specific heat of water (kJ/kg°C),  $\Delta T$  is the temperature difference between the hot water and the surroundings, m is the mass of stored water (kg). Assuming 50% of the stored hot water is available for usage, then tank can accommodate over 202.67 kWh as sensible heat at 55 °C.

### 4.3. Heat distribution

In standard DHN a heat transfer fluid, usually water, is passed through a two-circuit system (flow and return). However, project SCENIC utilised a four-circuit configuration comprised of a network and generation loop (see Figure 2). Within the network loop a flow pipe transports hot water from a CTS to the consumer, a return pipe delivers cooled water back. Within the generation loop, a flow pipe delivers heat from the prosumer's distributed energy source to a CTS, a return pipe delivers cooled water back.

For accuracy in the heat distribution design of such a system we consider the following key factors:

1. Correct heat loads - if incorrect, oversizing of pipes will lead to greater heat losses
2. Diversity – again to avoid oversizing (see Section 2.1)
3. Limiting installation costs
  - a. Avoiding hard-dig areas such as asphalt roads
  - b. Use of polymer pipes for flexibility resulting in less requirement for joints
  - c. Utilisation of twin pipes

#### Rehau Rauthermex pipe

Rehau Rauthermex pipe has been selected as the heat distribution infrastructure due to its excellent thermal insulation. The polyurethane (PU) foam insulation and corrugated outer jacket help retain heat and allow for flexibility, in turn reducing heat losses, improving ease of installation, and limiting jointing requirement (see Figure 4).



Figure 4 – RAUTHERMEX preinsulated bonded pipe main components. Single pipe (left). Twin (bottom) and single (top) pipe (right), (Rehau 2014)

The piping system is made up of a crosslinked polyethylene (PE-Xa) water bearing carrier pipe, pentaneblown PU foam insulation and a PE-LLD outer jacket. Consequently, the product is advantageous as it durable, providing corrosion and chemical resistance, has permanently low heat and pressure loss, and very low roughness.

#### Pipe diameter

Each pipe section must accommodate the peak heat load of those properties down flow of the network. Moreover, when sizing pipe sections the principle, as small as possible, as big as necessary, should be followed.

Network distribution pipe diameter is inferred from the pipe flow rate and pressure loss. Flow rate can be calculated from the known heating requirement and the temperature difference between flow and return pipes. Flow rate is

$$V = \frac{Q}{C_p \cdot (\vartheta_V - \vartheta_R) \cdot \rho} \quad (3)$$

where V is the heat medium flow rate (l/s), Q is the peak heat flow (kW), C<sub>p</sub> is the specific heat capacity of water (kJ/kg·K),  $\vartheta_V$  is the flow temperature in the network (°C),  $\vartheta_R$  is the return temperature in the network (°C), and  $\rho$  is the density of water (kg/l).

Using calculated flow rate and the manufacturer's specification the pipe should be as small as possible without exceeding a 200-250 Pa/m pressure loss, it is possible to identify the most appropriate branch pipe sizes.

#### Pipe configuration

The benefits of using a twin pipe was quantified based on the network operating temperatures and the following heat loss calculation

$$Q = U (\vartheta_B - \vartheta_E) \quad (4)$$

where Q is heat loss during operation (W/m), U is thermal heat transfer coefficient (W/mK),  $\vartheta_B$  is average operating temperature (°C), and  $\vartheta_E$  is soil temperature (°C). Using the equation above the heat loss reduction when using twin compared to single pipes has been calculated (Table 6).

Table 6 - Comparison of heat loss in single and twin pipes - project SCENIC

Diameter requirement (mm)	2x single pipes		Twin pipe heat loss (W/m)		Heat loss reduction (%)
	Thermal heat transfer coefficient (W/mK)	Heat loss (W/m)	Thermal heat transfer coefficient (W/mK)	Heat loss (W/m)	
25	0.099	6.44	0.139	4.52	30
32	0.121	7.87	0.183	5.95	24
40	0.151	9.82	0.211	6.86	30

#### Pumps

Pumps are fundamental to heat distribution in networked hydronic systems. For DHN, pumps are not the main energy consumer in systems, but correct sizing is important to deliver minimum energy transport costs. Due to variable heat demand maximum duty pumping occurs over very few operating hours. However, pump size must be based on maximum system load, specifically maximum flow and pressure loss as well as peak efficiency. As a result, variable speed pumps with a good control strategy are ideally suited to gain lower heat, less power, and better efficiencies.

Another important factor is temperature difference within a distribution loop as it will affect pumping requirement. If  $\Delta T$  is low, higher flow rates are required to satisfy heat demand, therefore causing higher pressure loss and hence pumping costs increase.  $\Delta T$  should be as high as possible to minimise pumping costs.

Pump duty is sized to overcome the flow resistance in the pipework and the pressure differential at HIUs. When determining pump duty the following hydraulic requirements are essential:

- Total inflow  $Q_i$  (l/s) equals duty flow of pump  $Q_p$  (l/s)
- Duty head of pump  $H_p$  (m)  $\geq$  Total head  $H_{total}$  (m)

(CIBSE 2014)



Alongside these hydraulic requirements, a minimum pump energy consumption must be taken into account. Therefore, both generation and network loops use the *Grundfos - MAGNA3 D 32-120 F Model B* pump which has the highest energy efficiency on the market. The MAGNA 3 is designed for pumping liquid through heating systems with variable flows. The pump duty point can be optimised to reduce energy costs. As a result, pumps were sized to work at 30 - 75% of the total load. It is important for correct operation that the system range lies within the duty range of the pump (see *Table 7*).

*Table 7 - Grundfos - MAGNA3 D 32-120 F Model B duty range compared to project SCENIC parameters (Grundfos 2015)*

Parameter	MAGNA3 (N) Single-head pumps ranges	Project SCENIC ranges
Flow rate, Q	21.81 l/s	1.99 l/s
Head, H	18 m	12 m
System pressure	1.6 Moa (16 bar)	Max. 3 bar
Liquid temperature	-10 to 110 °C	30 °C to 55 °C

Overall, benefits of the pump include low energy consumption, built-in differential pressure and temperature sensor, heat energy monitor, and easy system optimisation.

#### 4.4. Heat exchanger

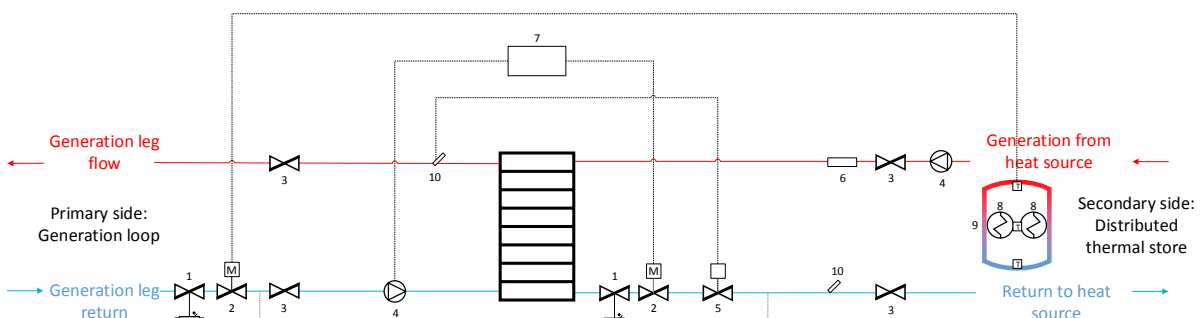
Heat exchangers separate the primary heat network and secondary consumer circuits. The appropriate Heat Interface Unit (HIU) containing flat plate heat exchangers are required based on peak kW SH and DHW requirements (see *Table 3*), and system operating temperatures.

The domestic properties in project SCENIC have preinstalled heating and hot water systems, as a result, a direct connection was not an option for SH. An indirect HIU was selected for both SH and DHW to provide a physical barrier between primary and secondary loops. In LTDH a heat exchanger barrier between loops prevents the spread of *Legionella bacterium*. As the temperature in the network buffer tanks is likely to fall below the required 60 °C to prevent the spread of *Legionella*, a DHW heat exchanger is essential. Potable DHW temperatures will be boosted on the secondary side with an immersion heater to meet the 50 °C tap temperature requirement.



*Figure 5 - HIU in situ outside the Tarmac CdFH 4 house. Prosumer unit (right), consumer unit (left)*

For the network loop, supplying SH and DHW to each property, a *Danfoss FlatStation – 7 Series DS Fully Insulated* was chosen. Furthermore, a bespoke *Danfoss FlatStation – 3 Series BS Basic Fully Insulated* was designed to accommodate prosumer participation within the generation loop. *Figure 6* illustrates how the FlatStation redesign facilitated the supply of heat from distributed generation sources within buildings into the network for distribution.



*Figure 6 – Danfoss FlatStation - 3 Series BS Basic Fully Insulated Indirect Prosumer HIU circuit diagram. Key: 1 – differential pressure controller, 2 – on/off valve, 3 – isolation valve, 4 – pump, 5 – thermostatic valve, 6 – energy meter, 7 – electrical wiring box, 8 – heat exchanger, 9 – hot water tank with immersion temperature sensors, 10 – temperature sensor node*

*Sizing*

Table 8 specifies the selection of Danfoss HIU on each of the test site properties. Sizing was based on heating capacity and supply/return temperature. Furthermore, Danfoss HIU significantly outperform others on the market due to their specialised valve technology and energy saving features.

Table 8 - HIU specification and location - project SCENIC

Parameter	Consumer unit		Prosumer unit
Product	Danfoss FlatStation – 7 Series DS Fully Insulated	Danfoss FlatStation – 7 Series DS Fully Insulated	Danfoss FlatStation – 3 Series BS Basic Fully Insulated
Model	VVX-I-FI-1-3	VVX-I-FI-1-2	VX-2
Installed on	Mark Group House, David Wilson House	BASF, EON, Nottingham, Tarmac 10, Tarmac 12	All
Heating capacity	SH 10 kW; DHW 35 kW	SH 7 kW; DHW 35 kW	7 kW

**5. ENERGY FLOWS**

Typically heat networks require two energy inputs, heat energy to compensate for distribution heat losses, and electrical energy for pumping to compensate for frictional losses. Within this paper we have discussed the design of project SCENIC’s heat network, however, as a MES both heat and power networks will be linked. As a result, the energy inputs and outputs are more complicated than the typical model. Figure 7 illustrates how the energy flows and system configuration will operate.

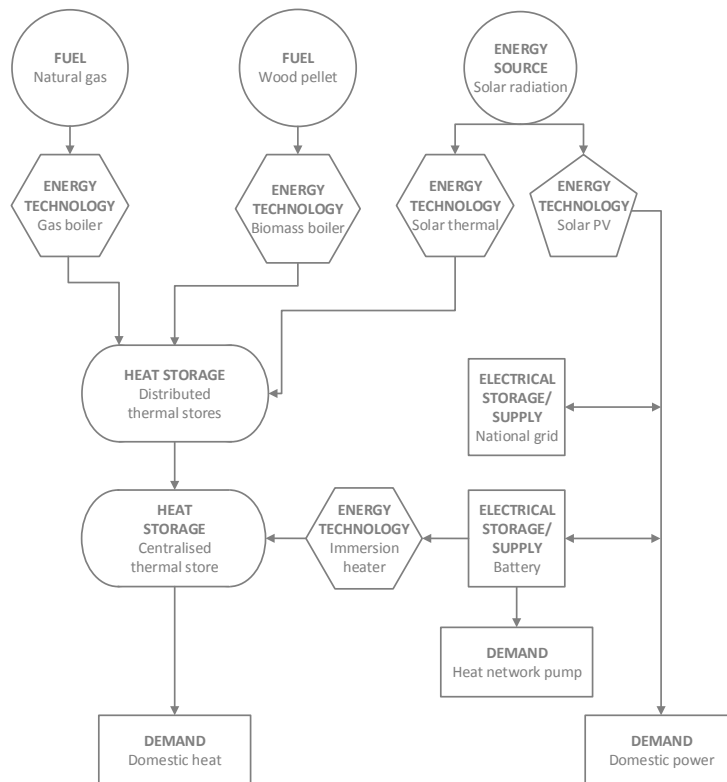


Figure 7 – Energy flow outline project SCENIC

The extent to which each energy technology will supply heat or power will depend on the scheduling scenarios to be tested within the next phase of the project.

**6. DISCUSSION AND CONCLUSION**

The paper discusses the design and sizing of the first community scale MES heat and power network with distributed energy generation. Prosumer participation is facilitated through a double loop heat pipe configuration, allowing consumers to be both buyers and sellers of heat. In addition, the use of renewable energy generation and energy storage enables LTDH, which in turn reduces operational costs, heat losses, energy consumption and carbon emissions.

In order to reduce the well-documented system design margin, the SCENIC heat network will operate at low temperature. To permit LTDH, there must be adequate heat transfer through radiators inside each property. As a result, the next phase of project SCENIC will tackle the redesign of interior heating systems to allow heat to be input and output from the properties. The adequate transfer of heat is essential to maintain comfort levels and reduce the energy consumption of the network.

Heat and power network integration will be addressed in the next phase of the project through the installation of a 23 kW lithium ion battery. The battery will power an immersion heater in the CTS and distributed heat generation technologies. In turn, the battery will be charged by the numerous distributed photovoltaic arrays on site.

A formative element in achieving system efficiency is the improved operation and scheduling of the technologies. A holistic control approach for optimising decentralised heat generators, pumps, and valves will require well-functioning monitoring, communication, and decision support tools. As a result, a large part of project SCENIC will be focussed on controlling the system components designed and sized in this paper.

In summary, infrastructure has been installed at the University of Nottingham's Creative Energy Homes test site to facilitate distributed generation and the prosumer concept in a combined heat and power network. For the heat network, overall configuration, component sizing, and HIU redesign have been explained in this paper. The work presented here acts as a base from which power integration, control systems, and prosumer business model design can be built upon extending the relevance of the projects outcomes.

## 7. REFERENCES

- CIBSE see: Chartered Institution of Building Services Engineers (2014). Public health and plumbing engineering. CIBSE Guide G: 2014. London, The Chartered Institution of Building Services Engineers London.
- Dalla Rosa, A. and J. E. Christensen (2011). "Low-energy district heating in energy-efficient building areas." *Energy* 36(12): 6890-6899.
- Dalla Rosa, A., H. Li, S. Svendsen, S. Werner, U. Persson, K. Ruehling, C. Felsmann, M. Crane, R. Burzynski and C. Bevilacqua (2014). Annex X Final report: Toward 4th Generation District Heating: Experience and Potential of Low-Temperature District Heating
- European Commission. (2016). "Heating and cooling." Retrieved 28th February, 2017, from <https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling>.
- Grundfos (2015). MAGNA3, Model A-B-C, Circulator pumps. GRUNDFOS DATA BOOKLET.
- Li, H. and S. Svendsen (2012). "Energy and exergy analysis of low temperature district heating network." *Energy* 45(1): 237-246.
- Lund, H., S. Werner, R. Wiltshire, S. Svendsen, J. E. Thorsen, F. Hvelplund and B. V. Mathiesen (2014). "4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems." *Energy* 68: 1-11.
- Olsen, P. K., H. Lambertsen, B. Bøhm, C. C. H., S. Svendsen, C. T. Larsen and J. Worm (2008). A new Low-Temperature District Heating system for low-energy buildings. The 11th International Symposium on District Heating and Cooling, Reykjavik.
- Østergaard, D. S. and S. Svendsen (2016). "Case study of low-temperature heating in an existing single-family house—A test of methods for simulation of heating system temperatures." *Energy and Buildings* 126: 535-544.
- Østergaard, D. S. and S. Svendsen (2016). "Replacing critical radiators to increase the potential to use low-temperature district heating – A case study of 4 Danish single-family houses from the 1930s." *Energy*.
- Paulsen, O., J. Fan, S. Furbo and J. E. Thorsen (2008). Consumer unit for low energy district heating net. The 11th international symposium on district heating and cooling.
- Rehau (2014). RAUVITHERM AND RAUTHERMEX PRE-INSULATED PIPE - TECHNICAL INFORMATION. SAV systems (2016). Design & Product Guide - Danfoss FlatStations.
- Torío, H. and D. Schmidt (2010). "Development of system concepts for improving the performance of a waste heat district heating network with exergy analysis." *Energy and Buildings* 42(10): 1601-1609.
- UN FCC see: United Nations Framework Convention on Climate Change (2014a). "Kyoto Protocol." Retrieved 3rd May, 2017, from [http://unfccc.int/kyoto\\_protocol/items/2830.php](http://unfccc.int/kyoto_protocol/items/2830.php).
- UN FCC see: United Nations Framework Convention on Climate Change. (2014b). "The Paris Agreement." Retrieved 3rd May, 2017, from [http://unfccc.int/paris\\_agreement/items/9485.php](http://unfccc.int/paris_agreement/items/9485.php).
- Wu, W., B. Wang, S. Shang, W. Shi and X. Li (2016). "Experimental investigation on NH<sub>3</sub>-H<sub>2</sub>O compression-assisted absorption heat pump (CAHP) for low temperature heating in colder conditions." *International Journal of Refrigeration* 67: 109-124.
- Yan, J., D. J. Lee, S. K. Chou, U. Desideri, H. Li, H. Li and S. J. Wang (2014). "International Conference on Applied Energy, ICAE2014Challenges in Smart Low-temperature District Heating Development." *Energy Procedia* 61: 1472-1475.
- Yang, X., H. Li and S. Svendsen (2016). "Evaluations of different domestic hot water preparing methods with ultra-low-temperature district heating." *Energy* 109: 248-259.