BUILDING SIMULATION REPORT FOR GUILDFORD BOROUGH COUNCIL

A Mixed Use Scheme – Domestic Properties (flats & houses)

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Author: Andrew Cooper, Director **|** **Reviewed**: Ed Gabbitas, Director **|** **Issue Status: 2.0**

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1. INTRODUCTION

This building simulation report summarises the findings of up to 132 simulations using SAP[1] software on a detached house, two terraces of residential houses and three blocks of flats forming part of a mixed use scheme. These models are based on an adapted development provided to EVORA EDGE by Guildford Borough Council for the purpose of this study.

The simulations study the performance of four different but common building services solutions for domestic properties, which we refer to throughout this report as System 1, System 2, System 3 and System 4. Throughout the simulations the building models building fabric and lighting are the same. However, the heating and domestic hot water services varies in each building. Low and Zero Carbon (LZC) technologies are incorporated to augment or replace conventional non-LZC technologies.

The modelled simulations calculate a building's Dwelling Emission Rate (DER) as a result of the energy it is predicted to consume. Templates around occupancy and occupational parameters, such as hours of operation and temperature set points, are provided in a Standard Assessment Procedure (SAP) which was developed by the Building Research Establishment (BRE) for government. To comply with Part L1A *Conservation of fuel and power in new dwellings* of Building Regulations (Part L1A), a Target Emission Rate (TER) and Target Fabric Energy Efficiency (TFEE) is set, and the DER and Dwelling Fabric Energy Efficiency (DFEE) must achieve or better (≤) these targets.

[1] The Standard Assessment Procedure (SAP) is the methodology used to assess and compare the energy and environmental performance of dwellings

In addition to building regulations, the TER is used in planning policy as a benchmark for sustainable development by setting out the maximum level of predicted CO_2 emissions that a building or development is permitted to emit. As part of an extant planning policy Guildford Borough Council (GBC) requires the DER of a new building to be at least 10% lower than the TER, with any reduction achieved through the use of on-site LZC technologies.

GBC is currently in consultation to increase this target to either 15 or 20% and this document forms part of a series of reports to help determine if these targets are technically feasible, and if so, what the potential effect of revising this policy would be in terms of development costs to property developers. While all our simulations are expected to pass the TFEE, the focus of the study is therefore on the DER and TER since this is the primary planning benchmark.

1.1. The Simulations

Part L1A has five criterion and a requirement for any developer to analyse and take into account the technical, environmental and economic feasibility of using high-efficiency alternative systems in construction, if available[2]. For a building to pass the exacting requirements of Part L1A it must be designed and constructed to a standard that meets or betters the TER of a Notional Dwelling (DER ≤ TER). A building that is constructed to the limiting parameters of Part L1A will fail Criterion 1, which is the Criterion that requires the DER ≤ TER.

[2] These systems are to include decentralised energy supply systems based on energy from renewable sources, cogeneration, district or block heating or cooling, particularly where it is based entirely or partially on energy from renewable sources, and heat pumps

Each model simulated is identical in every respect other than its building services, which may or may not include renewable energy systems. To ensure that the model is capable of passing Part L1A the building fabric and thermal bridging is based upon the requirements of a Notional Dwelling, and these remain unchanged throughout the various iterations of the model(s). By ensuring that the building construction and fabric remains as a constant, we can calculate a ‘base building’ construction cost. This in turn allows us to identify where additional expenditure is required to facilitate the CO_2 reduction targets of four benchmarks, detailed below.

System 1 starts with the least number of LZC technologies possible for a typical services solution, and as the targets become more challenging, then more efficient conventional systems and/or LZC technologies are incorporated into the model(s) to augment or replace less efficient and/or non LZC technologies. Systems 2 to 4 on the other hand, start with LZC technologies, for example primary fossil fuel heating is typically replaced with heat pumps. Simulations have been run against four benchmarks, these are:

1) The Dwelling Emission Rate is equal to or lower than the Target Emission Rate (DER≤ TER). This is a requirement of Criterion 1 of Approved Documents Part L1A of Building Regulations 2010 (Part L)

2) The DER must be 10% lower than the TER. This is the Extant Policy

3) The DER must be 15% lower than the TER. This is a proposed borough policy which we refer to as Proposed Policy A

4) The DER must be 20% lower than the TER. This is a proposed borough policy which we refer to as Proposed Policy B

1.2. Building Information Model (BIM)

To prepare this report we have used a building information model or BIM using IES engineering software - the Virtual Environment or VE. PDF drawings were provided to EVORA EDGE by GBC on a proposed development scheme in Guildford adapted for this study. These were converted into DWG files and scaled using AutoDesk AutoCad, and then in turn converted to DXF drawings so that they could be imported into the VE. We then imported additional models of commercial buildings from previous projects using gbXML and/or GEM files to create a 'virtual mixed use scheme'. This allowed us to model various types and numbers of buildings using a federated BIM which was shared between two principal energy modellers.

The BER and TER calculations and costs were all undertaken in the same model(s) and these are in turn available as IES Cabinet Files for future use. Nomenclature of itemised costs are based on the RICS New Rules of Measurement *Order of cost estimating and cost planning for capital building works.* A representation of the federated BIM is shown below.

1.3. Report Structure

This report has been arranged into the following sections. An executive summary, a more detailed tabulated section with basic technical information on our energy simulations, a summary of our costing methodology, and an extract from the BIMs showing our cost calculations and cost sources. Methodologies and sources of data have been clearly stated, however, it is important to note project limitations, which are expanded on in the section below.

1.4. Disclaimers

With any building, existing or proposed, there are almost an infinite number of design parameters for architects and engineers to consider including:

- Structure
- Orientation and Massing
- HVAC and Lighting Types
- Combination of HVAC and Fuel Types
- LZC Technologies

Whilst we have considered many scenarios, it is not possible to cover all potential design parameters. The aim of this research is to identify if it is possible to pass four benchmarks using the geometry and construction type of buildings which either already exist, or are proposed as part of a planning application; while assuming common design parameters and HVAC systems which are based upon a Notional Building or best (typical) market practice.

To do this we have looked at a number of building and system types adopting a hierarchical approach to favour the most efficient system(s). Where values or efficiencies are detailed in the Notional Building these are adopted. However where these values are not provided, or where they seem low when assessed against technologies readily available in the market, then these were replaced by values or efficiencies detailed in either Part L1A, or the Energy Technology List (ETL)[3], or other reputable or market sources.

Costs are indicative and for benchmarking purposes only. They exclude VAT and fees associated with design, professional services and project management. They do however include for preliminaries, profit and overheads for the services contractor. Build costs have typically been taken at the median of a range of costs detailed in SPONS 2017 unless indicated otherwise. Greater detail and information on our costing methodology has been provided in Section 4. of this report.

[3] The ETL (or Energy Technology Product List, ETPL) is a government-managed list of energy-efficient plant and machinery, such as boilers, electric motors, and air conditioning and refrigeration systems that qualify for full tax relief.

2. EXECUTIVE SUMMARY

Our findings over the following pages are summarised in the form of four schematics, one for each type of HVAC system including; a common domestic low temperature hot water heating system, an air source heat pump system (air-to-water), a ground source heat pump system, and a heat network using gas fired combined heat and power (CHP). Each schematic shows the effect of each iterative simulation on the DER in order to meet or better a benchmark, the financial cost to the developer for each metre square (m^2) of building space to achieve this. Finally the schematic shows, expressed as a percentage increase, the cost of improving a building from Part L1A and the Extant Policy to a building that can comply with Proposed Policy B – the most stringent of the proposed policies.

2.1 System 1: Results

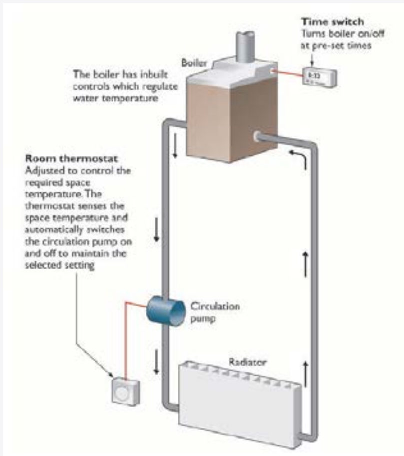
System 1 comprises a gas fired central heating system. The heat source is a condensing combination boiler, heat is transferred through a low temperature hot water (LTHW) circuit to radiators with thermostatic radiator valves. Domestic hot water is delivered directly by the combination boiler. Condensing boilers are only more efficient than conventional high-efficiency boilers when they operate in condensing mode, this is when they utilise the latent heat from the exhaust gases. To do this the return water temperatures must be less than 55°C. This means reduced flow temperatures, and typically, larger radiators or underfloor heating is required to facilitate this. System 1 is capable of passing Part L1A without any LZC technologies, but requires photovoltaics (PV) in increasing capacity to pass existing and proposed policies. However once PV is added, a building capable of passing the Extant Policy is then able to pass both proposed policies. This provides an opportunity to developers to value-engineer out design features should, for example, GBC opt for Proposed Policy A.

The results of the case studies are as follows:

- The cost of Proposed Policy A and B is up to 0.97% more expensive than constructing a building that complies with Criterion 1 of Part L1A.
- The difference in cost between Extant Policy construction costs and Policy A and B construction costs is up to 0.41%.

System 1: Results schematic

Shown below a typical boiler and LTHW circuit



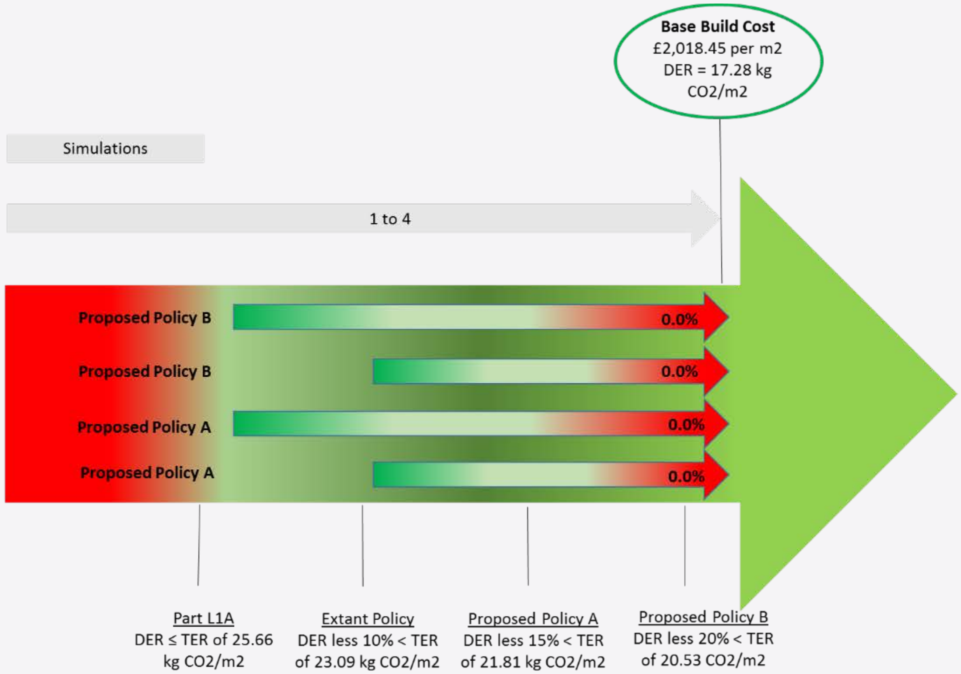
Source of picture, the BSRIA *Illustrated Guide to Mechanical Building Services*

2.2 System 2: Results

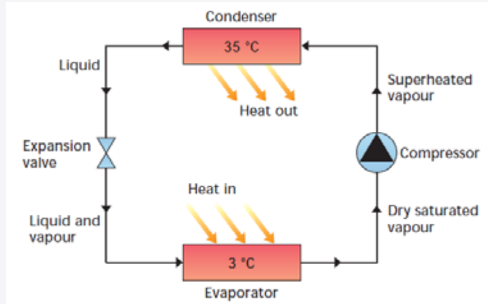
System 2 incorporates an air to water air source heat pump or ASHP. This type of system uses the vapour compression cycle and should be operated in a similar way to a condensing boiler (in condensing mode) which means low flow and return temperatures. This is because heat pumps operate more efficiently when there is a lower temperature difference between the heat source (air) and the heat sink (the conditioned space). These systems can operate with radiators or underfloor heating, but as per System 1, the radiators should be sized for the lower flow temperatures. Heat pumps are considered to be an LZC technology by GBC, and operated correctly can be very efficient across the heating season. System 2, which incorporates an indirect hot water storage tank with hot water also heated by the ASHP, easily passes Part L1A and the extant and proposed policies without any additional LZC technology such as PV or solar heat. As a result the base build cost remains fixed across all four benchmarks. Our findings are:

- There is no difference in cost to a developer between the benchmarks since our base case building passes all four.

System 2: Results schematic



Shown below is a schematic of the vapour compression cycle.



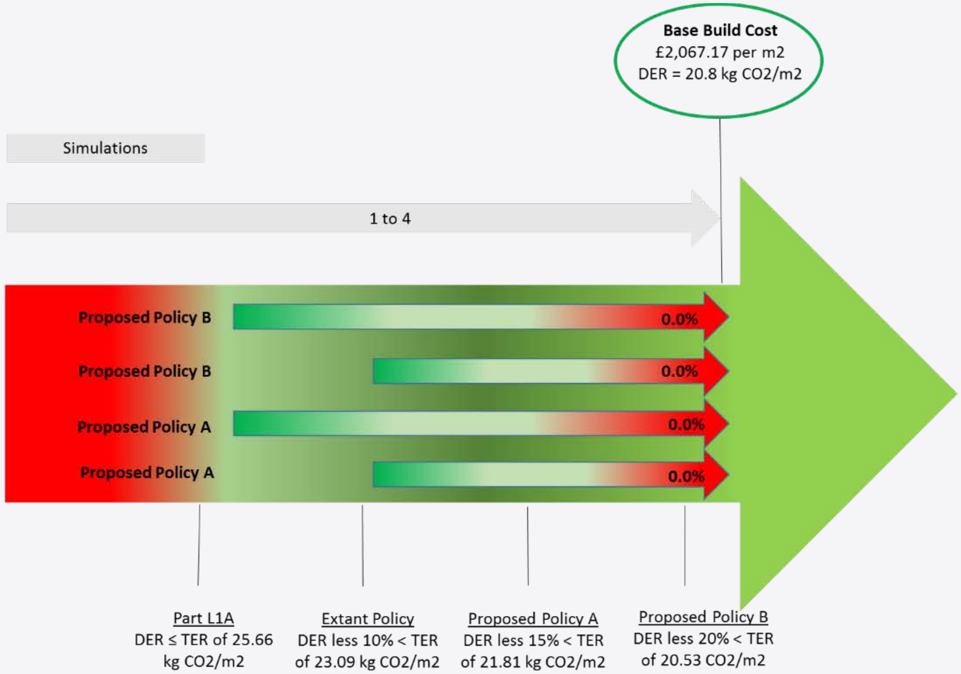
Source of picture, CIBSE AM14 *Hot water heating systems*

2.3 System 3: Results

System 3 is a ground to water heat pump (GSHP), which operates in the same way as System 2 - other than the source of heat is the ground and not the air. GSHP are typically more efficient than ASHP because the temperature of the ground at depth is 1) more constant and 2) typically higher than the temperature of air during winter. This means a reduced temperature difference between the source and sink (See System 2) across a heating season. Due to the limitations of the SAP (domestic) modelling tool, the DER for the GSHP modelled in System 3 is in fact worse than System 2 - which is somewhat counter intuitive. Nevertheless our remit is not to critique SAP and our modelling still suggests System 3 can pass Part L1A, the extant and proposed policies without any additional LZC technology, such as PV or solar heat. As a result the base build cost remains fixed across all four benchmarks. Our findings are:

- There is no difference in cost to a developer between the benchmarks since our base case building passes all four.

System 3: Results schematic



Shown below, a GSHP unit in a garage and collector coils

Source of pictures, CIBSE TM51 *Ground source heat pumps* and BSRIA *Illustrated Guide to Mechanical Building Services (courtesy of Kensa Heat Pumps)*

2.4 System 4: Results

System 4 comprises a district or block heating scheme, otherwise known as a heat network. Heat networks can address the ‘energy trilemma’ of:

1. Reducing greenhouse gases through the use of LZC technology

2. Improving security of energy supply by diversifying energy resources and,

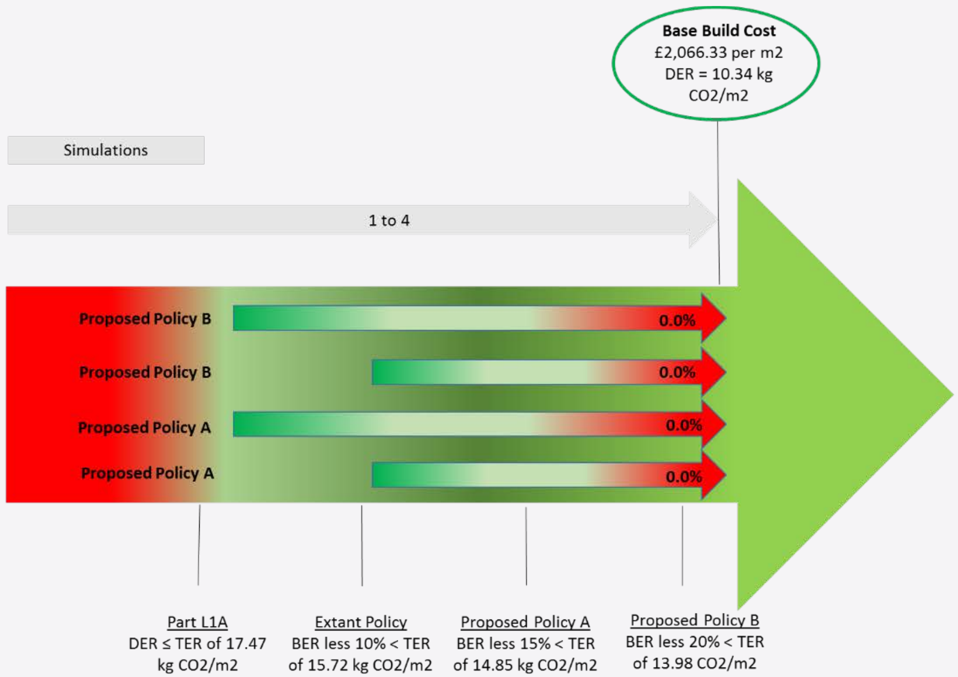
3. Offering a supply of heat that is good value.

The primary source of heating modelled is a gas fired combined heat and power engine (CHP). This typically requires conventional fossil fuel boilers to augment the heat supply or to act as a backup heat source. In this CHP energy scenario, gas is used to generate electricity and this generates heat as a waste product which is recycled to heat water. The electricity produced has lower CO_2 emissions than electricity supplied through the grid since it does not face the same inefficiencies, such as transmission losses[4]. CHP is considered, therefore, to be a LZC technology. Our findings are:

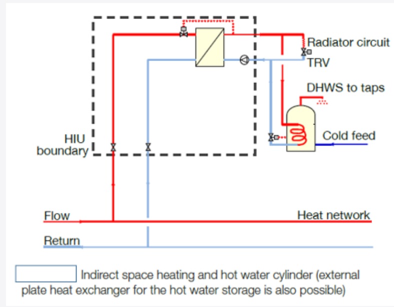
- System 4 can pass Part L1A and the extant and proposed policies without any additional LZC technologies, such as PV or solar heat, and the base build cost remains fixed across all four benchmarks.

[4] In addition CHP can deliver good financial savings provided operational circumstances support its application. This is because electricity is more expensive than gas, so with CHP electricity is being generated for the same price as gas.

System 4: Results schematic



Shown below, a schematic for a typical connection to a heat network



Source of schematic CIBSE CP1 *Heat networks: Code of Practice for the UK*

2.5 A Comparison of System Performance

The table below compares the results of our simulations so that we can better understand cost-effectiveness alongside the impact on predicted CO_2 emissions. CO_2 emission are linked to energy consumption (kWh) and therefore, potentially, operational costs. System performance can be judged in two ways. The first, and in all probability, the most relevant to developers is establishing the most cost-effective way to reach Proposed Policy A or B. **This is highlighted in green**. In this case System 1, below, is the most cost-effective. Boxes that have been blacked out indicate that the previous simulation was capable of passing the target benchmark, and as a result it is not necessary to run additional simulations. For example, the simulation run to pass benchmark 1 for System 2 also passes benchmarks 2, 3 and 4, so these have been blacked out.

The second metric assesses the cost (£) of reducing CO_2 emissions. 0 = Zero operational carbon, the further away from zero the higher the cost (£) per Tonne (T) of CO_2 saved[5]. System 1 is the most cost-effective way to reach Proposed Policy A and B but System 4 is likely to deliver greater cost (£) and CO^2 savings.

[5] Calculated as: BER * system cost / 1,000 (= Tonnes of CO_2)

Benchmark	System 1 BER kg CO_2/m^2	System 2 BER kg CO_2/m^2	System 3 BER kg CO_2/m^2	System 4 BER kg CO_2/m^2	System 1 Cost per m^2 v carbon metric	System 2 Cost per m^2 v carbon metric	System 3 Cost per m^2 v carbon metric	System 4 Cost per m^2 v carbon metric
1. The BER ≤ TER. This is a requirement of Criterion 1 of Part L2A	17.52	17.28	20.80	10.34	£1,988.21 £34.83/TCO^2	£2,018.45 £34.88/TCO^2	£2,067.17 £42.99/TCO^2	£2,066.33 £21.37/TCO^2
2. The BER must be 10% lower than the TER. This is the Extant Policy	15.70				£1,999.25 £31.39/TCO^2			
3. The BER must be 15% lower than the TER. This is a proposed borough policy which we refer to as Proposed Policy A	13.85				£2,007.44 £27.80/TCO^2			
4. The BER must be 20% lower than the TER. This is a proposed borough policy which we refer to as Proposed Policy B								

3. SIMULATION RESULTS

The following two tables provide greater detail and granularity to the modelled buildings. The columns show the simulation number (1 to 4), the building type and target benchmark, the BER and TER, indicative costs and salient technical details.

3.1 System 1: Domestic LTHW Heating System Using Gas Fired Boilers

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
1.	**Building type** Typical residential properties including detached, terrace and end-of-terrace domestic houses and blocks of flats. **Benchmark** The DER ≤ TER. This is a requirement of Criterion 1 of Part L1A. **Summary – pass** It is typically possible to pass the requirements of Criterion 1 without LZC	DER: 17.52 TER: 17.81 The DER is 1.63 % lower than the TER	DFEE: 47.22 TFEE: 55.46 The DFEE is 14.86 % lower than the TFEE	£11,800,013.00 or £1,988.21 per functional unit (m2)	**Building fabric** Air permeability 5 at 50 Pa (m3/(h.m2) = 5 Thermal Bridging, taken at SAP psi values of 0.05 Fabric U values, as per the notional building Glazing g values, as per the notional building **HVAC** Heating A low temperature hot water system using radiators. The heat source is a gas fired condensing combination boiler(s) with a gross efficiency of 89.50% as per the requirements of the notional building.

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
	technologies by mirroring the Notional Building.				<u>Air conditioning</u> N/A <u>Ventilation</u> Ventilation is provided naturally with the exception of kitchens, bathrooms/WCs where mechanical extraction has been assumed at the SAP default rates. **Lighting** 100% efficient. **Lighting controls** Manually controlled. **Domestic Hot Water** Domestic hot water is provided through the combination boiler(s). **Renewable energy systems** N/A **Design challenges/considerations**

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
					N/A
2.	**Building type** Typical residential properties including detached, terrace and end-of-terrace domestic houses and blocks of flats. **Benchmark** The DER must be 10% lower than the TER. This is the Extant Policy. **Summary - pass** By adding a 0.5kWp PV system to each demise the DER of simulation 2 is 11.18 % lower than the TER meaning that a building with this specification is likely to pass the Extant Policy and Policy A and Policy B. Developers could therefore use this to value engineer down the size of the PV reducing costs.	DER: 15.70 TER: 16.03 (the TER in Simulation 1 less 10%) The DER is 11.18 % less than the TER (the TER detailed in simulation 1)	DFEE: 47.22 TFEE: 55.46 The DFEE is 14.86 % lower than the TFEE	£11,865,547.00 or £1,999.25 per functional unit (m2) This represents an increase over the base build cost of £65,534.00 or 0.56%	As per simulation 1 but with an additional 0.5 kWp mono crystalline PV system on pitched roofs, or on flat roof mounts facing due south-east at a 30 degree incline. NB We have simulated 7 out of 13 flats per block. Therefore 39m2 of flat roof space (or 78m2 of a pitched roof) is required. The modelled building has a flat roof extending to 294 m2. The usable surface area of each (terraced) house is circa 26m2. Large detached houses may require >0.5kWp, but the relationship between the base building cost and revised cost (to meet a benchmark) should remain. Please also note that this simulation is based on the median point between Simulation 3 and Simulation 1.

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
3 & 4	**Building type** Typical residential properties including detached, terrace and end-of-terrace domestic house and blocks of flats. **Benchmark** The DER must be 15% lower than the TER. This is Proposed Policy B. **Summary - pass** By adding a 1kWp PV system to each demise the DER of simulation 3 and 4 is 22.25 % lower than the TER meaning that a building with this specification is likely to pass Policy A and Policy B. Developers could therefore use this to value engineer down the size of the PV reducing costs.	DER: 13.85 TER: 15.14 (the TER in Simulation 1 less 15%) The DER is 22.25 % less than the TER (the TER detailed in simulation 1)	DFEE: 47.22 TFEE: 55.46 The DFEE is 14.86 % lower than the TFEE	£11,914,147.00 or £2,007.44 per functional unit (m2) This represents an increase over the base build cost of £114,134.00 or 0.97%	As per simulation 1 but with an additional 1 kWp mono crystalline PV system on pitched roofs, or on flat roof mounts facing due south-east at a 30 degree incline. NB We have simulated 7 out of 13 flats per block. Therefore 156m2 of flat roof space (or 78m2 of a pitched roof) is required. The modelled building has a flat roof extending to 294 m2. The usable surface area of each house is circa 26m2. Large detached houses may require >1kWp, but the relationship between the base building cost and revised cost (to meet a benchmark) should remain.

3.2 System 2: Air to Water Air Source Heat Pump (ASHP) system

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
1 to 4	**Building type** Typical residential properties including terrace and end-of-terrace domestic houses and blocks of flats. **Benchmark** The DER ≤ TER. This is a requirement of Criterion 1 of Part L1A. The DER must be 10% lower than the TER. This is the Extant Policy. The DER must be 15% lower than the TER. This is Proposed Policy B. The DER must be 20% lower than the TER. This is Proposed Policy A.	**DER:** 17.28 **TER:** 25.66 The DER is 32.66% lower than the TER	DFEE: 47.22 TFEE: 55.46 The DFEE is 14.86 % lower than the TFEE	£11,979,488.00 or £2,018.45 per functional unit (m2)	**Building fabric** Air permeability 5 at 50 Pa (m3/(h.m2) = 5 Thermal Bridging, taken at SAP psi values of 0.05 Fabric U values, as per the notional building Glazing g values, as per the notional building **HVAC** Heating An air to water heat pump system using a low temperature hot water hydronic circuit with radiators (increased in size to account for appropriate flow/return temps). Typical CoP[6] of the ASHP is >4.6. This is based on a system available in SAP Appendix Q. Air conditioning N/A

[6] Coefficient of Performance (CoP). For each unit of energy input 4.6 units of heat are transferred as an output under test conditions.

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
	Summary - **pass** It is possible to comply with all four benchmarks if using air to water heat pumps with market typical efficiencies				<u>Ventilation</u> Ventilation is provided naturally with the exception of kitchens, bathrooms/WCs where mechanical extraction has been assumed at the SAP default rates. **Lighting** 100% efficient. **Lighting controls** Manually controlled **Domestic Hot Water** Hot water is heated indirectly by the ASHP and stored in a 150 litre calorifier with heat loss calculated at 1.89 kWh/day. **Design challenges/considerations** Heat pumps are designed to deliver water often at lower levels than conventional boiler systems. However for condensing boilers to condense, flow and return temperatures should also be low, with return temperatures at <55°C. When sizing pipework and radiators there should

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
					be little cost differential between System 1 and System 2 but many developers still size radiators around higher flow and return temperatures typical to non-condensing boilers. Nevertheless in terms of our cost analysis we have chosen to increase costs associated with LTHW infrastructure to account for any difference in flow and return temperatures.

3.4 *System 3: Ground to water heat pump system (GSHP)*

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
1 to 4	**Building type** Typical residential properties including terrace and end-of-terrace domestic houses and blocks of flats. **Benchmark** The DER ≤ TER. This is a requirement of Criterion 1 of Part L1A.	**DER:** 20.80 **TER:** 25.66 The DER is 19% lower than the TER, but we	DFEE: 47.22 TFEE: 55.46 The DFEE is 14.86 % lower than the TFEE	£12,584,003.00 or £2,067.17 per functional unit (m2)	**Building fabric** Air permeability 5 at 50 Pa (m3/(h.m2) = 5 Thermal Bridging, taken at SAP psi values of 0.05 Fabric U values, as per the notional building Glazing g values, as per the notional building **HVAC** Heating A ground to water heat pump system using a low temperature hot water hydronic circuit with radiators

	The DER must be 10% lower than the TER. This is the Extant Policy. The DER must be 15% lower than the TER. This is Proposed Policy B. The DER must be 20% lower than the TER. This is Proposed Policy A. **Summary - pass** It is possible to comply with three of the four benchmarks based on our modelling, but we also believe that with additional research into the nuances of SAP modelling (see design challenges/considerations) that all four benchmarks can be passed with GSHP.	believe that with additional modelling through SAP 20% can also be achieved– see technical details for more information			(increased in size to account for appropriate flow/return temps). Typical CoP of the ASHP is >4.0. This is based on a system available in SAP Appendix Q (which is lower than the CoP of an alternative ASHP in Appendix Q, and somewhat counter intuitive). <u>Air conditioning</u> N/A <u>Ventilation</u> Ventilation is provided naturally with the exception of kitchens, bathrooms/WCs where mechanical extraction has been assumed at the SAP default rates. **Lighting** 100% efficient. **Lighting controls** Manually controlled **Domestic Hot Water** Hot water is heated indirectly by the ASHP and stored in a 150 litre calorifier with heat loss calculated at 1.89 kWh/day **Design challenges/considerations**

					The performance of systems is determined by the SAP Appendix Q database. Systems in the database are assigned through SAP and the efficiencies are fixed (unlike with SBEM and DSM commercial models where efficiencies are entered by the modeller). In this case the CoP of the GSHP is lower than ASHP (System 2) assigned and the DER is therefore worse. In practice annual system efficiencies are based on Seasonal CoP (SCoP) and we would expect these to be higher (better) for the GSHP than the ASHP as there is a lower temperature difference between ground temperatures and air temperatures and room temperatures. We assume that with additional modelling and/or research against the Appendix Q database that the DER can be reduced further without impacting on development costs. We have highlighted this issue to STROMA.

3.5 System 4: District or block heating using gas fired CHP as the principal heat source

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
1 to 4	**Building type** Typical residential properties including terrace and end-of-terrace domestic houses and blocks of flats. **Benchmark** The DER ≤ TER. This is a requirement of Criterion 1 of Part L1A. The DER must be 10% lower than the TER. This is the Extant Policy. The DER must be 15% lower than the TER. This is Proposed Policy B. The DER must be 20% lower than the TER. This is Proposed Policy A.	**DER:** 10.34 **TER:** 17.47 The DER is 40.82% lower than the TER	DFEE: 47.22 TFEE: 55.46 The DFEE is 14.86 % lower than the TFEE	£12,263,651.00 or £2,066.33 per functional unit (m2)	**Building fabric** Air permeability 5 at 50 Pa (m3/(h.m2) = 5 Thermal Bridging, taken at SAP psi values of 0.05 Fabric U values, as per the notional building Glazing g values, as per the notional building **HVAC** Heating A low temperature hot water system using radiators via a block or district heating system. The primary heat source is a gas fired combined heat and power unit with the following details. Thermal seasonal efficiency 50% Heat fraction 1 (100% of heat supplied) Electric efficiency 30% Air conditioning N/A

Simulation Building		BER kg CO_2/m^2	TER kg CO_2/m^2	Indicative costs of construction	Technical detail
	Summary - pass It is possible to comply with all four benchmarks through the use of district or block heating where the primary source of heating is a gas fired CHP.				<u>Ventilation</u> Ventilation is provided naturally with the exception of kitchens, bathrooms/WCs where mechanical extraction has been assumed at the SAP default rates. **Lighting** 100% efficient. **Lighting controls** Manually controlled. **Domestic Hot Water** Hot water is provided through the heat network and a heat interface unit (HIU). **Design challenges/considerations** N/A

4. COSTS

The costs detailed over the following pages have been taken from the BIMs which are available as cabinet files (CAB files). The headings include an ID, a code which defines the basis of the cost multiplier, a rate (£), quantity, weight, base cost, cost £, and cost £ /. Explanations are provided below:

4.1 ID

The ID is based on the nomenclature of the RICS New Rules of Measurement.

4.2 Code

The code is assigned through the VE and informs the quantity. Code 11, as an example, is the code for multiplying the rate by the quantity which is based on the Gross Internal Floor Area (GIFA), while Code 1 measures the quantity by item. For example, 1 or 2 No. boilers etc.

4.3 Rate

This is the rate (£) to be multiplied by the quantity.

4.4 Quantity

This is the basis of the cost multiplier.

4.5 Weight

This applies a weighted value to the quantity, a weight of 1 = 100% as a multiplier against the quantity. In the costs below a rate of £1,845.00 per m^2[7] has been adopted as the build cost, however this sum includes building services. Using BSRIA Rules of thumb as a guide, we have applied a discount rate to allow us to extract typical building services costs from the inclusive development cost. This is so that we can analyse the impact of different building services (on costs). For example, an adjusted weighting of 0.18 results in a weighting of 0.82 (1 – 0.18 = 0.82). The purpose of the exercise is to provide a consistent 'base build cost' across the simulations with the final project inclusive cost (i.e. with building services) reassessed against the range of costs provided in SPONS 2017[8]. The following weighting rules have been adopted throughout the project:

Property type	HVAC system type	Unadjusted BSRIA weighting	Less allowance for lifts[9] etc.	Adjusted weighting
Commercial (Offices)	Natural ventilation and no air conditioning	0.30	0.05	0.25
Commercial (Offices)	Mechanical ventilation and air conditioning	0.34	0.05	0.29

[7] This is a blended rate to account for the ratio between flats and houses in our scheme
[8] In other words we would expect the project Cost per m2 to be within the range provided by SPONS 2017 after an adjustment for location.
[9] Items included in the BSRIA weighting have been added in our cost modelling as separate line items using the RICS NRM and therefore an allowance needs to be made (discounted) to avoid double counting.

Property type	HVAC system type	Unadjusted BSRIA weighting	Less allowance for lifts[9] etc.	Adjusted weighting
Commercial (Retail)	Mechanical ventilation and air conditioning	0.21	N/A	0.21
Commercial (Care Homes etc.)	Natural ventilation and no air conditioning	0.23	0.05	0.18
Commercial (Care Homes etc.)	Mechanical ventilation and air conditioning	0.33	0.05	0.28
Residential	Natural ventilation and no air conditioning	0.23	0.025	0.205

4.6 Base Cost

The base cost is an unadjusted cost (rate x quantity).

4.7 Cost

This is the adjusted cost. It is the cost multiplied by a location adjustment factor, a quality factor, and a complexity factor. In SPONS 2017 the location adjustment factor for the south east is 0.96, while a quality and complexity factor of unity (1) has been applied in the BIM representing a medium quality, medium complexity development for the type of building modelled.

4.8 Cost £ /

This is the cost per functional unit. In this case the functional unit is taken as m^2.

5. SYSTEM 1, SIMULATION 1

ID	Description	Code	Rate	Quantity	Weight	Base cost	Cost £	Cost £ /
6	**Complete buildings and building units - Houses**							
6.1.1	Complete buildings - Houses	5						
6	Complete buildings and building units (SPONS A&B 2017 - median cost) weighting applied 72.6% (flat...	11	1,845.00	5,935	0.79	8,650,559.00	8,304,536.50	1,399.25
5	Services (BES)	11	0.00	0	1.00	0.00	0.00	0.00
5.1	Sanitary installations (SA) (SPONS M&E 2017 - median cost)	11	100.00	5,935	1.00	593,500.06	569,760.00	96.00
5.3	Disposal installation (DI) (SPONS M&E 2017 - median cost)	11	24.50	5,935	1.00	145,407.50	139,591.20	23.52
5.4	Water installations (WI) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.5	Heat source (HS) (SPONS M&E 2017 - median cost)	11	11.50	5,935	1.00	68,252.50	65,522.40	11.04
5.6	Space heating and air conditioning (SHAC) (SPONS M&E 2017 - median cost) - based on affordable (...	11	80.00	5,935	1.00	474,800.00	455,808.00	76.80
5.7	Ventilation systems (VS) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.8	Electrical installations (EI) (SPONS M&E 2017 - median cost)	11	112.50	5,935	1.00	667,687.50	640,979.94	108.00
5.9	Fuel installations / systems (FI) (SPONS M&E 2017 - median cost)	11	15.50	5,935	1.00	91,992.50	88,312.81	14.88
5.11	Fire and lightning protection (FLP) (SPONS M&E 2017 - median cost)	11	29.00	5,935	1.00	172,115.00	165,230.38	27.84
5.12	Communication, security and cntrol systems (CSC) (SPONS M&E 2017 - median cost)	11	100.50	5,935	1.00	596,467.50	572,608.81	96.48
5.13	Special installations / Systems (SI) (SPONS M&E 2017 - median cost)	11	31.00	5,935	1.00	183,985.00	176,625.59	29.76
							11,800,013.00	**1,988.21**
	CAPITAL COST						**11,800,013.00**	**1,988.21**

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6. SYSTEM 1, SIMULATION 2

ID	Description	Code	Rate	Quantity	Weight	Base cost	Cost £	Cost £ /
6	**Complete buildings and building units - Houses**							
6.1.1	Complete buildings - Houses	5						
6	Complete buildings and building units (SPONS A&B 2017 - median cost) weighting applied 72.6% (flat...	11	1,845.00	5,935	0.79	8,650,559.00	8,304,536.50	1,399.25
5	Services (BES)	11	0.00	0	1.00	0.00	0.00	0.00
5.1	Sanitary installations (SA) (SPONS M&E 2017 - median cost)	11	100.00	5,935	1.00	593,500.06	569,760.00	96.00
5.3	Disposal installation (DI) (SPONS M&E 2017 - median cost)	11	24.50	5,935	1.00	145,407.50	139,591.20	23.52
5.4	Water installations (WI) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.5	Heat source (HS) (SPONS M&E 2017 - median cost)	11	11.50	5,935	1.00	68,252.50	65,522.40	11.04
5.6	Space heating and air conditioning (SHAC) (SPONS M&E 2017 - median cost) - based on affordable (...	11	80.00	5,935	1.00	474,800.00	455,808.00	76.80
5.7	Ventilation systems (VS) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.8	Electrical installations (EI) (SPONS M&E 2017 - median cost)	11	112.50	5,935	1.00	667,687.50	640,979.94	108.00
5.8.5	PV panels (SPONS M&E 2017 - median cost)	11	2,025.00	25	1.00	50,625.00	48,600.00	8.19
5.9	Fuel installations / systems (FI) (SPONS M&E 2017 - median cost)	11	15.50	5,935	1.00	91,992.50	88,312.81	14.88
5.11	Fire and lightning protection (FLP) (SPONS M&E 2017 - median cost)	11	29.00	5,935	1.00	172,115.00	165,230.38	27.84
5.12	Communication, security and cntrol systems (CSC) (SPONS M&E 2017 - median cost)	11	100.50	5,935	1.00	596,467.50	572,608.81	96.48
5.13	Special installations / Systems (SI) (SPONS M&E 2017 - median cost)	11	31.00	5,935	1.00	183,985.00	176,625.59	29.76
2.3.1	Roof structure (additonal reinforcement flat roofs)	11	20.00	882	1.00	17,640.00	16,934.40	2.85
							11,865,547.00	**1,999.25**
	CAPITAL COST						**11,865,547.00**	**1,999.25**

7. SYSTEM 1, SIMULATION 3 AND 4

ID	Description	Code	Rate	Quantity	Weight	Base cost	Cost £	Cost £ /
6	**Complete buildings and building units - Houses**							
6.1.1	Complete buildings - Houses	5						
6	Complete buildings and building units (SPONS A&B 2017 - median cost) weighting applied 72.6% (flat...	11	1,845.00	5,935	0.79	8,650,559.00	8,304,536.50	1,399.25
5	Services (BES)	11	0.00	0	1.00	0.00	0.00	0.00
5.1	Sanitary installations (SA) (SPONS M&E 2017 - median cost)	11	100.00	5,935	1.00	593,500.06	569,760.00	96.00
5.3	Disposal installation (DI) (SPONS M&E 2017 - median cost)	11	24.50	5,935	1.00	145,407.50	139,591.20	23.52
5.4	Water installations (WI) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.5	Heat source (HS) (SPONS M&E 2017 - median cost)	11	11.50	5,935	1.00	68,252.50	65,522.40	11.04
5.6	Space heating and air conditioning (SHAC) (SPONS M&E 2017 - median cost) - based on affordable (...	11	80.00	5,935	1.00	474,800.00	455,808.00	76.80
5.7	Ventilation systems (VS) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.8	Electrical installations (EI) (SPONS M&E 2017 - median cost)	11	112.50	5,935	1.00	667,687.50	640,979.94	108.00
5.8.5	PV panels (SPONS M&E 2017 - median cost)	11	2,025.00	50	1.00	101,250.01	97,200.01	16.38
5.9	Fuel installations / systems (FI) (SPONS M&E 2017 - median cost)	11	15.50	5,935	1.00	91,992.50	88,312.81	14.88
5.11	Fire and lightning protection (FLP) (SPONS M&E 2017 - median cost)	11	29.00	5,935	1.00	172,115.00	165,230.38	27.84
5.12	Communication, security and cntrol systems (CSC) (SPONS M&E 2017 - median cost)	11	100.50	5,935	1.00	596,467.50	572,608.81	96.48
5.13	Special installations / Systems (SI) (SPONS M&E 2017 - median cost)	11	31.00	5,935	1.00	183,985.00	176,625.59	29.76
2.3.1	Roof structure (additonal reinforcement flat roofs)	11	20.00	882	1.00	17,640.00	16,934.40	2.85
							11,914,147.00	**2,007.44**
	CAPITAL COST						**11,914,147.00**	**2,007.44**

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8. SYSTEM 2, SIMULATIONS 1 TO 4

ID	Description	Code	Rate	Quantity	Weight	Base cost	Cost £	Cost £ /
6	**Complete buildings and building units - Residential**							
6.1.1	Complete buildings - Residential	5						
6	Complete buildings and building units (SPONS A&B 2017 - median cost) weighting applied 72.6% (flat...	11	1,845.00	5,935	0.79	8,650,559.00	8,304,536.50	1,399.25
5	Services (BES)	11	0.00	0	1.00	0.00	0.00	0.00
5.1	Sanitary installations (SA) (SPONS M&E 2017 - median cost)	11	100.00	5,935	1.00	593,500.06	569,760.00	96.00
5.3	Disposal installation (DI) (SPONS M&E 2017 - median cost)	11	24.50	5,935	1.00	145,407.50	139,591.20	23.52
5.4	Water installations (WI) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.5	Heat source (HS) Heat pumps = 5935m2 * 70w / 1000 * £500 (per kW)	1	207,725.00	1	1.00	207,725.00	199,416.00	33.60
5.6	Space heating and air conditioning (SHAC) (SPONS M&E 2017 - median cost + 10%) - based on affor...	11	88.00	5,935	1.00	522,280.00	501,388.75	84.48
5.7	Ventilation systems (VS) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.8	Electrical installations (EI) (SPONS M&E 2017 - median cost)	11	112.50	5,935	1.00	667,687.50	640,979.94	108.00
5.9	Fuel installations / systems (FI) (SPONS M&E 2017 - median cost)	11	15.50	5,935	1.00	91,992.50	88,312.81	14.88
5.11	Fire and lightning protection (FLP) (SPONS M&E 2017 - median cost)	11	29.00	5,935	1.00	172,115.00	165,230.38	27.84
5.12	Communication, security and cntrol systems (CSC) (SPONS M&E 2017 - median cost)	11	100.50	5,935	1.00	596,467.50	572,608.81	96.48
5.13	Special installations / Systems (SI) (SPONS M&E 2017 - median cost)	11	31.00	5,935	1.00	183,985.00	176,625.59	29.76
							11,979,488.00	**2,018.45**
	CAPITAL COST						**11,979,488.00**	**2,018.45**

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9. SYSTEM 3, SIMULATIONS 3 TO 4

ID	Description	Code	Rate	Quantity	Weight	Base cost	Cost £	Cost £ /
6	**Complete buildings and building units - Residential**							
6.1.1	Complete buildings - Residential	5						
6	Complete buildings and building units (SPONS A&B 2017 - median cost) weighting applied 72.6% (flat...	11	1,845.00	5,935	0.79	8,650,559.00	8,304,536.50	1,399.25
5	Services (BES)	11	0.00	0	1.00	0.00	0.00	0.00
5.1	Sanitary installations (SA) (SPONS M&E 2017 - median cost)	11	100.00	5,935	1.00	593,500.06	569,760.00	96.00
5.3	Disposal installation (DI) (SPONS M&E 2017 - median cost)	11	24.50	5,935	1.00	145,407.50	139,591.20	23.52
5.4	Water installations (WI) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.5	Heat source (HS) Heat pumps = 5935m2 * 70w / 1000 * £1225 (per kW)	1	508,926.00	1	1.00	508,926.00	488,568.91	82.32
5.6	Space heating and air conditioning (SHAC) (SPONS M&E 2017 - median cost + 10%) - based on affor...	11	88.00	5,935	1.00	522,280.00	501,388.75	84.48
5.7	Ventilation systems (VS) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.8	Electrical installations (EI) (SPONS M&E 2017 - median cost)	11	112.50	5,935	1.00	667,687.50	640,979.94	108.00
5.9	Fuel installations / systems (FI) (SPONS M&E 2017 - median cost)	11	15.50	5,935	1.00	91,992.50	88,312.81	14.88
5.11	Fire and lightning protection (FLP) (SPONS M&E 2017 - median cost)	11	29.00	5,935	1.00	172,115.00	165,230.38	27.84
5.12	Communication, security and cntrol systems (CSC) (SPONS M&E 2017 - median cost)	11	100.50	5,935	1.00	596,467.50	572,608.81	96.48
5.13	Special installations / Systems (SI) (SPONS M&E 2017 - median cost)	11	31.00	5,935	1.00	183,985.00	176,625.59	29.76
							12,268,641.00	**2,067.17**
	CAPITAL COST						**12,268,641.00**	**2,067.17**

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10. SYSTEM 4, SIMULATIONS 1 TO 4

ID	Description	Code	Rate	Quantity	Weight	Base cost	Cost £	Cost £ /
6	**Complete buildings and building units - Residential**							
6.1.1	Complete buildings - Residential	5						
6	Complete buildings and building units (SPONS A&B 2017 - median cost) weighting applied 72.6% (flat...	11	1,845.00	5,935	0.79	8,650,559.00	8,304,536.50	1,399.25
5	Services (BES)	11	0.00	0	1.00	0.00	0.00	0.00
5.1	Sanitary installations (SA) (SPONS M&E 2017 - median cost)	11	100.00	5,935	1.00	593,500.06	569,760.00	96.00
5.3	Disposal installation (DI) (SPONS M&E 2017 - median cost)	11	24.50	5,935	1.00	145,407.50	139,591.20	23.52
5.4	Water installations (WI) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.5	Heat source (HS) - backup boiler (SPONS M&E 2017 - median cost)	11	11.50	5,935	1.00	68,252.50	65,522.40	11.04
5.5	Heat source (HS) CHP = 5935 * 70w / 1000 * £636	1	264,226.00	1	1.00	264,226.00	253,656.95	42.74
5.6	Space heating and air conditioning (SHAC) (SPONS M&E 2017 - median cost + 10%) - based on affor...	11	88.00	5,935	1.00	522,280.00	501,388.75	84.48
5.7	Ventilation systems (VS) (SPONS M&E 2017 - median cost)	11	54.50	5,935	1.00	323,457.50	310,519.19	52.32
5.8	Electrical installations (EI) (SPONS M&E 2017 - median cost)	11	112.50	5,935	1.00	667,687.50	640,979.94	108.00
5.9	Fuel installations / systems (FI) (SPONS M&E 2017 - median cost)	11	15.50	5,935	1.00	91,992.50	88,312.81	14.88
5.11	Fire and lightning protection (FLP) (SPONS M&E 2017 - median cost)	11	29.00	5,935	1.00	172,115.00	165,230.38	27.84
5.12	Communication, security and cntrol systems (CSC) (SPONS M&E 2017 - median cost)	11	100.50	5,935	1.00	596,467.50	572,608.81	96.48
5.13	Special installations / Systems (SI) (SPONS M&E 2017 - median cost)	11	31.00	5,935	1.00	183,985.00	176,625.59	29.76
5.13.1	Specialist piped supply installations (heat network - £1250 per m)	11	1,250.00	137	1.00	171,250.00	164,400.00	27.70
							12,263,651.00	**2,066.33**
	CAPITAL COST						**12,263,651.00**	**2,066.33**

CONTACT US:

w: evoraglobal.com/edge

e: info@evoraglobal.com

t: +44 (0)20 3326 7333

EVORA EDGE Head Office

The Hop Exchange

Suite 73-74

24 Southwark Street

London

SE1 1TY