Ministry of Housing,
Communities &
Local Government

Energy Performance of Buildings Directive

Second Cost Optimal Assessment for the United Kingdom (excluding Gibraltar)

January 2019
Ministry of Housing, Communities and Local Government

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Executive Summary

The Energy Performance of Buildings Directive[1] requires that minimum energy requirements in national building regulations are set "with a view to achieving cost-optimal levels". Cost optimal being the best level of energy performance that can be achieved whilst remaining cost effective over the lifetime of a new building or improvement measure to an existing building.

This Report provides the second cost optimal assessment of energy performance requirements for the United Kingdom (UK) as required by this Directive.

The structure of the Report follows the Cost Optimal Methodology[2] published by the European Commission to compare current requirements in building regulations against cost optimal levels for houses, apartments and typical non-residential buildings including offices.

An extensive range of measures including insulation, windows, boilers and renewable systems providing varying levels of energy performance improvement have been selected and applied to these reference buildings. The resulting impact of these measures upon new and existing building energy performance and the associated lifecycle costs and benefits (including energy and carbon savings) are calculated using the European methodology to establish cost optimal levels.

The current energy requirements in Building Regulations averaged across the UK are then compared against these cost optimal levels. The headline results include:

Reference building/measure *[units of energy performance]*	***Cost Optimal Level***	***Current Requirements***	***Gap (%)***
New Houses [kWh/m^2/yr]	96	92	+ 4%
New Apartment Building [kWh/m^2/yr]	77	90	- 14%
New Non-Residential Buildings [kWh/m^2/yr]	201	175	+ 13%
Houses: Replacement Windows [U-value: W/m^{2}K]	1.6	1.6	0
Houses: Replacement Boilers Efficiency [%]	88	88	0
Non-Residential Buildings: Replacement Lighting [lm/W]	59	60	+ 2%
Non-Residential Buildings: Replacement Ventilation [W/l/s]	1.9	2.2	- 16%

A positive percentage denotes that current requirements are better than the cost optimal level whilst a negative denotes that they are poorer.

[1] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010
[2] Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012

Where current energy requirements are significantly poorer than the theoretical cost optimal level, and this gap cannot be justified on the grounds of technical, functional and economic feasibility, the report sets out plans to review national requirements and make improvements to address this. The next steps for reviewing these energy performance requirements are set out in the Government's Clean Growth Strategy[3] and in equivalent publications by the devolved UK administrations (see Section 1 for details).

Looking further ahead, the Government has also announced an ambition to halve the energy use of new buildings by 2030 as part of a 'Clean Growth Mission' under the UK's Industrial Strategy[4]. This will consider what role a trajectory of improving energy performance requirements has to support a wider approach alongside innovation related to buildings and the use of buildings including more efficient and smarter appliances, smart controls and modern methods of construction.

[3] The Clean Growth Strategy: Leading the way to a low carbon future, October 2017
[4] UK Industrial Strategy, Clean Growth Mission, May 2018

1. Introduction

Article 5 of the European Directive 2010/31/EU on the energy performance of buildings (EPBD) requires Member States to ensure that the minimum energy performance requirements in their national building regulations are set "with a view to achieving cost-optimal levels". Cost-optimal is defined in the EPBD as the energy performance level which leads to the lowest cost during the estimated economic lifecycle of a building or an improvement measure.

In March 2012, the European Commission established a comparative methodology framework for calculating these cost-optimal levels for new buildings and for energy efficiency improvements to existing buildings. Member States are required to use this framework to calculate the cost-optimal levels of minimum energy performance requirements using reference buildings to represent the typical building stock in that country.

Member States are then required to compare the results of these calculations with the minimum energy performance requirements currently in force. If the results of this comparison show that current energy requirements are significantly less energy efficient than cost-optimal levels, then Member States are required to justify this and where this cannot be justified set out their plans for reducing the gap. The results of these calculations, input data and assumptions used, justifications and plans must be submitted in a report to the European Commission every five years.

The first of these cost-optimal reports for the United Kingdom (UK) was submitted to the European Commission in May 2013[5]. Gibraltar submitted a separate standalone report.

This second report has been commissioned by the Ministry of Housing, Communities and Local Government (MHCLG). It presents the input data, assumptions, cost optimal calculations and comparison with current energy requirements for England, Scotland, Wales and Northern Ireland. Gibraltar will again be submitting a separate standalone report.

The report is structured in accordance with European Commission Delegated Regulation (EU) No 244/2012 plus associated Guidelines and templates (hereinafter referred to as the Cost Optimal Methodology). Any adaptations to the template are for ease of presentation of the data.

There are some important differences between the Cost Optimal Methodology used for comparative purposes across EU Member States and the Treasury Green Book[6] methodology used for UK Government policy assessments. Caution should therefore be exercised in making any direct comparisons between the results of this report and UK Impact Assessments.

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[5] 1st UK EPBD Cost Optimal Report to European Commission May 2013

[6] The Green Book: appraisal and evaluation in central government

For example, the carbon price assumptions in the Cost Optimal Methodology and those provided in Supplementary Guidance to the UK Treasury Green Book[7] are very different. The UK analysis attempts to value the "lock-in" effects of well insulated building fabric by valuing impacts over a longer time period than set out in the Cost Optimal Methodology. This involves valuing energy and carbon savings further into the future, typically 60 years for new homes, when estimates for these prices in UK guidance are higher.

This cost optimal assessment enables comparison to be made between EU Member States and this report should also be viewed in that context, rather than just as a standalone document. Following receipt of all cost optimal reports, the European Commission will publish an overarching report on the progress of all Member States in reaching cost optimal levels in their energy performance requirements.

Also, our analysis has highlighted some impracticality when applying the Cost Optimal Methodology in a real world setting. For example, the current energy requirements for roof insulation in houses and apartment buildings in the UK are less efficient than the theoretical cost optimal level. However, the EPBD says that these requirements should also be technically and functionally feasible and we will need to be mindful of the potential impacts of increasing loft insulation thicknesses upon roof detailing and provision of adequate ventilation to the roof space.

Similarly cost optimal levels for insulating walls in some buildings may not be technically and functionally feasible where fire and safety requirements have to be observed. Other examples that could justify a lesser requirement are where there may be planning constraints upon external appearance, where to avoid moisture problems it is not appropriate to insulate cavity walls exposed to wind driven rain or where the thickness of internal wall insulation has a disproportionate effect upon room sizes.

Where the gap between current requirements and cost optimal levels is significant and cannot be justified we will consider how this gap can be addressed as part of the next planned review of energy requirements (see below).

Cost optimal levels are compared with current energy requirements in Building Regulations at the time this analysis was carried out i.e. a snaphot in time.

To obtain a clear cost optimal curve and identify the optimum point a range of performance values are selected for each measure and package of measures considered (e.g. insulation U-values, technical building system efficiencies and inclusion of renewables) to give a spread of primary energies and lifecycle costs. This includes solutions that perform more poorly than the primary energy target reflecting current regulations and solutions that perform better.

[7] Supplementary Guidance to the UK Treasury Green Book

This range should also be useful in helping to inform future Nearly Zero Energy Building (NZEB) requirements in the EPBD (from January 2019 in respect of new public buildings and end of 2020 in respect of all new buildings); with a minimum aim of setting these at the cost optimal level.

Where current energy requirements are significantly less efficient than the theoretical cost optimal level we will consider making technically and functionally feasible improvements to address this gap, as part of the next planned review of energy requirements.

In England, the next steps for reviewing these energy efficiency requirements are set out in the Governments Clean Growth Strategy. This sets out that there will be a formal consultation on strengthening energy requirements by the end of 2018 where the evidence shows that this is cost effective and affordable and it is safe and practical to do so. The Clean Growth Strategy is clear that this consultation will be subject to the conclusions of the independent review of building regulations and fire safety[8].

For Scotland, a commitment to review energy standards in building regulations is made in Chapter 2 (Buildings) of The Climate Change Plan 2018-32 (March 2018)[9]. This review has now commenced and will investigate the potential to further reduce energy use in both new buildings and where work is undertaken in existing buildings.

In July 2014, the Welsh Government introduced changes to the energy efficiency requirments of the Building Regulation in Wales. A further review of the energy efficiency requirements has started and, will aim as a minimum, to deliver the Energy Performance in Buildings Directive 2010 requirement to set NZEB standards at a cost optimal level or better.

Northern Ireland Building Regulations generally follow those of England and amended following a revision to England's regulations. Officials are currently preparing draft amendment proposals to both legislation and supporting guidance to accord with the current position in England. This work may be supplemented with any additional amendments necessary to follow developments in England.

The Government has also announced an ambition to halve the energy use of new buildings by 2030 as part of a 'Clean Growth Mission' under the UK's Industrial Strategy[10]. This will consider what role a trajectory of improving energy performance requirements has to support a wider approach alongside innovation related to buildings and the use of buildings including more efficient and smarter appliances, smart controls and modern methods of construction.

[8] Independent Review of Building Regulations and Fire Safety
[9] www.gov.scot/Publications/2018/02/8867
[10] UK Industrial Strategy, Clean Growth Mission, May 2018

Part A: Domestic Buildings

2. Reference Buildings

2.1 New Buildings

According to the Cost Optimal Methodology, Member States should establish at least one reference building for the following domestic building categories:

- Single family buildings
- Apartment blocks and multifamily buildings

For this assessment we have used a typical single family dwelling and a typical apartment building. In selecting the building types, we initially reviewed the new build mix for England. To determine the split between housing and flats, the mix of different dwelling types was estimated drawing on analysis from MHCLG housing statistics[11]. The data was averaged over a two year period indicating a 68:32 split between houses and flats. The proportion of houses that are detached, semi-detached or terraced was estimated using the assumptions used in the Impact Assessment for Part L 2013[12]. This is considered a reasonable basis for analysis because, while the ratio of flats to houses can vary in response to market conditions, the split of houses between the three main variants is more consistent.

The build mix is given in Table 2.1. Based on this, a semi-detached house has been used to represent single family buildings, and a four-storey apartment block has been used to represent apartment blocks and multifamily buildings.

Table 2.1: The projected build mix

Building type	*% in build mix*
Detached house	20%
Semi-detached house	29%
Terraced house	14%
Flats (gas)	29%
Flats (electric)	9%

The building designs used for this assessment are as proposed by the house-building industry as being representative of the new build housing stock. These dwelling designs have been modified for this work to align with the Government's space standards and some additional industry discussions.

[11] MHCLG Statistics. Permanent dwellings completed, by house and flat, number of bedrooms and tenure, England (Live Table 254)
[12] Changes to Part L of the Building Regulations, Impact Assessment, August 2013.

The two building designs selected are both assumed to be of masonry cavity wall construction as being representative of the most common construction type for new dwellings.

- Single Family Buildings: 84.4m^2 Semi-detached House (2 storey)
- Apartment blocks and multifamily buildings: Building with 1,922 m^2 of apartment floor area, made up of 16 x 70.1m^2 larger apartments and 16 x 50.0m^2 smaller apartments in a 4 storey building (32 flats in total, 8 per floor)

Table 2.2 provides a more detailed summary of the reference buildings using the template provided with the Cost Optimal Methodology. It includes the primary energy associated with building specifications that comply with current national regulations based on Part L 2013 of the Building Regulations (England)[13], Technical Handbook Section 6 of the Scottish Building Regulations (2015)[14], Part L 2014 of the Building Regulations (Wales)[15] and Part F 2012 of the Building Regulations (Northern Ireland)[16]. It is noted that for all four countries the national standard is performance based, against a carbon dioxide (CO_2) metric. Different compliant solutions may have different primary energies. A typical compliant solution has been selected in determining the primary energy associated with the national regulations.

Table 2.2: Reference Buildings for New Domestic Buildings

Building Category	***Building Geometry***		***Shares of window area on the building envelope and windows with no solar access***	***Floor area m^2 as used in building code***	***Typical primary energy performance according to current regulations (kWh/m^2/yr)***			***Component level requirements***
	Area of N/E/S/W facade (m²)	Volume (m³)	Ratio of window area over facade area separately for N/E/S/W facades		England and Wales	Scotland	Northern Ireland	
Semi-detached house	E: 26.0 S: 41.8 W: 26.0	215.1	E: 0.29 S: 0.04 W: 0.20	84.4	93	74	101	In general, there are recommended minimum component performance levels but currently these are not mandated (with the exception of Wales that had mandated minimum component level requirements). In this work we have always ensured that all component measures are at least as good as the recommended mandated levels.
Apartment block	N:18.7 E: 22.6 (per large apartment); E: 18 (per small apartment)	168.2 (per large apartment); 120 (per small apartment)	N:0.42 E: 0.26 (large apartment); E: 0.54 (small apartment)	70.1 (per large apartment); 50 (per small apartment)	92	71	92	

[13] Conservation of fuel and power: Approved Document L 2013 Edition
[14] Scottish Building Regulations, Technical Handbooks, Section 6 (energy), 2015 Edition
[15] Conservation of fuel and power: Approved Document L 2014 Edition - Wales
[16] Conservation of fuel and power: Technical Booklet F 2012 Edition – Northern Ireland

Table 2.3 (a-f) provides a summary of the energy performance data used in the modelling for both of the reference buildings. It includes example compliant specifications to meet current national Regulations for all building types. As the national regulations are performance-based, a building may comply by adopting alternative measures.

Table 2.3a: Energy Performance Relevant Data – New Semi-Detached House, meeting current regulations in England and Wales

			Quantity	***Unit***
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height		8.2 x 5.1 x 5.1	m
Fabric	Fabric u-values	Wall	0.18	W/m²K
		Roof	0.11	W/m²K
		Floor	0.15	W/m²K
		Window	1.2	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.05	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	5.1	m³/m².hr
		Heat recovery efficiency	-	%
	Heating system	Fuel	Gas	-
		Generation	89.5	%
		Control	Time+ temperature zone control, boiler interlock	-
	DHW system	Generation	89.5	%
		Control	From main system	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		43	kWh/m²/yr
	Cooling energy		-	kWh/m²/yr
	DHW energy		29	kWh/m²/yr
	Lighting energy		4	kWh/m²/yr
	Auxiliary energy		1	kWh/m²/yr
Energy Generation	Energy generated		-	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	72	kWh/m²/yr
		Electricity	5	kWh/m²/yr
	Primary energy		93	kWh/m²/yr

Table 2.3b: Energy Performance Relevant Data – New Apartment Building, meeting current regulations in England and Wales

			Quantity	*Unit*
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height (per large apartment) Length x Width x Height (per small apartment)		9.4 x 7.8 x 2.4 7.1 x 7.5 x 2.4	m
Fabric	Fabric u-values	Wall	0.18	W/m²K
		Roof	0.11	W/m²K
		Floor	0.15	W/m²K
		Window	1.2	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.05 – 0.09	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	5	m³/m².hr
		Heat recovery efficiency	-	%
	Heating system	Fuel	Gas	-
		Generation	89.5	%
		Control	Programmer, room stat, TRVs, boiler interlock	-
	DHW system	Generation	89.5	%
		Control	From main system	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		35	kWh/m²/yr
	Cooling energy		-	kWh/m²/yr
	DHW energy		35	kWh/m²/yr
	Lighting energy		5	kWh/m²/yr
	Auxiliary energy		1	kWh/m²/yr
Energy Generation	Energy generated		-	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	70	kWh/m²/yr
		Electricity	6	kWh/m²/yr
	Primary energy		92	kWh/m²/yr

Table 2.3c: Energy Performance Relevant Data – New Semi-Detached House, meeting current regulations in Scotland

			Quantity	*Unit*
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height		8.2 x 5.1 x 5.1	m
Fabric	Fabric u-values	Wall	0.17	W/m²K
		Roof	0.11	W/m²K
		Floor	0.15	W/m²K
		Window	1.4	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.08	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	7	m³/m².hr
		Heat recovery efficiency	-	%
	Heating system	Fuel	Gas	-
		Generation	89	%
		Control	Time+ temperature zone control, weather compensation, boiler interlock, delayed start	-
	DHW system	Generation	89	%
		Waste water heat recovery efficiency	45 (2 systems)	%
		Control	Separately timed, thermostat	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		45	kWh/m²/yr
	Cooling energy		-	kWh/m²/yr
	DHW energy		26	kWh/m²/yr
	Lighting energy		4	kWh/m²/yr
	Auxiliary energy		1	kWh/m²/yr
Energy Generation	Energy generated (Solar PV)		8	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	71	kWh/m²/yr
		Electricity	-3	kWh/m²/yr
	Primary energy		74	kWh/m²/yr

Table 2.3d: Energy Performance Relevant Data – New Apartment Building, meeting current regulations in Scotland

			Quantity	*Unit*
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height (per large apartment) Length x Width x Height (per small apartment)		9.4 x 7.8 x 2.4 7.1 x 7.5 x 2.4	m
Fabric	Fabric u-values	Wall	0.17	W/m²K
		Roof	0.11	W/m²K
		Floor	0.15	W/m²K
		Window	1.4	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.08	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	5	m³/m².hr
		Heat recovery efficiency	-	%
	Heating system	Fuel	Gas	-
		Generation	89	%
		Control	Time+ temperature zone control, weather compensation, boiler interlock, delayed start	-
	DHW system	Generation	89	%
		Waste water heat recovery efficiency	45 (1 system)	%
		Control	Separately timed, thermostat	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		33	kWh/m²/yr
	Cooling energy			kWh/m²/yr
	DHW energy		35	kWh/m²/yr
	Lighting energy		5	kWh/m²/yr
	Auxiliary energy		1	kWh/m²/yr
Energy Generation	Energy generated (Solar PV)		9	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	69	kWh/m²/yr
		Electricity	-3	kWh/m²/yr
	Primary energy		71	kWh/m²/yr

Table 2.3e: Energy Performance Relevant Data – New Semi-Detached House, meeting current regulations in Northern Ireland

			Quantity	*Unit*
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height		8.2 x 5.1 x 5.1	m
Fabric	Fabric u-values	Wall	0.2	W/m²K
		Roof	0.15	W/m²K
		Floor	0.15	W/m²K
		Window	1.6	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.05	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	5	m³/m².hr
		Heat recovery efficiency	-	%
	Heating system	Fuel	Gas	-
		Generation	89.5	%
		Control	Time+ temperature zone control, boiler interlock	-
	DHW system	Generation	89.5	%
		Control	Separately timed, thermostat	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		49	kWh/m²/yr
	Cooling energy			kWh/m²/yr
	DHW energy		30	kWh/m²/yr
	Lighting energy		4	kWh/m²/yr
	Auxiliary energy		1	kWh/m²/yr
Energy Generation	Energy generated			kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	79	kWh/m²/yr
		Electricity	5	kWh/m²/yr
	Primary energy		101	kWh/m²/yr

Table 2.3f: Energy Performance Relevant Data – New Apartment Building, meeting current regulations in Northern Ireland

			Quantity	*Unit*
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height (per large apartment) Length x Width x Height (per small apartment)		9.4 x 7.8 x 2.4 7.1 x 7.5 x 2.4	m
Fabric	Fabric u-values	Wall	0.15	W/m²K
		Roof	0.11	W/m²K
		Floor	0.13	W/m²K
		Window	1.2	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.05 – 0.09	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	4.2	m³/m².hr
		Heat recovery efficiency	-	%
	Heating system	Fuel	Gas	-
		Generation	89.5	%
		Control	Programmer, room stat, TRVs, boiler interlock	-
	DHW system	Generation	89.5	%
		Control	From main system	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		33	kWh/m²/yr
	Cooling energy			kWh/m²/yr
	DHW energy		37	kWh/m²/yr
	Lighting energy		5	kWh/m²/yr
	Auxiliary energy		1	kWh/m²/yr
Energy Generation	Energy generated			kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	70	kWh/m²/yr
		Electricity	6	kWh/m²/yr
	Primary energy		92	kWh/m²/yr

2.2 Existing Buildings

According to the Cost Optimal Methodology, Member States should establish at least two reference buildings for each building category for existing buildings subject to major renovation - taking into account the characteristics of the national building stock. Hence, two variations have been selected for each of the two reference buildings considered for new domestic buildings in Section 2.1.

For existing domestic buildings, each of the two reference buildings has been modelled with two different wall constructions, giving a total of four reference buildings for existing domestic buildings. These two wall constructions are a pre-1978 uninsulated cavity wall and uninsulated solid wall. This represents the two most common construction types within the UK which would be expected to have significantly different baseline energy performances, significant potential for energy efficiency upgrades and different options available for wall retrofit.

The same two building models have been used as for new domestic buildings i.e. same size and geometry; except that the apartment building is assumed to be only 3 storeys and to be made up of 12 large apartments in total, 4 per floor (the individual flats have the same dimensions as the new building large apartments). A larger 4 storey apartment block was included for new domestic buildings as feedback was that it was more representative of currently constructed buildings.

The principal reason for this is that it provides a useful comparison with the new domestic building results. Furthermore, it would be expected that the new building floor areas selected are not significantly different to existing building floor areas and that the floor area is much less significant in determining the cost optimum level than the initial energy efficiencies assumed in the base case (i.e. current) existing building models.

Baseline energy performance for the existing buildings has been modelled based upon baseline fabric performance values informed by the default values for different building construction types and ages used in Reduced Data SAP (RDSAP)[17], which is the part of the UK's National Calculation Methodology used for existing dwellings. Additional assumptions are informed by the Cambridge Housing Model[18] which uses SAP calculations to estimate energy use for existing homes and upgrade scenarios. The Housing Model uses a wide variety of data sources including the English Housing Survey[19].

The baseline wall U-values have been adjusted based on recent research[20] suggesting that the thermal performance of both older cavity wall dwellings and solid wall dwellings when measured is better than had previously been assumed.

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[17] The Government's Standard Assessment Procedure for Energy Rating of Dwellings, RDSAP (Appendix S) 2012 edition
[18] Cambridge Housing Model, Cambridge Architectural Research Ltd
[19] English Housing Survey, Ministry of Housing, Communities and Local Government
[20] Solid wall heat losses and the potential for energy saving, BEIS, November 2017

Table 2.4 provides a summary of the reference domestic buildings using the template provided in the Cost Optimal Methodology. Information has been omitted on building geometry, window area and floor area which are already provided in Table 2.2. Information has also been omitted on building technologies and base case performance specifications as these are provided in more detail in Table 2.5 (a-d).

Table 2.4 includes the primary energy associated with the base case reference buildings, and with building specifications that comply with current national regulations which apply to existing buildings when the relevant improvement measures are made based on Part L 2013 of the Building Regulations (England), Technical Handbook Section 6 of the Scottish Building Regulations (2015), Part L 2014 of the Building Regulations (Wales) and Part F 2012 of the Building Regulations (Northern Ireland). England, Northern Ireland, Scotland and Wales usually have the same requirements for the measures considered (except for wall and roof insulation) and thus have largely been considered together in this evaluation.

Table 2.4: Reference Buildings for Existing Buildings

Building Category	***Construction Type***	***Primary energy for base case (no improvements)***	***Primary energy performance kWh/m^2/yr***					
			Wall improved to current standards		***Windows improved to current standards***	***Roof improved to current standards***		***Heating system improved to current standards***
			Eng, NI, Wales (u=0.55 cavity, 0.3 solid)	Scotland (u=0.22)	UK (u=1.6)	Eng, NI, Wales (u=0.16)*	Scotland (u=0.15)*	UK (gas boiler 88% eff)
Semi-detached house	Cavity	358	300	277	352	345	345	350
	Solid	353	263	257	347	340	340	346
Apartment building	Cavity	217	193	184	203	206	206	207
	Solid	209	172	170	196	198	198	199

* Assumes insulation at joists (ceiling level). Slightly more relaxed standards apply if insulation is at rafter level or for flat roofs.

Table 2.5 (a-d) provides a summary of the energy performance data based on the base case reference buildings without improvements made. Again, information has been omitted on the buildings themselves which was provided in Table 2.2.

Table 2.5a: Energy Performance Relevant Data – Existing Semi-Detached House, Cavity Wall, Base Case

			Quantity	***Unit***
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height		8.2 x 5.1 x 5.1	m
Fabric	Fabric u-values	Wall (external)	1.5	W/m²K
		Wall (party – cavity, unfilled, unsealed)	0.5	W/m²K
		Roof	0.68	W/m²K
		Floor	0.67	W/m²K
		Window	3.1	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.15	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	20	m³/m².hr
		Ventilation type	Natural	-
	Heating system	Fuel	Gas	-
		Generation	83.5	%
		Secondary heating	10	%
		Control	Programmer, room stat, TRVs, boiler interlock	-
	DHW system	Generation	83.5	%
		Control	-	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		167	kWh/m²/yr
	Secondary heating energy		79	kWh/m²/yr
	DHW energy		52	kWh/m²/yr
	Lighting energy		7	kWh/m²/yr
	Auxiliary energy		2	kWh/m²/yr
Energy Generation	Energy generated		-	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	298	kWh/m²/yr
		Electricity	9	kWh/m²/yr
	Primary energy		358	kWh/m²/yr

Table 2.5 (a-d) provides a summary of the energy performance data based on the base case reference buildings without improvements made. Again, information has been omitted on the buildings themselves which was provided in Table 2.2.

Table 2.5b: Energy Performance Relevant Data – Existing Apartment Building, Cavity Wall, Base Case

			Quantity	***Unit***
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height (per apartment)		9.4 x 7.8 x 2.4	m
Fabric	Fabric u-values	Wall (external)	1.5	W/m²K
		Wall (party – cavity, unfilled, unsealed)	0.5	W/m²K
		Roof	0.68	W/m²K
		Floor	0.40	W/m²K
		Window	3.1	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.15	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	20	m³/m².hr
		Ventilation type	Natural	-
	Heating system	Fuel	Gas	-
		Generation	83.5	%
		Secondary heating	0	%
		Control	Programmer, room stat, TRVs, boiler interlock	-
	DHW system	Generation	83.5	%
		Control	-	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		137	kWh/m²/yr
	Secondary heating energy		-	kWh/m²/yr
	Cooling energy		-	kWh/m²/yr
	DHW energy		36	kWh/m²/yr
	Lighting energy		7	kWh/m²/yr
	Auxiliary energy		2	kWh/m²/yr
Energy Generation	Energy generated		-	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	173	kWh/m²/yr
		Electricity	9	kWh/m²/yr
	Primary energy		217	kWh/m²/yr

Table 2.5c: Energy Performance Relevant Data – Existing Semi-Detached House, Solid Wall, Base Case

			Quantity	***Unit***
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height		8.2 x 5.1 x 5.1	m
Fabric	Fabric u-values	Wall (external)	1.7	W/m²K
		Wall (party – solid)	0	W/m²K
		Roof	0.68	W/m²K
		Floor	0.67	W/m²K
		Window	3.1	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.15	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	20	m³/m².hr
		Ventilation type	Natural	-
	Heating system	Fuel	Gas	-
		Generation	83.5	%
		Secondary heating	10	%
		Control	Programmer, room stat, TRVs, boiler interlock	-
	DHW system	Generation	83.5	%
		Control	-	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		165	kWh/m²/yr
	Secondary heating energy		77	kWh/m²/yr
	Cooling energy		-	kWh/m²/yr
	DHW energy		52	kWh/m²/yr
	Lighting energy		7	kWh/m²/yr
	Auxiliary energy		2	kWh/m²/yr
Energy Generation	Energy generated		-	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	294	kWh/m²/yr
		Electricity	9	kWh/m²/yr
	Primary energy		353	kWh/m²/yr

Table 2.5d: Energy Performance Relevant Data – Existing Apartment Building, Solid Wall, Base Case

			Quantity	*Unit*
Calculation	Method and tool(s)	SAP 2012		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.127	kWh/kWh
		Grid Supplied Electricity	2.364	
		On-site Generated Electricity	-2.364	
Climate	Location	East Pennines		
	Climate data	SAP 2012 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height (per apartment)		9.4 x 7.8 x 2.4	m
Fabric	Fabric u-values	Wall (external)	1.7	W/m²K
		Wall (party – solid)	0	W/m²K
		Roof	0.68	W/m²K
		Floor	0.40	W/m²K
		Window	3.1	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.15	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	20	m³/m².hr
		Heat recovery efficiency	Natural	%
	Heating system	Fuel	Gas	-
		Generation	83.5	%
		Secondary heating	0	%
		Control	Programmer, room stat, TRVs, boiler interlock	-
	DHW system	Generation	83.5	%
		Control	-	-
Setpoints and Schedules	Temperature setpoint	Temperature	21 (living area) 21 – HLP + HLP² / 12 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by SAP 2012. The heating schedule is 9 hours / day on weekdays, 16 hours / day at weekends October - May.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		130	kWh/m²/yr
	Secondary heating energy		-	kWh/m²/yr
	Cooling energy		-	kWh/m²/yr
	DHW energy		36	kWh/m²/yr
	Lighting energy		7	kWh/m²/yr
	Auxiliary energy		2	kWh/m²/yr
Energy Generation	Energy generated		-	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	166	kWh/m²/yr
		Electricity	9	kWh/m²/yr
	Primary energy		209	kWh/m²/yr

3. Measures and Packages

3.1 New Buildings

A list of potential measures has been compiled using the Cost Optimal Methodology guidelines document and design experience. Since it is impractical to evaluate every permutation of the selected measures, we have grouped the measures into packages. These packages are listed in Table 3.1.

The packages represent six different components of a building design (fabric, openings, thermal bridging, ventilation, heating and photovoltaic panels (PV)), so that selecting one package from each component forms a complete building design.

In total, 576 alternatives have been considered for each reference building model. The values selected for each of the measures (e.g. fabric u-values, building services options) within the packages have been chosen to give a large spread of primary energies and lifecycle costs. This helps to obtain a clear cost optimal front and identification of the optimum point. It includes solutions that together might comprise a building model that performs more poorly than the primary energy target set by the current regulations. It should be noted that the highest PV option (40% of foundation area) pushes the limits of what may be reasonable for domestic buildings to achieve when site-specific factors are taken into account.

It should be noted that some possible measures have been omitted from these packages. There are a number of reasons for this:

- Site specific measures: Various measures are particularly dependent on site constraints. For example, building orientation and feasibility of wind turbines are all likely to depend on the site and the surrounding context. The assumption taken is that the cost optimal point should be based on measures that any designer can typically adopt, if not the cost optimal point may be unrealistic to achieve in many real cases.

- Design measures: Some measures impact on design constraints that are not incorporated in the building primary energy requirement. In particular, there is concern that by modifying the percentage of glazing or introducing shading to optimise on primary energy, it may result in inadequate daylight levels. Furthermore, this is building-dependent – a particular percentage of glazing may provide appropriate day lighting in one building design but not another. Therefore these two measures have not been considered in the list of packages.

- Default measures: There are other measures that are likely to be included in new buildings by default, for example, 100% low energy lighting. These have not been included in the packages - they will simply be added into the base building models assumed in all cases. Since these measures do not vary, there is no need to identify separately costs for them.

Table 3.1: Measures to be included in analysis

Fabric (4 options)	***1***	***2***	***3***	***4***
Wall U-value (W/m²K)	0.21	0.18	0.15	0.12
Roof U-value (W/m²K)	0.13	0.11	0.11	0.11
Floor U-value (W/m²K)	0.15	0.15	0.13	0.10

Openings (2 options)	***1***	***2***
Window U-value (W/m²K)	1.2	0.8
Door U-value (W/m²K)	1.2	1.0

Thermal bridging (3 options)	***1***	***2***	***3***
y-value	Default (0.15)	Improved (varies by housetype)	Advanced (varies by housetype)

Ventilation (2 options)	***1***	***2***
Ventilation type	Natural ventilation (intermittent extract fans)	MVHR

Heating (4 options)				
Space Heating Source	Condensing gas boiler (89.5% efficiency)	Condensing gas boiler (89.5% efficiency)	Condensing gas boiler (89.5% efficiency)	Air Source Heat Pump (space heating COP 2.95)
Communal option for flats? (all heating systems are individual for houses)	No	No	Yes	No
Controls	Time and temperature zone control (houses) / Programmer, room thermostat and TRVs (flats)	As for gas boiler	As for gas boiler	Time and temperature zone control (houses) / Programmer and room thermostat (flats)
Emitters	Radiators	Radiators	Radiators	Large (low temperature) radiators
Domestic Hot Water Source	As for space heating	As for space heating + waste water heat recovery	As for space heating + solar hot water (supplying c.50% of DHW heat)	As for space heating + electric immersion

PV (3 options)			
PV Installation (percentage of foundation area)	0%	20%	40%

3.2 Existing Buildings – Elemental Analysis

A list of potential measures has been compiled using the Cost Optimal Methodology Guidelines document and design experience. For the elemental analysis, each measure has been assessed separately. The measures which have been assessed are listed in Table 3.2.

The measures selected are those most commonly applied for renovation improvements to the building fabric and heating system. The values selected for each of the measures (e.g. the fabric u-values and heating options) have been chosen to give a spread of primary energies and lifecycle costs. It includes some fabric options which might perform more poorly than the limiting standards set for individual elements by the current regulations.

It does not include thinner forms of internal wall insulation, which may not meet theoretical cost-optimal levels, but could be the only option where external insulation is not permitted and a greater thickness of internal insulation has a disproportionate effect upon room sizes. The Government is currently running a research project looking at the effectiveness of these products, which will report later in 2018.

Table 3.2: Measures included in the analysis – Existing Buildings

Fabric - Cavity Walls	***Cavity Wall U-value (W/m²K)***	***Insulation***
Base case (for information)	1.5	None – 50mm uninsulated cavity
Option 1	0.55	Fully filled (50mm) cavity
Option 2	0.24	Fully filled cavity and 50mm internal insulation
Option 3	0.18	Fully filled cavity and 80mm internal insulation
Option 4	0.22	Fully filled cavity and 100mm external insulation
Option 5	0.14	Fully filled cavity and 200mm external insulation
Option 6	0.32	50mm internal insulation (unfilled cavity)
Option 7	0.22	80mm internal insulation (unfilled cavity)

Fabric – Solid Walls	***Solid Wall U-value (W/m²K)***	***Insulation***
Base case (for information)	1.7	None – uninsulated solid wall, 225mm (9inch) wall
Option 1	0.30	50mm internal insulation
Option 2	0.21	80mm internal insulation
Option 3	0.30	100mm external insulation
Option 4	0.17	200mm external insulation

Fabric – Roof	***Roof U-value (W/m²K)***	***Insulation***
Base case (for information)	0.68	50mm mineral wool insulation
Option 1	0.29	100mm mineral wool insulation quilt between joists PLUS 50mm above joists
Option 2	0.13	100mm mineral wool insulation quilt between joists PLUS 200mm above joists
Option 3	0.11	100mm mineral wool insulation quilt between joists PLUS 250mm above joists

Fabric – Windows	***Window U-value (W/m²K)***	***Type***
Base case (for information)	3.1	Double glazed
Option 1	1.6	Double glazed U-PVC windows
Option 2	1.4	Double glazed U-PVC windows
Option 3	1.2	Double glazed U-PVC windows
Option 4	0.9	Triple glazed U-PVC windows

Heating	***Base Case (for information)***	***Option 1***	***Option 2***	***Option 3***
Space Heating Source	Condensing Gas boiler (83.5% efficiency)	Condensing Gas boiler (88% efficiency)	Condensing Gas boiler (88% efficiency)	Air Source Heat Pump (space heating COP 2.95)
Communal option for flats? (all heating systems are individual for houses)	No	No	Yes	No
Controls	Programmer, room thermostat and TRVs, modulating boiler with interlock	Programmer, room thermostat and TRVs, modulating boiler with interlock	As for gas boiler	Programmer and room thermostat
Emitters	Radiators	Radiators	Radiators	Large (low temperature) radiators
Domestic Hot Water Source	As for space heating	As for space heating	As for space heating + solar hot water (supplying c.50% of DHW heat)	As for space heating + electric immersion

3.3 Existing Buildings – Analysis of Packages

In addition to the elemental analysis, existing building measures were assessed on a package basis (i.e. with more than one measure implemented at a time).

The measures which have been assessed for domestic buildings are listed in Table 3.3. The measures selected are those most commonly applied for renovation improvements to the building fabric and heating system. The values selected for each of the measures (e.g. the fabric u-values and heating options) have been chosen to give a spread of primary energies and lifecycle costs.

Fabric, heating and PV packages have been tested in combination. Of note, the “Cost Optimal Fabric Package” is based on the cost-optimal elemental solutions from the previous UK reports. In total, 81 options were modelled for each of the four reference buildings.

Table 3.3: Packages included in analysis – Existing Buildings Package Modelling

Fabric (9 options)	***Do nothing***	***All Fabric Package (Roof, Wall, Window)*** ***All***	***All + Fabric Package (Roof, Wall, Window)*** ***All+***	***Roof and Wall Upgrade*** ***Roof + Wall***	***Roof and Window Upgrade*** ***Roof + Window***	***Roof Only Upgrade*** ***Roof***	***Wall Only Upgrade*** ***Wall***	***Window Only Upgrade*** ***Window***	***Window and Wall Upgrade*** ***Window + Wall***
Cavity Wall U-value (W/m²K)	1.5	0.55 (filled cavity)	0.24 (filled cavity and 50mm internal insulation)	0.55	1.5	1.5	0.55	1.5	0.55
Solid Wall U-value (W/m²K)	1.7	0.3 (50mm internal insulation)	0.21 (80mm internal insulation)	0.3	1.7	1.7	0.3	1.7	0.3
Roof U-value (W/m²K)	0.68	0.11	0.11	0.11	0.11	0.11	0.68	0.68	0.68
Window U-value (W/m²K)	3.1	1.6	1.4	3.1	1.6	3.1	3.1	1.6	1.6

Heating (3 options)			
Space Heating Source	Condensing gas boiler (88% efficiency)	Condensing gas boiler (88% efficiency)	Air Source Heat Pump (space heating COP 2.95)
Alternative communal option for flats?	No	Yes	No
Controls	Programmer, room thermostat and TRVs, modulating boiler with interlock	As for gas boiler	Programmer and room thermostat
Emitters	Radiators	Radiators	Large (low temperature) radiators
Domestic Hot Water Source	As for space heating	As for space heating + Solar Hot Water (supplying c.50% of DHW heat)	As for space heating + electric immersion

PV (3 options)			
PV Installation (percentage of foundation area)	0%	15%	30%

4. Primary Energy Demand

4.1 New Buildings

4.1.1. Energy Performance Assessment

This section outlines the procedure for determining the primary energy for each package of measures. Each of the two reference buildings was modelled using SAP 2012[21].

SAP (the Standard Assessment Procedure) implements the National Calculation Methodology for calculating the energy performance for domestic buildings in the UK. The current (2012) version of SAP is used to assess and demonstrate compliance with Part L of the English Building Regulations 2013, Part L of Welsh Building Regulations 2014, and Section 6 of Scottish Building Regulations 2015; and for the purposes of generating an Energy Performance Certificate when a building is constructed, sold or rented out. SAP 2009 is used to assess compliance with Part F of Northern Ireland Building Regulations 2012 and generating Energy Performance Certificates in Northern Ireland. For Northern Ireland, compliant models were developed in SAP 2009 and then these models imported into SAP 2012 to export results and assess the impact of different packages of measures.

To test each package of measures, the SAP building model input files were updated accordingly and run through the SAP tool. The energy end uses (e.g. space heating, water heating, lighting, pumps and fans) were recorded directly from the SAP output files. The end-use energies were then summed for each energy carrier to find the delivered energy requirement. Any on-site generated energy was also determined at this stage. The primary energy factors were then applied to the delivered energy and on-site generated energy. The latter was subtracted from the former to give the net primary energy.

Annex 1 of the Cost Optimal Methodolgy states that “Member States shall use a calculation period of 30 years for residential and public buildings”. We have therefore assumed a calculation period of 30 years for all domestic buildings.

4.1.2 Energy Performance Assessment

Table 4.1 summarises the results of the energy performance calculation for the most cost-optimal packages in both of the reference buildings. It includes the energy breakdown by end use, the total energy requirement per fuel carrier and the primary energy reduction over the reference cases. The primary energy factors used to calculate the total primary energy requirement are listed in Table 2.3. The delivered energy per carrier has been incorporated into Table 4.1 as more helpful than producing separate tables.

[21] The Government’s Standard Assessment Procedure for Energy Rating of Dwellings 2012 edition

Table 4.1a: Energy Demand Output Table
Semi Detached House

Package						Energy Use					Fuel Use			Primary Energy			
Fabric	Opening	TB	Vent	Heating	PV	Heat	DHW	Aux	Light	PV	Gas	Grid Elec.	Gen. Elec.	Total	% Red		
						kWh/m²/yr					kWh/m²/yr			kWh/m²/yr	E,W	NI	Scot
Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	16	14	3	4	-17	31	8	17	12	87%	88%	84%
Wall 0.18	Triple	Advanced	MVHR	Gas + SHW	40%	21	14	3	4	-17	35	8	17	17	81%	83%	77%
Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	29	23	3	4	-20	52	8	20	28	70%	72%	61%
Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	40	23	1	4	-20	63	5	20	35	62%	65%	52%
Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	45	23	1	4	-20	68	5	20	41	56%	60%	45%
Wall 0.21	Double	Advanced	NV	Gas	40%	45	29	1	4	-20	74	5	20	48	49%	53%	35%
Wall 0.21	Double	Advanced	NV	Gas + WWHR	0%	45	23	1	4	0	68	5	0	89	5%	12%	-20%
Wall 0.18	Double	Advanced	NV	Gas	0%	43	29	1	4	0	72	5	0	93	0%	8%	-26%
Wall 0.21	Double	Advanced	NV	Gas	0%	45	29	1	4	0	74	5	0	96	-2%	5%	-30%
Wall 0.21	Double	Default	NV	Gas	0%	56	29	1	4	0	85	5	0	108	-16%	-7%	-47%

Table 4.1b: Energy Demand Output Table
Apartment Building

Package						Energy Use					Fuel Use			Primary Energy			
Fabric	Opening	TB	Vent	Heating	PV	Heat	DHW	Aux	Light	PV	Gas	Grid Elec.	Gen. Elec.	Total	% Red		
						kWh/m²/yr					kWh/m²/yr			kWh/m²/yr	E,W	NI	Scot
Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	13	15	4	5	-6	28	8	6	37	60%	60%	48%
Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	16	15	4	5	-6	30	8	6	40	57%	57%	44%
Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	20	15	4	5	-6	34	8	6	44	52%	52%	38%
Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	32	15	0	5	-6	46	5	6	51	45%	45%	28%
Wall 0.21	Double	Advanced	NV	Gas + SHW	40%	36	15	0	5	-6	51	5	6	55	40%	40%	22%
Wall 0.21	Double	Default	NV	Gas + SHW	40%	43	15	0	5	-6	57	5	6	63	32%	32%	12%
Wall 0.18	Double	Default	NV	Gas	40%	41	35	1	5	-10	76	6	10	76	18%	18%	-7%
Wall 0.21	Double	Default	NV	Gas	40%	42	35	1	5	-10	77	6	10	77	17%	17%	-9%
Wall 0.21	Double	Default	NV	Gas	20%	42	35	1	5	-5	77	6	5	89	4%	4%	-25%
Wall 0.21	Double	Default	NV	Gas	0%	42	35	1	5	0	77	6	0	101	-9%	-9%	-42%

4.2 Existing Buildings

4.2.1 Energy Performance Assessment

The same process was followed as for new domestic buildings, as outlined in Section 4.1.1.

4.2.2 Energy Demand Calculation – Elemental Analysis

Tables 4.2 (a-d) summarise the results of the energy performance calculation for each of the four reference buildings. These tables include the energy breakdown by end use, the total energy requirement per fuel carrier and the primary energy reduction over the reference cases. The primary energy factors used to calculate the total primary energy requirement are listed in Table 2.5.

The delivered energy per carrier has been incorporated into Table 4.2 as more helpful than producing separate tables.

4.2.3 Energy Demand Calculation – Analysis of Packages

Tables 4.3 (a–d) summarise the results of the energy performance calculation for the most cost-optimal packages in each of the four reference buildings respectively. It includes the energy breakdown by end use and the total energy requirement per fuel carrier. The primary energy factors used to calculate the total primary energy requirement are listed in Table 2.5.

Table 4.2a: Energy Demand Output Table – Semi-detached House, 50mm Cavity Wall

Measure	***Value***	***Energy Use***					***Fuel Use***		***Primary Energy***		
		Heat	Sec. Heat	DHW	Aux	Light	Gas	Grid Elec.	Total	% Reduction over Reference	
		kWh/m²/yr					kWh/m²/yr		kWh/m²/yr	E,NI,W	S
Wall U-Value	0.14	115	54	52	2	7	221	9	271	10%	2%
Wall U-Value	0.18	117	55	52	2	7	224	9	274	9%	1%
Wall U-Value	0.22a	118	56	52	2	7	226	9	277	8%	0%
Wall U-Value	0.22b	118	56	52	2	7	226	9	277	8%	0%
Wall U-Value	0.24	119	56	52	2	7	228	9	278	7%	-1%
Wall U-Value	0.32	123	58	52	2	7	233	9	284	5%	-3%
Wall U-Value	0.55	132	62	52	2	7	247	9	300	0%	-8%
Window U-value	0.9	160	75	52	2	7	287	9	346	2%	2%
Window U-value	1.2	161	76	52	2	7	289	9	347	1%	1%
Window U-value	1.4	162	76	52	2	7	291	9	350	1%	1%
Window U-value	1.6	164	77	52	2	7	293	9	352	0%	0%
Heating Source	ASHP	69	81	14	0	7	81	90	305	13%	13%
Heating Source	Gas + SHW	167	82	15	1	7	265	8	318	9%	9%
Heating Source	Gas 88%	162	80	49	2	7	292	9	350	0%	0%
Roof U-value	0.11	159	74	52	2	7	285	9	343	1%	0%
Roof U-value	0.13	159	75	52	2	7	286	9	344	0%	0%
Roof U-value	0.29	162	76	52	2	7	291	9	350	-1%	-1%

Table 4.2b: Energy Demand Output Table – Apartment Block, 50mm Cavity Wall

Measure	***Value***	***Energy Use***					***Fuel Use***		***Primary Energy***		
		Heat	Sec. Heat	DHW	Aux	Light	Gas	Grid Elec.	Total	% Reduction over Reference	
		kWh/m²/yr					kWh/m²/yr		kWh/m²/yr	E,NI,W	S
Wall U-Value	0.14	106	0	36	2	7	142	9	182	6%	1%
Wall U-Value	0.18	107	0	36	2	7	143	9	183	5%	1%
Wall U-Value	0.22a	108	0	36	2	7	144	9	184	5%	0%
Wall U-Value	0.22b	108	0	36	2	7	144	9	184	5%	0%
Wall U-Value	0.24	108	0	36	2	7	144	9	184	4%	0%
Wall U-Value	0.32	110	0	36	2	7	146	9	187	3%	-1%
Wall U-Value	0.55	116	0	36	2	7	151	9	193	0%	-5%
Window U-value	0.9	119	0	36	2	7	155	9	197	3%	3%
Window U-value	1.2	121	0	36	2	7	157	9	199	2%	2%
Window U-value	1.4	123	0	36	2	7	159	9	201	1%	1%
Window U-value	1.6	125	0	36	2	7	161	9	203	0%	0%
Heating Source	Gas + SHW	129	0	14	1	7	143	8	181	13%	13%
Heating Source	ASHP	46	0	25	0	7	0	78	184	11%	11%
Heating Source	Gas 88%	130	0	34	2	7	164	9	207	0%	0%
Roof U-value	0.11	126	0	36	2	7	162	9	205	1%	0%
Roof U-value	0.13	127	0	36	2	7	163	9	205	0%	0%
Roof U-value	0.29	130	0	36	2	7	166	9	209	-1%	-1%

Table 4.2c: Energy Demand Output Table – Semi-detached House, Solid Wall

Measure	***Value***	***Energy Use***					***Fuel Use***		***Primary Energy***		
		Heat	Sec. Heat	DHW	Aux	Light	Gas	Grid Elec.	Total	% Reduction over Reference	
		kWh/m²/yr					kWh/m²/yr		kWh/m²/yr	E,NI,W	S
Wall U-Value	0.17	104	49	53	2	7	205	9	253	4%	1%
Wall U-Value	0.21	106	50	53	2	7	208	9	256	3%	0%
Wall U-Value	0.30a	110	52	53	2	7	214	9	263	0%	-2%
Wall U-Value	0.30b	110	52	53	2	7	214	9	263	0%	-2%
Window U-value	0.9	157	74	52	2	7	283	9	341	2%	2%
Window U-value	1.2	158	74	52	2	7	285	9	343	1%	1%
Window U-value	1.4	160	75	52	2	7	287	9	345	1%	1%
Window U-value	1.6	161	76	52	2	7	289	9	347	0%	0%
Heating Source	ASHP	68	80	14	0	7	80	89	301	13%	13%
Heating Source	Gas + SHW	164	81	15	1	7	261	8	313	9%	9%
Heating Source	Gas 88%	159	79	49	2	7	288	9	346	0%	0%
Roof U-value	0.11	156	73	52	2	7	281	9	339	1%	0%
Roof U-value	0.13	156	73	52	2	7	282	9	339	0%	0%
Roof U-value	0.29	160	75	52	2	7	287	9	345	-1%	-1%

Table 4.2d: Energy Demand Output Table – Apartment Block, Solid Wall

Measure	***Value***	***Energy Use***					***Fuel Use***		***Primary Energy***		
		Heat	Sec. Heat	DHW	Aux	Light	Gas	Grid Elec.	Total	% Reduction over Reference	
		kWh/m²/yr					kWh/m²/yr		kWh/m²/yr	E,NI,W	S
Wall U-Value	0.17	94	0	36	2	7	130	9	169	2%	1%
Wall U-Value	0.21	95	0	36	2	7	131	9	170	1%	0%
Wall U-Value	0.30a	98	0	36	2	7	134	9	172	0%	-1%
Wall U-Value	0.30b	98	0	36	2	7	134	9	172	0%	-1%
Window U-value	0.9	112	0	36	2	7	148	9	189	4%	4%
Window U-value	1.2	114	0	36	2	7	150	9	191	2%	2%
Window U-value	1.4	116	0	36	2	7	152	9	193	1%	1%
Window U-value	1.6	118	0	36	2	7	154	9	196	0%	0%
Heating Source	Gas + SHW	123	0	14	1	7	137	8	174	13%	13%
Heating Source	ASHP	43	0	25	0	7	0	75	178	11%	11%
Heating Source	Gas 88%	124	0	34	2	7	157	9	199	0%	0%
Roof U-value	0.11	120	0	36	2	7	155	9	197	1%	0%
Roof U-value	0.13	120	0	36	2	7	156	9	197	0%	0%
Roof U-value	0.29	123	0	36	2	7	159	9	201	-1%	-2%

Table 4.3a: Energy Demand Output Table - Semi-detached House, Cavity Wall

Package			***Energy Use***						***Fuel Use***			***Primary Energy***
Fabric	Heating	PV	Heat	Sec Heat	DHW	Aux	Light	PV	Gas	Grid Elec.	Gen. Elec.	Total
			kWh/m²/yr						kWh/m²/yr			kWh/m²/yr
All+	ASHP	30%	37	48	14	0	7	15	48	58	15	156
All+	Gas + SHW	30%	96	47	16	1	7	15	158	8	15	162
All	ASHP	30%	44	55	14	0	7	15	55	65	15	180
All+	Gas	30%	97	48	30	1	7	15	175	8	15	181
All	Gas + SHW	30%	110	55	16	1	7	15	181	8	15	187
Roof + Wall	ASHP	30%	47	59	14	0	7	15	59	68	15	192
All	Gas	30%	112	55	30	1	7	15	197	8	15	206
Roof + Wall	Gas	30%	120	59	30	1	7	15	209	8	15	218
Roof + Wall	Gas	0%	120	59	30	1	7	0	209	8	0	254
None	Gas	0%	168	83	30	1	7	0	281	8	0	336

Table 4.3b: Energy Demand Output Table - Apartment Block, Cavity Wall

Package			***Energy Use***						***Fuel Use***			***Primary Energy***
Fabric	Heating	PV	Heat	Sec Heat	DHW	Aux	Light	PV	Gas	Grid Elec.	Gen. Elec.	Total
			kWh/m²/yr						kWh/m²/yr			kWh/m²/yr
All+	Gas + SHW	30%	69	0	12	0	7	10	81	7	10	85
All	Gas + SHW	30%	77	0	12	0	7	10	90	7	10	94
Roof + Wall	Gas + SHW	30%	88	0	12	0	7	10	100	7	10	105
All	Gas	30%	87	0	34	1	7	10	121	8	10	132
Roof + Wall	Gas	30%	100	0	34	1	7	10	134	8	10	146
Roof + Wall	Gas	15%	100	0	34	1	7	5	134	8	5	158
Roof + Wall	Gas	0%	100	0	34	1	7	0	134	8	0	170
Wall	Gas	0%	110	0	34	1	7	0	144	8	0	181
Roof	Gas	0%	121	0	34	1	7	0	154	8	0	193
None	Gas	0%	131	0	34	1	7	0	164	8	0	204

Table 4.3c: Energy Demand Output Table - Semi-detached House, Solid Wall

Package			***Energy Use***						***Fuel Use***			***Primary Energy***
Fabric	Heating	PV	Heat	Sec Heat	DHW	Aux	Light	PV	Gas	Grid Elec.	Gen. Elec.	Total
			kWh/m²/yr						kWh/m²/yr			kWh/m²/yr
All+	ASHP	30%	31	41	14	0	7	15	41	53	15	134
All+	Gas + SHW	30%	82	40	16	1	7	15	138	8	15	139
All	Gas + SHW	30%	87	43	16	1	7	15	146	8	15	148
All+	Gas	30%	83	41	30	1	7	15	155	8	15	158
All	Gas	30%	89	44	30	1	7	15	163	8	15	167
Roof + Wall	Gas	30%	97	48	30	1	7	15	175	8	15	181
Roof + Wall	Gas	0%	97	48	30	1	7	0	175	8	0	217
Roof	Gas	30%	154	76	30	1	7	15	260	8	15	277
Roof	Gas	0%	154	76	30	1	7	0	260	8	0	313
None	Gas	0%	166	82	30	1	7	0	277	8	0	332

Table 4.3d: Energy Demand Output Table - Apartment Block, Solid Wall

Package			***Energy Use***						***Fuel Use***			***Primary Energy***
Fabric	Heating	PV	Heat	Sec Heat	DHW	Aux	Light	PV	Gas	Grid Elec.	Gen. Elec.	Total
			kWh/m²/yr						kWh/m²/yr			kWh/m²/yr
All+	Gas + SHW	30%	58	0	12	0	7	10	70	7	10	72
All	Gas + SHW	30%	61	0	12	0	7	10	74	7	10	76
Roof + Wall	Gas + SHW	30%	73	0	12	0	7	10	85	7	10	89
All+	Gas	30%	65	0	34	1	7	10	99	8	10	107
All	Gas	30%	69	0	34	1	7	10	103	8	10	112
Roof	Gas + SHW	30%	100	0	12	0	7	10	112	7	10	119
Roof + Wall	Gas	30%	82	0	34	1	7	10	116	8	10	126
Roof	Gas	30%	114	0	34	1	7	10	148	8	10	162
Roof	Gas	0%	114	0	34	1	7	0	148	8	0	186
None	Gas	0%	124	0	34	1	7	0	158	8	0	197

5. Global Cost Calculation

5.1 Introduction

This section presents the analysis for new and existing domestic buildings. In each case, the cost data is initially presented followed by the results of the macro-economic and financial cost analysis.

In undertaking this work, various underpinning costs have been assumed. The costs are 2017 prices and where necessary, as indicated below, previous years data has been adjusted for inflation to 2017 prices using, for construction costs, the projections published by the Building Cost Information Service (BCIS)[22] and, for energy and greenhouse gas prices, the Office for National Statistics (ONS) Gross Domestic Product (GDP) deflator series[23] and projections from the Office of Budget Responsibility[24].

5.2 New Buildings

5.2.1 Capital Costs and Asset Lifetimes

Introduction

The capital and lifecycle dataset developed separately for DCLG in 2015 was used as the basis for the new build domestic cost data used in this study. The data was adjusted in the following ways:

- The previous 2015 costs were updated to 2016 prices based on the BCIS All Tender Price Index adjustments seen between Q2-3 2015 and Q2-3 2016 and adjusted to take learning into account.
- 2016 costs were inflated to 2017 prices using the BCIS All Tender Price Index projections for 2017.
- Prices and learning rates for photovoltaic (PV) installations were adapted from an updated cost analysis for the former Department of Energy and Climate Change
- Learning rates were indexed with 2017 as the start year (i.e. 100% of cost).

The remainder of this section describes the cost data sourced and the 2016 and projected 2017 prices developed for use in the cost optimal modelling.

[22] Building Cost Information Service, Royal Institute of Chartered Surveyors
[23] Implied GDP deflator at market prices, Office for National Statistics
[24] Economic and fiscal outlook, Office of Budget Responsibility, March 2016

Basis of the cost analysis

The developed costs were based on the expert view of external cost consultant specialists, drawing on evidence from internal cost datasets, published price book data and confidential information provided by a national housebuilder.

The cost analysis is intended to reflect typical national costs from June 2016 that might be incurred by a medium sized housebuilder using traditional (i.e. masonry) construction methods and with reasonably efficient supply chain, design development and construction processes.

Costs incurred by individual organisations will vary according to their procurement strategies, the location of their activity (e.g. costs will be higher in London and the South East of England) and the detail of their housing product.

Further, costs can vary considerably with market conditions, particularly where (as is the case in 2015) activity levels result in a change in the availability of skills and materials. In these situations it is not unusual to see quite large (several percentage points) change in overall costs from month to month.

The specifications have been priced as defined. The following minor assumptions are noted, where the practical application may deviate from that modelled:

- The specifications for external walls and party walls refer to three different densities of block work (i.e. 0.15W/mK; 0.16W/mK, and 0.19W/mK). In reality, house builders may select to use one type only throughout.
- The flat roof assumptions for the apartment block comprise two layers of insulation, plywood and plasterboard.
- In the ground floor details, the cost for U-value of 0.11 excludes any associated impact on the building storey heights resulting from the use of 180mm thick insulation.

The costs are exclusive of land value, preliminaries, overheads and profits (OH&P), contingency, fees and VAT.

Building Fabric

The fabric cost rates are presented as elemental costs. For houses, these are for a semi-detached house. For flats, the costs assume a four storey building comprising 32 flats. Asset lives have been assumed to be 60 years, with the exception of 30 years for windows and external doors.

Table 5.1 shows the elemental costs used in the modelling for different fabric performance specifications.

Table 5.1: Cost data for building fabric elements

Element	*Performance Rating*	*Unit*	*Cost (£ per unit)*					
			2015		*2016*		*2017 (forecast)*	
			House	*Flat*	*House*	*Flat*	*House*	*Flat*
External Walls	0.21 W/m^2 K	Per m² of wall area	120	120	124	137	128	142
	0.18 W/m^2 K		122	122	126	141	130	145
	0.15 W/m^2 K		130	130	135	149	139	154
	0.12 W/m^2 K		147	147	152	166	157	171
Party Walls	0 W/m^2 K	Per m² of wall area	70	70	72	72	75	75
Ground Floor	0.15 W/m^2 K	Per m² of floor area	194	194	201	201	208	208
	0.13 W/m^2 K		198	198	205	205	211	211
	0.11 W/m^2 K		209	209	216	216	223	223
Roof	Pitched roof, insulated ceiling (core house types): 0.13 W/m^2 K	Per m² of roof area	185	185	191	191	198	198
	Pitched roof, insulated ceiling (core house types): 0.11 W/m^2 K		187	187	194	194	200	200
	Flat roof: 0.13 W/m^2 K		n/a	n/a	na	58	na	60
	Flat roof: 0.11 W/m^2 K		n/a	n/a	na	67	na	69
	Pitched roof, insulation at rafters (room-in-roof house type): 0.13 W/m^2 K		239	239	247	na	255	na
	Pitched roof, insulation at rafters (room-in-roof house type): 0.11 W/m^2 K		241	241	249	na	257	na

Table 5.2 shows the elemental costs used in the modelling for different window and door specifications.

Table 5.2: Cost data for windows and doors

Element	*Performance Rating*	*Unit*	*Cost (£ per unit)*					
			2015		*2016*		*2017*	
			House	*Flat*	*House*	*Flat*	*House*	*Flat*
Windows	1.2 W/m^2 K	Per m² of window area	402	402	416	416	425	425
	0.8 W/m^2 K		473	473	489	489	499	499
Doors	1.2 W/m^2 K	Per door	670	670	693	693	715	715
	1.0 W/m^2 K		737	737	762	762	787	787

Table 5.3 shows the elemental costs used in the modelling for different air permeability and thermal bridging specifications. The cost analysis for air tightness levels is based on a level of 5.0m³/hr/m² being that which is now relatively routinely achieved by the housing sector and represents standard current practice. A level of 3.0m³/hr/m² reflects performance that is higher than standard practice but which is achievable given additional focus on quality control and supervision.

Thermal bridging costs have been developed using specifications in the NHBC Foundation's *Part L 2013 - where to Start Guide*[25]. Costs include enhanced lintels, ground floor junction insulation and insulation to eaves, gable walls, and beyond the last truss in the roof space. The cost data is underpinned by detailed analysis of the length of lintels, cavity closers and cavity trays for each dwelling type together with analysis of the implications of wider cavities on the costs of each specification item. Note that the costs are for each dwelling unit i.e. for the apartment building, the costs are for each individual flat.

Table 5.3: Cost data for air permeability and thermal bridging

Element	*Performance Rating*	*Unit*	*Cost (£ per unit)*					
			2015		*2016*		*2017*	
			House	*Flat*	*House*	*Flat*	*House*	*Flat*
Air Permeability	5.0m³/hr/m²	Per dwelling	0	0	0	0	0	0
	3.0m³/hr/m²		250	250	259	259	266	266
Thermal Bridging	0.15 W/m³ K	Per dwelling	0	0	0	0	0	0
	Improved		188	197	195	204	201	210
	Advanced		337	331	349	343	360	353

[25] Part L 2013 - where to start: An introduction for house builders and designers NF58. Masonry Construction. NHBC Foundation, 2014.

Building services and renewable energy

Cost analysis for each building services option was undertaken on a 'per dwelling' basis rather than an elemental basis with the services costs separated by typical life expectancy to facilitate calculation of lifecycle costs. Note that for apartment buildings, the costs relate to the individual flats.

Table 5.4 shows the developed cost data for both whole home mechanical ventilation and heat recovery systems and extract fans. The lifetime of all systems is 15 years.

Table 5.4: Cost data for ventilation systems

Service type	***Specification***	***Unit***	***Cost (£ per unit)***					
			2015		***2016***		***2017***	
			House	***Flat***	***House***	***Flat***	***House***	***Flat***
Mechanical Ventilation and Heat Recovery	Houses - MVHR unit inc ducts, grills, power supply, controllers and installation.	Per dwelling	2,588		2,676		2,762	
	Flats - MVHR unit inc ducts, grills, power supply, controllers and installation.			2,050		2,120		2,188
Extract fans	Extractor fan including installation, wiring, ductwork, etc.	Per fan	200		207		213	

Table 5.5 shows the developed cost data for the different heating systems analysed.

Table 5.5: Cost data for heating systems (per unit)

Service type	***Specification***	***Life expectancy***	***Cost (£ per unit)***					
			2015		***2016***		***2017***	
			House	***Flat***	***House***	***Flat***	***House***	***Flat***
System Gas boilers								
Terraced	18kW System Boiler	15	1,275		1,318		1,361	
	200l cylinder	20	1,100		1,137		1,174	
	Radiators	20	700		724		747	
	Pipework	40	2,425		2,507		2,588	
	Gas supply	40	1,200		1,241		1,280	
Combi Gas boilers								
Terraced	Combi 30kW	15	1,225		1,267		1,307	
	Radiators	20	700		724		747	
	Pipework	40	2,130		2,202		2,273	
	Gas supply	40	1,200		1,241		1,280	
Flats	Combi 30kW	15		1,185		1,225		1,264
	Radiators	20		600		620		640
	Pipework	40		1,550		1,603		1,654
	Gas supply	40		1,325		1,370		1,414

Service type	Specification	Life expectancy	Cost (£ per unit)					
			2015		2016		2017	
			House	Flat	House	Flat	House	Flat
Waste water heat recovery								
Houses	Pipe based system -	40	620		641		662	
Flats	Tray based system -	20		1,010		1044		1078
Solar Thermal								
Terraced	System boiler 18kW	15	1,275		1,318		1,361	
	210l cylinder including solar store	20	1,200		1,241		1,281	
	Flat plate panel - 2.5 m^2	25	2,950		3,050		3,108	
	Radiators	20	700		724		747	
	Pipework	40	2,305		2,383		2,460	
	Gas supply	40	1,200		1,241		1,280	
Flats	Boiler	15		797		824		850
	HIU	15		1,000		1,034		1,067
	1500 litre solar store	20		234		242		250
	Flat plate panels - 80 sqm total (4 storey block of 32 flats)	25		689		713		726
	Radiators	20		2,100		620		640
	Pipework	40		811		2,441		2,519
	Gas supply	40		141		145		150
Air Source Heat Pump (ASHP)								
Terraced	ASHP - 5kW	15	3,612		3,735		3,828	
	150l cylinder	20	1,050		1,086		1,120	
	Radiators (large)	20	875		905		934	
	Pipework	40	2,365		2,445		2,524	
	Increased electrical infrastructure and base	30	175		181		187	
Flats	ASHP - 5kW	15		3,487		3,606		3,696
	120l cylinder	20		1,000		1,034		1,067
	Radiators (large)	20		750		776		800
	Pipework	40		1,550		1,603		1,654
	Increased electrical infrastructure and base	30		175		181		187

The costs for Photovoltaics (PV) have been developed from those published by the former Department of Energy and Climate Change (DECC) in August 2015[26].

For installations of less than 4kWp (i.e. housing scenarios), a split between fixed and variable costs was derived by taking the ratio of fixed to variable costs (in 2017) estimated in DECC's previous (2012) published cost analysis on solar PV[27] and applying these to the total cost per kWp shown in the 2015 projections for 2017.

The <4kWp aggregator 'central case' costs were used as the basis for housing installations on the basis that for new build installations procured by volume house builders would achieve similar economies to those achieved by aggregators.

The fixed and variable split was used to estimate the installation costs for a range of different installation sizes representing varying percentages of roof area being given over to either PV in isolation or a combination of PV and solar thermal systems.

For flats, installations were >10kWp and so the appropriate 2017 cost as published in DECC's 2015 analysis was used to derive cost estimates. For these larger installations no split between fixed and variable costs was provided on the basis that fixed costs are less material for larger areas of installation.

Inverter costs were subtracted from the calculated installation costs for each system (for both housing and flats) and costed separately on the basis of £1000 per array for houses and £3,000 per array for flats.

The PV panels and other cost items were assumed to have a life expectancy of 25 years with inverters lasting for 15 years before requiring replacement.

Table 5.6 shows the fixed and variable costs estimated for <4kWp systems on new homes and 10-50kWp systems on new flats.

Table 5.6: Fixed and variable costs of photovoltaic arrays of different sizes

Install scenario	*Fixed costs (based on 2.6 kW system)*	*Variable costs (based on 2.6 kW system)*	*Total cost per kWp (for 2.6 kWp)*
<4kW Aggregators	£770	£972	£1,268
10-50kW	£0	£1,050	£1,050

[26] Small-scale generation cost update, Parson's Brinkerhoff, August 2015.
[27] Solar PV cost update, Parson's Brinkerhoff, May 2012.

Table 5.7 shows the estimated installation costs for the range of installation sizes considered in this study including the split between array and inverter costs.

Table 5.7: Cost data for photovoltaic systems of varying sizes

Service type	*Specification*	*Cost (£ for defined system)*	
		2017	
		House	*Flat*
Houses[28]	PV array (0kWp) - panels + rooftop installation	£0	
	PV array (0kWp) - inverter and feed / distribution	£0	
	PV array (0.8kWp) - panels + rooftop installation	£548	
	PV array (0.8kWp) - inverter and feed / distribution	£1,000	
	PV array (1.1kWp) - panels + rooftop installation	£839	
	PV array (1.1kWp) - inverter and feed / distribution	£1,000	
	PV array (1.8kWp) - panels + rooftop installation	£1,519	
	PV array (1.8kWp) - inverter and feed / distribution	£1,000	
	PV array (2.1kWp) - panels + rooftop installation	£1,811	
	PV array (2.1kWp) - inverter and feed / distribution	£1,000	
Flats[29]	PV array (0kWp) - panels and rooftop installation		£0
	PV array (0kWp) - inverters and feed / distribution		£0
	PV array (12kWp) - panels and rooftop installation		£9,600
	PV array (12kWp) - inverters and feed / distribution		£3,000
	PV array (14kWp) - panels and rooftop installation		£11,700
	PV array (14kWp) - inverters and feed / distribution		£3,000
	PV array (24kWp) - panels and rooftop installation		£22,200
	PV array (24kWp) - inverters and feed / distribution		£3,000

[28] The 1.1kWp and 2.1kWp cases are for the 20% and 40% options respectively. The 0.8kWp and 1.8kWp cases are for the 20% and 40% options respectively where solar thermal is also included which takes up part of the available roofspace.

[29] The 12kWp and 24kWp cases are for the 20% and 40% options respectively. The 14kWp case is for the 40% option respectively where solar thermal is also included which takes up part of the available roofspace. In the 20% PV scenario where solar thermal is also included, it is assumed that only 20% of the roof area is covered with any kind of solar panel – prioritising SHW and then adding PV in the remaining space – and that the SHW takes up all of the space for the flats, so there is no remaining space for PV.

5.2.2 Maintenance costs

Some of the services options will incur an annual maintenance cost to support effective and safe operations. Table 5.8 shows the maintenance costs for gas boilers, Mechanical Ventilation with Heat Recovery (MVHR) and Air Source Heat Pumps (ASHP). Maintenance cost estimates are drawn from expert opinion and would be subject to market validation.

Table 5.8: Maintenance costs

Service type	Maintenance costs per annum
Gas boiler (system and combi)	£160
Gas boiler with solar hot water	£160
MVHR	£110
ASHP	£110

5.2.3 Projected cost reductions

The future costs of key technologies used in the various house type specifications were estimated using cost adjustments derived from either modelled learning rates or published price trajectories. Where learning rates models were used (ASHP and Solar Thermal) the technology learning rates were derived from previous research by Element Energy[30] together with technology deployment projections from International Energy Agency analysis[31]. For other technologies where future reductions in real cost are projected the future cost trajectory is derived from published research or, in the case of air tightness, extension of assumptions used in previous modelling for Part L 2013[32]. For triple glazing, future costs are derived from published research[33].

Modelled cost reductions for photovoltaics are based on a combination of near term estimates derived from the previously referenced work by Parson's Brinkerhoff (up to 2021) and longer term cost trends estimated by the International Energy Agency[34]. The near term projections for cost reductions are more conservative than those used previously as they take in to account the impact of Minimum Import Prices for PV applied within the EU area.

Table 5.9 shows the modelled learning rates for each technology for which future reductions in real cost are projected. For other technologies it is assumed that the real current cost will not change materially over the lifetime of the policy period. It is acknowledged that changes in real cost may occur for any technology based on changes in commodity prices, technology and market conditions.

[30] Potential for Microgeneration, Element Energy for The Energy Saving Trust, 2005
[31] Technology Roadmap: Energy-efficient Buildings: Heating and Cooling Equipment, IEA 2011
[32] Changes to Part L of the Building Regulations, Impact Assessment, August 2013
[33] Riding down the experience curve for energy efficient envelopes, Jakob and Madlener, 2004
[34] Technology Roadmap: Solar Photovoltaic Energy, IEA 2014

Table 5.9: Projected cost reductions for different technologies

Technology	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2030*	*2035*	*2040*	*2045*	*2050-2100*
Air to Water Heat Pumps	101%	100%	99%	99%	98%	97%	97%	96%	95%	95%	94%	92%	89%	86%	83%	80%
Solar thermal	101%	100%	99%	97%	96%	95%	94%	93%	91%	90%	89%	85%	79%	74%	70%	66%
Photovoltaics	101%	100%	99%	98%	96%	95%	94%	90%	86%	82%	78%	62%	56%	54%	52%	50%
Triple Glazed Windows	101%	100%	99%	98%	97%	96%	95%	94%	93%	92%	91%	87%	87%	87%	87%	87%
Airtightness	200%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Note: Costs in 2016 are above 100% recognising that some learning is expected to arise between 2016 and those in place in 2017.

5.2.4 Energy prices

For the purposes of this work, low, central and high energy prices have been used as shown in Table 5.10 (a-b), taken from the Interdepartmental Analyst Group (IAG) tables revised in September 2015[35] and adjusted to 2017 prices. The retail prices (Table 5.10a) are used for the financial analysis and the variable prices (Table 5.10b) are used for the macro-economic analysis.

5.2.5 Cost of greenhouse gas emissions

The assumed cost of greenhouse gas emissions for the macroeconomic calculations is shown in Table 5.11. These have been taken from the projected Emissions Trading System (ETS) carbon prices defined in the Commission reference scenario up to 2050, updated in 2013[36]. This scenario assumes the implementation of existing legislation, but takes no account of further decarbonisation. Again, an earlier version of this data is referred to in Annex 2 of the Cost Optimal Methodology. Sensitivity analysis has also been applied, shown in Table 5.2c, based upon the IAG 2015 data for central costs of traded and non-traded carbon. The Commission carbon prices have been converted from euros to pounds assuming £1 = 1.17 euros (based on European Central Bank 2010 exchange rates, as the costs in the source report were 2010 prices).

The carbon dioxide (CO_2) factors used in the calculations of the cost of greenhouse gas emissions have been taken from the IAG tables, Table 1 (domestic long-run marginal factors for electricity), and Table 2a (gas).

5.2.6 Discount rates

A central real discount rate for the financial calculation of 6% has been used, with an additional sensitivity at 10%.

A central discount rate for the macroeconomics calculation of 3.5% has been used, as is also used for Government Impact Assessments in England, and a sensitivity of 3% has been used as required by the Commission.

[35] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions
[36] EU energy, transport and greenhouse gas emissions trends to 2050, 2013.

Table 5.10a: Energy Costs - Retail

			2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Low	**Electricity**	*p/kWh*	15.7	16.3	16.5	17.3	16.9	17.8	17.2	17.7	18.7	18.4
Low	**Gas**	*p/kWh*	3.8	3.7	3.6	3.5	3.5	3.6	3.4	3.5	3.6	3.6
Central	**Electricity**	*p/kWh*	16.8	17.6	18.1	18.5	18.6	19.0	18.8	19.3	20.2	20.2
Central	**Gas**	*p/kWh*	4.3	4.3	4.3	4.4	4.5	4.6	4.5	4.6	4.7	4.8
High	**Electricity**	*p/kWh*	17.8	18.9	19.6	19.8	19.9	20.8	20.4	20.8	21.7	21.6
High	**Gas**	*p/kWh*	4.8	5.0	5.1	5.3	5.4	5.6	5.6	5.8	5.9	6.1

			2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Low	**Electricity**	*p/kWh*	19.2	19.1	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
Low	**Gas**	*p/kWh*	3.7	3.7	3.8	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Central	**Electricity**	*p/kWh*	20.7	20.4	20.0	20.1	20.1	20.1	20.1	20.1	20.1	20.1
Central	**Gas**	*p/kWh*	4.9	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
High	**Electricity**	*p/kWh*	22.0	21.8	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
High	**Gas**	*p/kWh*	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1

			2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Low	**Electricity**	*p/kWh*	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
Low	**Gas**	*p/kWh*	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Central	**Electricity**	*p/kWh*	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1
Central	**Gas**	*p/kWh*	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
High	**Electricity**	*p/kWh*	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
High	**Gas**	*p/kWh*	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1

Table 5.10b: Energy Costs - Variable

			2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Low	**Electricity**	*p/kWh*	8.0	7.8	8.5	9.4	9.2	9.9	9.8	10.4	10.9	10.6
Low	**Gas**	*p/kWh*	1.3	1.2	1.2	1.2	1.3	1.3	1.4	1.5	1.5	1.6
Central	**Electricity**	*p/kWh*	9.2	9.1	9.9	10.2	10.7	10.9	11.1	11.7	12.2	12.2
Central	**Gas**	*p/kWh*	1.9	1.9	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6
High	**Electricity**	*p/kWh*	10.4	10.5	11.2	11.4	12.2	12.1	12.6	13.1	13.5	13.1
High	**Gas**	*p/kWh*	2.5	2.6	2.7	2.8	3.0	3.2	3.3	3.5	3.7	3.7

			2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Low	**Electricity**	*p/kWh*	11.1	11.0	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Low	**Gas**	*p/kWh*	1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Central	**Electricity**	*p/kWh*	12.3	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
Central	**Gas**	*p/kWh*	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
High	**Electricity**	*p/kWh*	13.4	12.8	12.8	12.6	12.6	12.6	12.6	12.6	12.6	12.6
High	**Gas**	*p/kWh*	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7

			2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Low	**Electricity**	*p/kWh*	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Low	**Gas**	*p/kWh*	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Central	**Electricity**	*p/kWh*	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
Central	**Gas**	*p/kWh*	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
High	**Electricity**	*p/kWh*	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
High	**Gas**	*p/kWh*	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7

Table 5.11: Cost of Carbon

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Reference (frag. action, ref. fossil f. prices)	£/TCO_2	6.7	7.7	8.7	9.6	10.4	11.1	11.9	12.6	13.4	17.4

		2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Reference (frag. action, ref. fossil f. prices)	£/TCO_2	21.4	25.5	29.5	33.5	37.7	41.9	46.1	50.2	54.4	58.4

		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Reference (frag. action, ref. fossil f. prices)	£/TCO_2	62.5	66.5	70.5	74.5	76.6	78.7	80.8	82.9	85.0	87.1

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Alternative (IAG central, traded)	£/TCO_2	6.1	6.3	6.5	6.8	14.2	21.6	29.0	36.4	43.8	51.2

		2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Alternative (IAG central, traded)	£/TCO_2	58.6	66.0	73.4	80.8	88.3	95.8	103.3	110.8	118.3	125.8

		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Alternative (IAG central, traded)	£/TCO_2	133.4	140.9	148.4	155.9	163.4	170.9	178.4	185.9	193.4	200.9

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Alternative (IAG central, non-traded)	£/TCO_2	66.2	67.2	68.3	69.3	70.4	71.6	72.7	73.9	75.0	76.2

		2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Alternative (IAG central, non-traded)	£/TCO_2	77.4	78.5	79.7	80.8	88.3	95.8	103.3	110.8	118.3	125.8

		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Alternative (IAG central, non-traded)	£/TCO_2	133.4	140.9	148.4	155.9	163.4	170.9	178.4	185.9	193.4	200.9

5.2.7 Results of the cost calculations

The following Tables summarise the results of the cost calculations for the most cost-optimal packages in each of the two reference buildings. Table 5.12 relates to the macroeconomic calculations and Table 5.13 relates to the financial calculations.

- Table 5.12a / Table 5.13a: Central energy price, central discount factors
- Table 5.12b / Table 5.13b: Low energy price, central discount factors
- Table 5.12c / Table 5.13c: High energy price, central discount factors
- Table 5.12d / Table 5.13d: Central energy price, alternative discount factors
- Table 5.12e: Central energy price, central discount factor, alternative cost of carbon

It is important to note that the initial investment costs in these tables only reflect the delivery of the building elements associated with the defined packages and other construction costs involved in completing the property are excluded.

The sensitivity analysis shows that with higher energy prices there is a tendency for solutions with lower primary energy to become relatively more favourable. Similarly, with lower discount rates, it makes solutions with lower primary energy relatively more favourable due at least partly to the higher net present value energy prices.

The cost optimum solution was the same for the semi-detached house under each sensitivity analyses. However, for the apartment building, the cost optimum solution changed between sensitivity analysis – in particular between the choice of a gas heating system alone and a gas heating system with solar thermal technology.

Furthermore, in the financial analysis for apartment buildings, PV falls outside of the cost optimal solution at the alternative higher discount rate.

Table 5.12a: Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Building	Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
New Semi-detached – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	699	56	3	3	-83	679
	Wall 0.18	Triple	Advanced	MVHR	Gas + SHW	40%	17	667	56	6	4	-77	655
	Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	28	587	56	8	5	-66	590
	Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	566	33	8	7	-67	547
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	549	33	10	7	-66	533
	Wall 0.21	Double	Advanced	NV	Gas	40%	48	541	33	13	8	-65	529
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	0%	89	512	33	42	9	-66	529
	Wall 0.18	Double	Advanced	NV	Gas	0%	93	507	33	44	9	-66	527
	Wall 0.21	Double	Advanced	NV	Gas	0%	96	504	33	45	9	-65	526
	Wall 0.21	Double	Default	NV	Gas	0%	108	499	33	50	11	-65	529
New Apartment block – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	37	476	61	21	3	-39	522
	Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	40	462	61	22	4	-37	512
	Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	44	447	61	24	4	-37	499
	Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	51	416	29	23	6	-37	437
	Wall 0.21	Double	Advanced	NV	Gas + SHW	40%	55	400	29	25	6	-37	423
	Wall 0.21	Double	Default	NV	Gas + SHW	40%	63	394	29	28	7	-36	422
	Wall 0.18	Double	Default	NV	Gas	40%	76	369	46	31	9	-33	422
	Wall 0.21	Double	Default	NV	Gas	40%	77	367	46	32	9	-33	421
	Wall 0.21	Double	Default	NV	Gas	20%	89	361	46	40	9	-33	423
	Wall 0.21	Double	Default	NV	Gas	0%	101	353	46	48	10	-33	424

Table 5.12b: Macroeconomic Costs (Low energy price, 3.5% discount rate, £/m²)

Building	Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
New Semi-detached – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	699	56	0	3	-83	675
	Wall 0.18	Triple	Advanced	MVHR	Gas + SHW	40%	17	667	56	1	4	-77	651
	Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	28	587	56	1	5	-66	583
	Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	566	33	0	7	-67	539
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	549	33	1	7	-66	524
	Wall 0.21	Double	Advanced	NV	Gas	40%	48	541	33	3	8	-65	520
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	0%	89	512	33	31	9	-66	518
	Wall 0.18	Double	Advanced	NV	Gas	0%	93	507	33	32	9	-66	515
	Wall 0.21	Double	Advanced	NV	Gas	0%	96	504	33	33	9	-65	513
	Wall 0.21	Double	Default	NV	Gas	0%	108	499	33	36	11	-65	514
New Apartment block – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	37	476	61	16	3	-39	517
	Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	40	462	61	17	4	-37	507
	Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	44	447	61	18	4	-37	493
	Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	51	416	29	16	6	-37	429
	Wall 0.21	Double	Default	NV	Gas + SHW	40%	63	394	29	19	7	-36	413
	Wall 0.21	Double	Improved	NV	Gas	40%	73	371	46	19	9	-34	411
	Wall 0.18	Double	Default	NV	Gas	40%	76	369	46	20	9	-33	411
	Wall 0.21	Double	Default	NV	Gas	40%	77	367	46	20	9	-33	410
	Wall 0.21	Double	Default	NV	Gas	20%	89	361	46	27	9	-33	411
	Wall 0.21	Double	Default	NV	Gas	0%	101	353	46	35	10	-33	411

Table 5.12c: Macroeconomic Costs (High energy price, 3.5% discount rate, £/m²)

Building	Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
New Semi-detached – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	699	56	8	3	-83	683
	Wall 0.18	Triple	Advanced	MVHR	Gas + SHW	40%	17	667	56	11	4	-77	661
	Wall 0.18	Triple	Advanced	MVHR	Gas + WWHR	40%	23	604	56	13	5	-67	611
	Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	28	587	56	16	5	-66	598
	Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	566	33	18	7	-67	557
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	549	33	21	7	-66	544
	Wall 0.18	Double	Advanced	NV	Gas	40%	45	545	33	24	8	-66	543
	Wall 0.21	Double	Advanced	NV	Gas	40%	48	541	33	25	8	-65	542
	Wall 0.21	Double	Advanced	NV	Gas	0%	96	504	33	60	9	-65	540
	Wall 0.21	Double	Default	NV	Gas	0%	108	499	33	67	11	-65	546
New Apartment block – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	37	476	61	27	3	-39	528
	Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	40	462	61	29	4	-37	519
	Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	44	447	61	31	4	-37	506
	Wall 0.18	Triple	Advanced	NV	Gas + SHW	40%	50	418	29	31	5	-37	446
	Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	51	416	29	32	6	-37	446
	Wall 0.12	Double	Advanced	NV	Gas + SHW	40%	52	414	29	33	6	-39	442
	Wall 0.15	Double	Advanced	NV	Gas + SHW	40%	53	405	29	33	6	-38	436
	Wall 0.18	Double	Advanced	NV	Gas + SHW	40%	54	402	29	34	6	-37	434
	Wall 0.21	Double	Advanced	NV	Gas + SHW	40%	55	400	29	34	6	-37	433
	Wall 0.21	Double	Default	NV	Gas	0%	101	353	46	63	10	-33	440

Table 5.12d: Macroeconomic Costs (Central energy price, 3% discount rate, £/m²)

Building	Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
New Semi-detached – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	704	59	4	3	-95	675
	Wall 0.18	Triple	Advanced	MVHR	Gas + SHW	40%	17	672	59	6	4	-88	653
	Wall 0.18	Triple	Advanced	MVHR	Gas + WWHR	40%	23	607	59	6	5	-77	601
	Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	28	590	59	9	6	-76	587
	Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	568	35	9	7	-77	542
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	551	35	11	8	-76	528
	Wall 0.21	Double	Advanced	NV	Gas	40%	48	543	35	14	9	-75	525
	Wall 0.18	Double	Advanced	NV	Gas	0%	93	509	35	47	10	-76	525
	Wall 0.21	Double	Advanced	NV	Gas	0%	96	505	35	48	10	-75	523
	Wall 0.21	Double	Default	NV	Gas	0%	108	501	35	53	12	-74	527
New Apartment block – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	37	480	65	22	4	-45	526
	Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	40	467	65	24	4	-42	517
	Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	44	451	65	25	5	-42	504
	Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	51	419	31	24	6	-42	438
	Wall 0.12	Double	Advanced	NV	Gas + SHW	40%	52	417	31	25	6	-45	434
	Wall 0.21	Double	Advanced	NV	Gas + SHW	40%	55	403	31	26	7	-42	425
	Wall 0.21	Double	Default	NV	Gas + SHW	40%	63	398	31	29	8	-41	424
	Wall 0.21	Double	Default	NV	Gas	40%	77	369	49	34	10	-38	424
	Wall 0.21	Double	Default	NV	Gas	20%	89	363	49	42	10	-38	426
	Wall 0.21	Double	Default	NV	Gas	0%	101	355	49	51	11	-38	428

Table 5.12e: Macroeconomic Costs (Central energy price, 3.5% discount rate, alternative cost of carbon, £/m²)

Building	Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
New Semi-detached – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	699	56	3	9	-83	685
	Wall 0.18	Double	Advanced	MVHR	Gas + WWHR	40%	26	590	56	7	16	-67	602
	Wall 0.21	Double	Advanced	NV	ASHP	40%	30	599	23	39	2	-67	596
	Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	566	33	8	20	-67	560
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	549	33	10	22	-66	547
	Wall 0.21	Double	Advanced	NV	Gas	40%	48	541	33	13	24	-65	545
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	0%	89	512	33	42	24	-66	545
	Wall 0.18	Double	Advanced	NV	Gas	0%	93	507	33	44	26	-66	544
	Wall 0.21	Double	Advanced	NV	Gas	0%	96	504	33	45	27	-65	543
	Wall 0.21	Double	Default	NV	Gas	0%	108	499	33	50	31	-65	549
New Apartment block – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	37	476	61	21	10	-39	528
	Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	40	462	61	22	11	-37	520
	Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	44	447	61	24	12	-37	507
	Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	51	416	29	23	16	-37	447
	Wall 0.12	Double	Advanced	NV	Gas + SHW	40%	52	414	29	23	17	-39	443
	Wall 0.15	Double	Advanced	NV	Gas + SHW	40%	53	405	29	24	17	-38	438
	Wall 0.18	Double	Advanced	NV	Gas + SHW	40%	54	402	29	24	17	-37	435
	Wall 0.21	Double	Advanced	NV	Gas + SHW	40%	55	400	29	25	18	-37	435
	Wall 0.21	Double	Default	NV	Gas	20%	89	361	46	40	27	-33	441
	Wall 0.21	Double	Default	NV	Gas	0%	101	353	46	48	28	-33	442

Table 5.13a: Financial Costs (Central energy price, 6% discount rate, £/m²)

Building	Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
New Semi-detached – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	815	51	17	-	-50	833
	Wall 0.18	Triple	Advanced	MVHR	Gas + SHW	40%	17	776	51	21	-	-46	802
	Wall 0.18	Triple	Advanced	MVHR	Gas + WWHR	40%	23	711	51	24	-	-40	745
	Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	28	690	51	28	-	-40	729
	Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	670	30	29	-	-40	689
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	650	30	33	-	-40	673
	Wall 0.21	Double	Advanced	NV	Gas	40%	48	640	30	38	-	-39	669
	Wall 0.18	Double	Advanced	NV	Gas	0%	93	601	30	76	-	-40	667
	Wall 0.21	Double	Advanced	NV	Gas	0%	96	597	30	78	-	-39	665
	Wall 0.21	Double	Default	NV	Gas	0%	108	592	30	87	-	-39	670
New Apartment block – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	37	550	55	38	-	-24	621
	Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	40	534	55	41	-	-22	608
	Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	44	516	55	44	-	-22	593
	Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	51	485	26	44	-	-22	533
	Wall 0.12	Double	Advanced	NV	Gas + SHW	40%	52	482	26	44	-	-24	529
	Wall 0.21	Double	Advanced	NV	Gas + SHW	40%	55	466	26	47	-	-22	517
	Wall 0.18	Double	Default	NV	Gas + SHW	40%	62	461	26	51	-	-22	517
	Wall 0.21	Double	Default	NV	Gas + SHW	40%	63	459	26	52	-	-21	516
	Wall 0.21	Double	Default	NV	Gas	20%	89	424	42	72	-	-20	518
	Wall 0.21	Double	Default	NV	Gas	0%	101	415	42	82	-	-20	520

Table 5.13b: Financial Costs (Low energy price, 6% discount rate, £/m²)

Building	Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
New Semi-detached – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	815	51	12	-	-50	828
	Wall 0.18	Triple	Advanced	MVHR	Gas + WWHR	40%	23	711	51	17	-	-40	738
	Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	28	690	51	20	-	-40	721
	Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	670	30	20	-	-40	680
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	650	30	23	-	-40	663
	Wall 0.21	Double	Advanced	NV	Gas	40%	48	640	30	27	-	-39	658
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	0%	89	606	30	60	-	-40	657
	Wall 0.18	Double	Advanced	NV	Gas	0%	93	601	30	63	-	-40	654
	Wall 0.21	Double	Advanced	NV	Gas	0%	96	597	30	64	-	-39	652
	Wall 0.21	Double	Default	NV	Gas	0%	108	592	30	72	-	-39	655
New Apartment block – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	37	550	55	33	-	-24	615
	Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	40	534	55	34	-	-22	602
	Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	44	516	55	37	-	-22	586
	Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	51	485	26	35	-	-22	525
	Wall 0.21	Double	Default	NV	Gas + SHW	40%	63	459	26	42	-	-21	506
	Wall 0.21	Double	Improved	NV	Gas	40%	73	436	42	48	-	-20	505
	Wall 0.18	Double	Default	NV	Gas	40%	76	433	42	49	-	-20	504
	Wall 0.21	Double	Default	NV	Gas	40%	77	431	42	50	-	-20	503
	Wall 0.21	Double	Default	NV	Gas	20%	89	424	42	59	-	-20	505
	Wall 0.21	Double	Default	NV	Gas	0%	101	415	42	68	-	-20	506

Table 5.13c: Financial Costs (High energy price, 6% discount rate, £/m²)

Building	Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
New Semi-detached – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	815	51	23	-	-50	839
	Wall 0.18	Triple	Advanced	MVHR	Gas + SHW	40%	17	776	51	28	-	-46	809
	Wall 0.18	Triple	Advanced	MVHR	Gas + WWHR	40%	23	711	51	33	-	-40	754
	Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	28	690	51	37	-	-40	738
	Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	670	30	40	-	-40	700
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	650	30	45	-	-40	685
	Wall 0.18	Double	Advanced	NV	Gas	40%	45	644	30	49	-	-40	684
	Wall 0.21	Double	Advanced	NV	Gas	40%	48	640	30	51	-	-39	682
	Wall 0.21	Double	Advanced	NV	Gas	0%	96	597	30	93	-	-39	680
	Wall 0.21	Double	Default	NV	Gas	0%	108	592	30	104	-	-39	687
New Apartment block – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	37	550	55	45	-	-24	627
	Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	40	534	55	47	-	-22	615
	Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	44	516	55	51	-	-22	600
	Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	51	485	26	53	-	-22	542
	Wall 0.12	Double	Advanced	NV	Gas + SHW	40%	52	482	26	54	-	-24	539
	Wall 0.15	Double	Advanced	NV	Gas + SHW	40%	53	472	26	55	-	-23	531
	Wall 0.18	Double	Advanced	NV	Gas + SHW	40%	54	468	26	56	-	-22	528
	Wall 0.21	Double	Advanced	NV	Gas + SHW	40%	55	466	26	57	-	-22	527
	Wall 0.21	Double	Default	NV	Gas	20%	89	424	42	88	-	-20	533
	Wall 0.21	Double	Default	NV	Gas	0%	101	415	42	98	-	-20	535

Table 5.13d: Financial Costs (Central energy price, 10% discount rate, £/m²)

Building	Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
New Semi-detached – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	794	35	12	-	-17	824
	Wall 0.18	Triple	Advanced	MVHR	Gas + SHW	40%	17	755	35	15	-	-16	789
	Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	28	677	35	20	-	-14	718
	Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	662	21	20	-	-14	689
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	641	21	23	-	-14	671
	Wall 0.21	Double	Advanced	NV	Gas	40%	48	632	21	27	-	-13	666
	Wall 0.21	Double	Advanced	NV	Gas + WWHR	0%	89	599	21	51	-	-14	657
	Wall 0.18	Double	Advanced	NV	Gas	0%	93	594	21	53	-	-14	654
	Wall 0.21	Double	Advanced	NV	Gas	0%	96	590	21	55	-	-13	652
	Wall 0.21	Double	Default	NV	Gas	0%	108	585	21	61	-	-13	653
New Apartment block – 30 year calc	Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	37	531	38	27	-	-8	589
	Wall 0.21	Triple	Advanced	MVHR	Gas + SHW	40%	40	515	38	29	-	-8	575
	Wall 0.21	Double	Advanced	MVHR	Gas + SHW	40%	44	496	38	31	-	-8	558
	Wall 0.21	Triple	Advanced	NV	Gas + SHW	40%	51	472	18	31	-	-8	513
	Wall 0.21	Double	Default	NV	Gas + SHW	40%	63	446	18	37	-	-7	493
	Wall 0.21	Double	Improved	NV	Gas	40%	73	427	29	42	-	-7	491
	Wall 0.18	Double	Default	NV	Gas	40%	76	425	29	43	-	-7	490
	Wall 0.21	Double	Default	NV	Gas	40%	77	423	29	44	-	-7	489
	Wall 0.21	Double	Default	NV	Gas	20%	89	415	29	51	-	-7	488
	Wall 0.21	Double	Default	NV	Gas	0%	101	407	29	58	-	-7	487

5.3 Existing Buildings – Elemental Analysis

5.3.1 Capital Costs and Asset Lifetimes

The capital cost data was sourced from a combination of recent tenders for relevant refurbishment projects and first principles cost planning drawing on published materials costs and labour rates for relevant trades.

Key assumptions underpinning the analysis are as follows:

General

- Properties are typical homes (two storey, three bed semi-detached house and a three storey apartment block with 12 units) heated via combination boilers with radiators in each room and wall mounted controls.
- Full access to the property is possible during typical work hours i.e. Monday - Friday, 9.00 - 17.00.
- Prices are based on undertaking work to a single property, no allowance for main contractor costs, 15% sub-contractor mark applied.
- All furniture, fixtures and equipment and obstacles are removed by the home occupant before works commence.
- Asbestos survey has been carried out and the property does not contain any other contaminated materials that may interfere with the works.
- Costs exclude preliminaries, overheads and profits (OH&P), contingency, fees and VAT.

Installation of Cavity Insulation

- Initial suitability survey identifies the property is suitable for installation.
- No allowance to sleeve existing vents, flues or other essential ventilation openings.
- External envelope is facing brickwork and the installation holes will be drilled through external mortar joints with minimal repointing, no allowance for rendering or external decoration.

Installation of Internal insulation

- Costs assume the use of rigid insulation board.
- Internal walls are in a suitable condition to be insulated i.e. dry, no structural defects, etc.
- No allowance for removing tiles in wet areas i.e. bathrooms or kitchens.
- No allowance for levelling walls with significant depth changes i.e. nothing ≥5mm between floor to ceiling.
- Increasing the wall thickness will require radiators to be removed and pipework to be modified to suit new wall thickness.
- Carpets, underlay and gripper rods to be modified to suit new wall thickness.
- Properties will not contain any cornice/ coving.

- Electrician will be required to adapt, plug sockets, extractor fans, etc. to suit new wall thickness.
- Window seals will need to be extended and reveals' will need to adapted to suit new external wall thickness.
- Existing carpet will be cut to suit new wall thickness.
- No allowance has been made for removing/reinstating kitchens.
- No allowance has been made for removing/reinstating gas appliance e.g. boilers, cookers etc.
- Skirting will be removed prior to installation, assumed they will be damaged and therefore not reused.
- Allowance to lay internal plastic sheeting to protect furniture, fixtures and equipment.
- New decoration comprises 3mm skim coat, emulsion paint to wall, new skirting, gloss to skirting allowance of 10% wastage for cutting around windows.

Installation of external wall insulation

- External wall is facing brickwork.
- Scaffold required for access to high level working.
- External insulation to apartments will be fitted to the entire block.
- Unable to find 200mm thick external wall product, allowed for 2 sheets of 100mm
- No allowance made for extension of roof eaves. Should this be required, substantial additional costs for removal and extension of the roofline would be incurred.
- Window seals will need to be extended and reveals' will be fitted with UPVC trims allowance of 10% wastage for cutting around windows.
- Costs include for removal and re-location, but not replacement, of existing rainwater goods.

Installation of roof insulation

- Loft space will not be boarded, no requirement to board following completion of the works.
- Loft space is fully accessible via a sufficiently sized access hatch.

Windows

- Triple glazed and high performance UPVC windows are based on indexed figures from the initial exercise carried out in 2015, market prices were obtained for 1.4 U Value windows.
- Mobile towers will be required to fit new windows.

The fabric cost rates are presented as elemental costs. For houses, these are for a semi-detached home. For flats, the costs assume a three storey building comprising 12 flats. Asset lives have been assumed to be 60 years, with the exception of 30 years for windows.

Table 5.14 shows the elemental costs used in the modelling for different fabric performance specifications.

Table 5.14: Cost data for building fabric elements

Option	*Performance rating (W/m^2K)*	*Specification*	*Unit*	*Cost (£ per unit)*			
				2016		*2017*	
				House	*Flat*	*House*	*Flat*
Cavity Walls			Per m^2 of wall area				
Base case (for information)	1.5	**None – 50mm uninsulated cavity** (100mm brick outer leaf, 50mm cavity, 100mm dense block inner leaf (1800kg/m3), 13mm plasterboard on dabs - adjusted to match proposed SAP 2016 default)		0	0	0	0
Option 1	0.55	**Fully filled 50mm cavity**: as above plus 50mm blown fibre (mineral wool) insulation (λ = 0.040 W/m.K)		7	10	8	10
Option 2	0.24	**Fully filled 50mm cavity (as above) plus 50mm internal insulation**: dot+dabs, 50mm insulation (λ = 0.020 W/m.K), plasterboard, 3mm plaster skim		97	148	100	152
Option 3	0.18	**Fully filled 50mm cavity (as above) plus 80mm internal insulation**: dot+dabs, 80mm insulation (λ = 0.020 W/m.K), plasterboard, 3mm plaster skim		103	154	106	159
Option 4	0.22	**Fully filled 50mm cavity (as above) plus 100mm external insulation:** standard EPS or mineral wool (λ = around 0.036 W/m.K), render - e.g. mineral wool, various EPS boards		107	149	110	153
Option 5	0.14	**Fully filled 50mm cavity (as above) plus 200mm external insulation:** standard EPS or mineral wool (λ = around 0.036 W/m.K), render - e.g. mineral wool, various EPS boards		130	161	134	167
Option 6	0.32	**50mm internal insulation (unfilled cavity):** dot+dabs, 50mm insulation (λ = 0.020 W/m.K), plasterboard, 3mm plaster skim		90	138	92	142
Option 7	0.22	**80mm internal insulation (unfilled cavity):** dot+dabs, 80mm insulation (λ = 0.020 W/m.K), plasterboard, 3mm plaster skim		96	144	99	149

Option	Performance rating (W/m^2K)	Specification	Unit	Cost (£ per unit)			
				2016		2017	
				House	Flat	House	Flat
Solid Walls			Per m² of wall area				
Base case (for information)	1.7	**None – uninsulated solid wall**: 225mm brick wall, 13mm dense plaster (adjusted to match proposed SAP 2016 default U-value)		0	0	0	0
Option 1	0.3	As above plus 50mm internal insulation: 25mm x 47mm timber battens at 600mm centres, 50mm insulation (λ = 0.020 W/m.K) backed on 12.5mm plasterboard, 3mm plaster skim		94	142	97	147
Option 2	0.21	As above plus 80mm internal insulation: 25mm x 47mm timber battens at 600mm centres, 80mm insulation (λ = 0.020 W/m.K) backed on 12.5mm plasterboard, 3mm plaster skim		100	148	103	153
Option 3	0.3	100mm external insulation: standard EPS or mineral wool (λ = around 0.036 W/m.K), render - e.g. mineral wool, various EPS boards		100	139	103	144
Option 4	0.17	200mm external insulation: standard EPS or mineral wool (λ = around 0.036 W/m.K), render - e.g. mineral wool, various EPS boards		123	152	126	157
Roof			Per m² of roof area				
Base case (for information)	0.68	50mm mineral wool insulation		0	0	0	0
Option 1	0.29	150mm mineral wool insulation quilt above joists		8	8	8	8
Option 2	0.13	150mm mineral wool insulation quilt between joists PLUS 150mm above joists		11	11	11	11
Option 3	0.11	150mm mineral wool insulation quilt between joists PLUS 200mm above joists		11	11	11	11
Windows			Per m² of window area				
Base case (for information)	3.1	Double glazed		0	0	0	0
Option 1	1.6	Double glazed U-PVC windows (g-value 0.63)		253	259	262	268
Option 2	1.4	Double glazed U-PVC windows (g-value 0.63)		287	292	296	302
Option 3	1.2	Double glazed U-PVC windows (g-value 0.63)		416	416	429	429
Option 4	0.9	Triple glazed U-PVC windows (g-value 0.57)		489	489	504	504

Heating

Table 5.15 shows the developed cost data for the different heating systems analysed, as well as the asset lifetimes.

Table 5.15: Cost data for heating systems (per unit)

Service type	*Specification*	*Life expectancy*	*Cost (£ per unit)*			
			2016		*2017*	
			House	*Flat*	*House*	*Flat*
New gas boiler (combi), controls and pipework insulation	Boiler + controls + valves	15	£4,210	£3,950	£4,345	£4,076
	Pipework (gas and dhw)	40	£600	£350	£619	£361
	No lifecycle (i.e. strip out costs)	0	£650	£450	£657	£464
	Total		**£5,460**	**£4750**	**£5,635**	**£4,902**
New gas boiler (communal for flats) and solar water heating	Boilers + controls + valves	15	£4,420	£3,003	£4,561	£3,099
	Hot water cylinder	20	£1,760	£1,360	£1,816	£1,404
	Solar thermal panels	25	£3,400	£3,400	£3,509	£3,509
	Pipework (gas and dhw)	40	£600	£350	£619	£361
	No lifecycle (i.e. strip out costs)	0	£650	£667	£657	£688
	Total		**£10,830**	**£8,780**	**£11,177**	**£9,061**
Replace gas boiler with ASHP and add new low temp radiators	ASHP + controls + valves	15	£6,120	£5,480	£6,316	£5,655
	Hot water cylinder+ radiators	20	£1,490	£990	£1,538	£1,022
	Pipework (gas and dhw)	40	£600	£350	£619	£361
	No lifecycle (i.e. strip out costs)	0	£1,130	£930	£1,166	£960
	Total		**£9,340**	**£7,750**	**£9,639**	**£7,998**

5.3.2 Other cost information

Maintenance costs, projected cost reductions, energy prices and cost of greenhouse gas emissions used are the same as for new homes provided in Section 5.2.
In addition, the same discount rates were used as for new homes.

5.3.3 Results of the cost calculations

The following Tables summarise the results of the cost calculations for the most cost-optimal packages in each of the two reference buildings. Table 5.16 relates to the macroeconomic calculations and Table 5.17 relates to the financial calculations.

- Table 5.16a / Table 5.17a: Central energy price, central discount factors
- Table 5.16b / Table 5.17b: Low energy price, central discount factors
- Table 5.16c / Table 5.17c: High energy price, central discount factors
- Table 5.16d / Table 5.17d: Central energy price, alternative discount factors
- Table 5.16e: central energy price, central discount factor, alternative cost of carbon

The sensitivity analysis shows that with lower energy prices there is a tendency for fabric improvements with higher primary energy to become relatively more favourable. Where the costs are similar for different levels of fabric performance (additional roof insulation, solid wall insulation), the cost optimal level includes solutions with a higher primary energy at lower energy prices.

Table 5.16a: Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Dwelling Type	Wall Type	Package	Value	PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Semi Detached	*50mm Cavity*	Wall U-Value	0.14	271	128	0	121	27	-24	253
		Wall U-Value	0.18	274	99	0	122	28	-18	230
		Wall U-Value	0.22a	277	104	0	123	28	-19	236
		Wall U-Value	0.22b	277	92	0	123	28	-17	226
		Wall U-Value	0.24	278	93	0	124	28	-17	228
		Wall U-Value	0.32	284	86	0	126	29	-16	225
		Wall U-Value	0.55	300	7	0	133	30	-1	169
		Window U-value	0.9	346	88	0	151	35	0	274
		Window U-value	1.2	347	74	0	152	36	0	262
		Window U-value	1.4	350	51	0	153	36	0	240
		Window U-value	1.6	352	45	0	154	36	0	235
		Heating Source	ASHP	305	164	23	232	16	-4	430
		Heating Source	Gas + SHW	318	188	33	139	33	-13	379
		Heating Source	Gas 88%	350	97	33	153	36	-1	319
		Roof U-value	0.11	343	5	0	150	35	-1	190
		Roof U-value	0.13	344	5	0	150	35	-1	190
		Roof U-value	0.29	350	4	0	153	36	-1	192
Apartment Block	*50mm Cavity*	Wall U-Value	0.14	182	69	0	85	18	-13	159
		Wall U-Value	0.18	183	62	0	85	18	-11	154
		Wall U-Value	0.22a	184	62	0	86	18	-11	154
		Wall U-Value	0.22b	184	59	0	86	18	-11	152
		Wall U-Value	0.24	184	60	0	86	18	-11	153
		Wall U-Value	0.32	187	56	0	87	18	-10	151
		Wall U-Value	0.55	193	4	0	89	19	-1	111
		Window U-value	0.9	197	99	0	91	19	0	209
		Window U-value	1.2	199	84	0	92	20	0	196
		Window U-value	1.4	201	59	0	93	20	0	172
		Window U-value	1.6	203	52	0	94	20	0	166
		Heating Source	Gas + SHW	181	181	66	83	18	-14	334
		Heating Source	ASHP	184	165	27	168	5	-3	362
		Heating Source	Gas 88%	207	105	40	95	20	0	259
		Roof U-value	0.11	205	4	0	94	20	-1	117
		Roof U-value	0.13	205	4	0	94	20	-1	118
		Roof U-value	0.29	209	3	0	96	21	-1	119
Semi Detached	*Solid*	Wall U-Value	0.17	253	121	0	114	25	-22	238
		Wall U-Value	0.21	256	96	0	115	26	-18	219
		Wall U-Value	0.30a	263	90	0	118	26	-17	217
		Wall U-Value	0.30b	263	97	0	118	26	-18	223
		Window U-value	0.9	341	88	0	149	35	0	272
		Window U-value	1.2	343	74	0	150	35	0	259
		Window U-value	1.4	345	51	0	151	35	0	237
		Window U-value	1.6	347	45	0	152	36	0	233
		Heating Source	ASHP	301	164	23	229	16	-4	427
		Heating Source	Gas + SHW	313	188	33	137	32	-13	377
		Heating Source	Gas 88%	346	97	33	151	35	-1	316
		Roof U-value	0.11	339	5	0	148	35	-1	187
		Roof U-value	0.13	339	5	0	149	35	-1	188

		Roof U-value	0.29	345	4	0	151	35	-1	190
Apartment Block	*Solid*	Wall U-Value	0.17	169	65	0	80	16	-12	149
		Wall U-Value	0.21	170	60	0	80	16	-11	146
		Wall U-Value	0.30a	172	58	0	81	17	-11	145
		Wall U-Value	0.30b	172	57	0	81	17	-11	145
		Window U-value	0.9	189	99	0	88	18	0	205
		Window U-value	1.2	191	84	0	89	19	0	192
		Window U-value	1.4	193	59	0	90	19	0	168
		Window U-value	1.6	196	52	0	90	19	0	162
		Heating Source	Gas + SHW	174	181	66	80	17	-14	330
		Heating Source	ASHP	178	165	27	162	5	-3	356
		Heating Source	Gas 88%	199	105	40	92	20	0	256
		Roof U-value	0.11	197	4	0	91	19	-1	113
		Roof U-value	0.13	197	4	0	91	19	-1	114
		Roof U-value	0.29	201	3	0	93	20	-1	115

Table 5.16b: Macroeconomic Costs (Low energy price, 3.5% discount rate, £/m²)

Dwelling Type	Wall Type	Package	Value	PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Semi Detached	*50mm Cavity*	Wall U-Value	0.14	271	128	0	85	27	-24	216
		Wall U-Value	0.18	274	99	0	85	28	-18	193
		Wall U-Value	0.22a	277	104	0	86	28	-19	199
		Wall U-Value	0.22b	277	92	0	86	28	-17	189
		Wall U-Value	0.24	278	93	0	87	28	-17	191
		Wall U-Value	0.32	284	86	0	88	29	-16	187
		Wall U-Value	0.55	300	7	0	92	30	-1	129
		Window U-value	0.9	346	88	0	105	35	0	227
		Window U-value	1.2	347	74	0	105	36	0	215
		Window U-value	1.4	350	51	0	106	36	0	193
		Window U-value	1.6	352	45	0	106	36	0	188
		Heating Source	ASHP	305	164	23	202	16	-4	400
		Heating Source	Gas + SHW	318	188	33	96	33	-13	336
		Heating Source	Gas 88%	350	97	33	106	36	-1	271
		Roof U-value	0.11	343	5	0	104	35	-1	143
		Roof U-value	0.13	344	5	0	104	35	-1	144
		Roof U-value	0.29	350	4	0	106	36	-1	145
Apartment Block	*50mm Cavity*	Wall U-Value	0.14	182	69	0	61	18	-13	135
		Wall U-Value	0.18	183	62	0	61	18	-11	130
		Wall U-Value	0.22a	184	62	0	61	18	-11	130
		Wall U-Value	0.22b	184	59	0	61	18	-11	127
		Wall U-Value	0.24	184	60	0	62	18	-11	128
		Wall U-Value	0.32	187	56	0	62	18	-10	126
		Wall U-Value	0.55	193	4	0	64	19	-1	86
		Window U-value	0.9	197	99	0	65	19	0	183
		Window U-value	1.2	199	84	0	65	20	0	169
		Window U-value	1.4	201	59	0	66	20	0	145
		Window U-value	1.6	203	52	0	67	20	0	139
		Heating Source	Gas + SHW	181	181	66	59	18	-14	310
		Heating Source	ASHP	184	165	27	153	5	-3	347
		Heating Source	Gas 88%	207	105	40	68	20	0	232
		Roof U-value	0.11	205	4	0	67	20	-1	90
		Roof U-value	0.13	205	4	0	67	20	-1	90
		Roof U-value	0.29	209	3	0	68	21	-1	91
Semi Detached	*Solid*	Wall U-Value	0.17	253	121	0	80	25	-22	204
		Wall U-Value	0.21	256	96	0	81	26	-18	184
		Wall U-Value	0.30a	263	90	0	82	26	-17	182
		Wall U-Value	0.30b	263	97	0	82	26	-18	188
		Window U-value	0.9	341	88	0	103	35	0	226
		Window U-value	1.2	343	74	0	104	35	0	213
		Window U-value	1.4	345	51	0	104	35	0	191
		Window U-value	1.6	347	45	0	105	36	0	186
		Heating Source	ASHP	301	164	23	199	16	-4	397
		Heating Source	Gas + SHW	313	188	33	94	32	-13	335
		Heating Source	Gas 88%	346	97	33	105	35	-1	270
		Roof U-value	0.11	339	5	0	103	35	-1	142
		Roof U-value	0.13	339	5	0	103	35	-1	142

		Roof U-value	0.29	345	4	0	104	35	-1	143
Apartment Block	*Solid*	Wall U-Value	0.17	169	65	0	57	16	-12	127
		Wall U-Value	0.21	170	60	0	58	16	-11	123
		Wall U-Value	0.30a	172	58	0	58	17	-11	122
		Wall U-Value	0.30b	172	57	0	58	17	-11	122
		Window U-value	0.9	189	99	0	63	18	0	180
		Window U-value	1.2	191	84	0	63	19	0	166
		Window U-value	1.4	193	59	0	64	19	0	142
		Window U-value	1.6	196	52	0	65	19	0	136
		Heating Source	Gas + SHW	174	181	66	57	17	-14	307
		Heating Source	ASHP	178	165	27	148	5	-3	342
		Heating Source	Gas 88%	199	105	40	66	20	0	229
		Roof U-value	0.11	197	4	0	65	19	-1	87
		Roof U-value	0.13	197	4	0	65	19	-1	88
		Roof U-value	0.29	201	3	0	66	20	-1	88

Table 5.16c: Macroeconomic Costs (High energy price, 3.5% discount rate, £/m²)

Dwelling Type	Wall Type	Package	Value	PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Semi Detached	*50mm Cavity*	Wall U-Value	0.14	271	128	0	164	27	-24	296
		Wall U-Value	0.18	274	99	0	166	28	-18	274
		Wall U-Value	0.22a	277	104	0	168	28	-19	281
		Wall U-Value	0.22b	277	92	0	168	28	-17	270
		Wall U-Value	0.24	278	93	0	169	28	-17	272
		Wall U-Value	0.32	284	86	0	172	29	-16	270
		Wall U-Value	0.55	300	7	0	181	30	-1	217
		Window U-value	0.9	346	88	0	207	35	0	330
		Window U-value	1.2	347	74	0	208	36	0	318
		Window U-value	1.4	350	51	0	209	36	0	296
		Window U-value	1.6	352	45	0	211	36	0	292
		Heating Source	ASHP	305	164	23	265	16	-4	463
		Heating Source	Gas + SHW	318	188	33	190	33	-13	431
		Heating Source	Gas 88%	350	97	33	210	36	-1	375
		Roof U-value	0.11	343	5	0	206	35	-1	245
		Roof U-value	0.13	344	5	0	206	35	-1	246
		Roof U-value	0.29	350	4	0	209	36	-1	249
Apartment Block	*50mm Cavity*	Wall U-Value	0.14	182	69	0	113	18	-13	187
		Wall U-Value	0.18	183	62	0	114	18	-11	183
		Wall U-Value	0.22a	184	62	0	115	18	-11	183
		Wall U-Value	0.22b	184	59	0	115	18	-11	181
		Wall U-Value	0.24	184	60	0	115	18	-11	182
		Wall U-Value	0.32	187	56	0	116	18	-10	180
		Wall U-Value	0.55	193	4	0	120	19	-1	142
		Window U-value	0.9	197	99	0	122	19	0	240
		Window U-value	1.2	199	84	0	123	20	0	227
		Window U-value	1.4	201	59	0	124	20	0	204
		Window U-value	1.6	203	52	0	126	20	0	198
		Heating Source	Gas + SHW	181	181	66	112	18	-14	363
		Heating Source	ASHP	184	165	27	182	5	-3	377
		Heating Source	Gas 88%	207	105	40	128	20	0	292
		Roof U-value	0.11	205	4	0	127	20	-1	150
		Roof U-value	0.13	205	4	0	127	20	-1	150
		Roof U-value	0.29	209	3	0	129	21	-1	152
Semi Detached	*Solid*	Wall U-Value	0.17	253	121	0	154	25	-22	278
		Wall U-Value	0.21	256	96	0	156	26	-18	260
		Wall U-Value	0.30a	263	90	0	160	26	-17	259
		Wall U-Value	0.30b	263	97	0	160	26	-18	265
		Window U-value	0.9	341	88	0	204	35	0	327
		Window U-value	1.2	343	74	0	205	35	0	315
		Window U-value	1.4	345	51	0	207	35	0	293
		Window U-value	1.6	347	45	0	208	36	0	289
		Heating Source	ASHP	301	164	23	261	16	-4	459
		Heating Source	Gas + SHW	313	188	33	188	32	-13	428
		Heating Source	Gas 88%	346	97	33	207	35	-1	372
		Roof U-value	0.11	339	5	0	203	35	-1	242
		Roof U-value	0.13	339	5	0	203	35	-1	243

		Roof U-value	0.29	345	4	0	207	35	-1	245
Apartment Block	*Solid*	Wall U-Value	0.17	169	65	0	106	16	-12	175
		Wall U-Value	0.21	170	60	0	107	16	-11	172
		Wall U-Value	0.30a	172	58	0	108	17	-11	172
		Wall U-Value	0.30b	172	57	0	108	17	-11	172
		Window U-value	0.9	189	99	0	117	18	0	235
		Window U-value	1.2	191	84	0	119	19	0	222
		Window U-value	1.4	193	59	0	120	19	0	198
		Window U-value	1.6	196	52	0	121	19	0	193
		Heating Source	Gas + SHW	174	181	66	108	17	-14	358
		Heating Source	ASHP	178	165	27	176	5	-3	370
		Heating Source	Gas 88%	199	105	40	123	20	0	287
		Roof U-value	0.11	197	4	0	122	19	-1	144
		Roof U-value	0.13	197	4	0	122	19	-1	145
		Roof U-value	0.29	201	3	0	124	20	-1	146

Table 5.16d: Macroeconomic Costs (Central energy price, 3% discount rate, £/m²)

Dwelling Type	Wall Type	Package	Value	PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Semi Detached	*50mm Cavity*	Wall U-Value	0.14	271	128	0	164	27	-24	296
		Wall U-Value	0.18	274	99	0	166	28	-18	274
		Wall U-Value	0.22a	277	104	0	168	28	-19	281
		Wall U-Value	0.22b	277	92	0	168	28	-17	270
		Wall U-Value	0.24	278	93	0	169	28	-17	272
		Wall U-Value	0.32	284	86	0	172	29	-16	270
		Wall U-Value	0.55	300	7	0	181	30	-1	217
		Window U-value	0.9	346	88	0	207	35	0	330
		Window U-value	1.2	347	74	0	208	36	0	318
		Window U-value	1.4	350	51	0	209	36	0	296
		Window U-value	1.6	352	45	0	211	36	0	292
		Heating Source	ASHP	305	164	23	265	16	-4	463
		Heating Source	Gas + SHW	318	188	33	190	33	-13	431
		Heating Source	Gas 88%	350	97	33	210	36	-1	375
		Roof U-value	0.11	343	5	0	206	35	-1	245
		Roof U-value	0.13	344	5	0	206	35	-1	246
		Roof U-value	0.29	350	4	0	209	36	-1	249
Apartment Block	*50mm Cavity*	Wall U-Value	0.14	182	69	0	113	18	-13	187
		Wall U-Value	0.18	183	62	0	114	18	-11	183
		Wall U-Value	0.22a	184	62	0	115	18	-11	183
		Wall U-Value	0.22b	184	59	0	115	18	-11	181
		Wall U-Value	0.24	184	60	0	115	18	-11	182
		Wall U-Value	0.32	187	56	0	116	18	-10	180
		Wall U-Value	0.55	193	4	0	120	19	-1	142
		Window U-value	0.9	197	99	0	122	19	0	240
		Window U-value	1.2	199	84	0	123	20	0	227
		Window U-value	1.4	201	59	0	124	20	0	204
		Window U-value	1.6	203	52	0	126	20	0	198
		Heating Source	Gas + SHW	181	181	66	112	18	-14	363
		Heating Source	ASHP	184	165	27	182	5	-3	377
		Heating Source	Gas 88%	207	105	40	128	20	0	292
		Roof U-value	0.11	205	4	0	127	20	-1	150
		Roof U-value	0.13	205	4	0	127	20	-1	150
		Roof U-value	0.29	209	3	0	129	21	-1	152
Semi Detached	*Solid*	Wall U-Value	0.17	253	121	0	154	25	-22	278
		Wall U-Value	0.21	256	96	0	156	26	-18	260
		Wall U-Value	0.30a	263	90	0	160	26	-17	259
		Wall U-Value	0.30b	263	97	0	160	26	-18	265
		Window U-value	0.9	341	88	0	204	35	0	327
		Window U-value	1.2	343	74	0	205	35	0	315
		Window U-value	1.4	345	51	0	207	35	0	293
		Window U-value	1.6	347	45	0	208	36	0	289
		Heating Source	ASHP	301	164	23	261	16	-4	459
		Heating Source	Gas + SHW	313	188	33	188	32	-13	428
		Heating Source	Gas 88%	346	97	33	207	35	-1	372
		Roof U-value	0.11	339	5	0	203	35	-1	242
		Roof U-value	0.13	339	5	0	203	35	-1	243

		Roof U-value	0.29	345	4	0	207	35	-1	245
Apartment Block	*Solid*	Wall U-Value	0.17	169	65	0	106	16	-12	175
		Wall U-Value	0.21	170	60	0	107	16	-11	172
		Wall U-Value	0.30a	172	58	0	108	17	-11	172
		Wall U-Value	0.30b	172	57	0	108	17	-11	172
		Window U-value	0.9	189	99	0	117	18	0	235
		Window U-value	1.2	191	84	0	119	19	0	222
		Window U-value	1.4	193	59	0	120	19	0	198
		Window U-value	1.6	196	52	0	121	19	0	193
		Heating Source	Gas + SHW	174	181	66	108	17	-14	358
		Heating Source	ASHP	178	165	27	176	5	-3	370
		Heating Source	Gas 88%	199	105	40	123	20	0	287
		Roof U-value	0.11	197	4	0	122	19	-1	144
		Roof U-value	0.13	197	4	0	122	19	-1	145
		Roof U-value	0.29	201	3	0	124	20	-1	146

Table 5.16e: Macroeconomic Costs (Central energy price, 3.5% discount rate, Alternative Cost of Carbon £/m²)

Dwelling Type	Wall Type	Package	Value	PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Semi Detached	*50mm Cavity*	Wall U-Value	0.14	271	128	0	164	27	-24	296
		Wall U-Value	0.18	274	99	0	166	28	-18	274
		Wall U-Value	0.22a	277	104	0	168	28	-19	281
		Wall U-Value	0.22b	277	92	0	168	28	-17	270
		Wall U-Value	0.24	278	93	0	169	28	-17	272
		Wall U-Value	0.32	284	86	0	172	29	-16	270
		Wall U-Value	0.55	300	7	0	181	30	-1	217
		Window U-value	0.9	346	88	0	207	35	0	330
		Window U-value	1.2	347	74	0	208	36	0	318
		Window U-value	1.4	350	51	0	209	36	0	296
		Window U-value	1.6	352	45	0	211	36	0	292
		Heating Source	ASHP	305	164	23	265	16	-4	463
		Heating Source	Gas + SHW	318	188	33	190	33	-13	431
		Heating Source	Gas 88%	350	97	33	210	36	-1	375
		Roof U-value	0.11	343	5	0	206	35	-1	245
		Roof U-value	0.13	344	5	0	206	35	-1	246
		Roof U-value	0.29	350	4	0	209	36	-1	249
Apartment Block	*50mm Cavity*	Wall U-Value	0.14	182	69	0	113	18	-13	187
		Wall U-Value	0.18	183	62	0	114	18	-11	183
		Wall U-Value	0.22a	184	62	0	115	18	-11	183
		Wall U-Value	0.22b	184	59	0	115	18	-11	181
		Wall U-Value	0.24	184	60	0	115	18	-11	182
		Wall U-Value	0.32	187	56	0	116	18	-10	180
		Wall U-Value	0.55	193	4	0	120	19	-1	142
		Window U-value	0.9	197	99	0	122	19	0	240
		Window U-value	1.2	199	84	0	123	20	0	227
		Window U-value	1.4	201	59	0	124	20	0	204
		Window U-value	1.6	203	52	0	126	20	0	198
		Heating Source	Gas + SHW	181	181	66	112	18	-14	363
		Heating Source	ASHP	184	165	27	182	5	-3	377
		Heating Source	Gas 88%	207	105	40	128	20	0	292
		Roof U-value	0.11	205	4	0	127	20	-1	150
		Roof U-value	0.13	205	4	0	127	20	-1	150
		Roof U-value	0.29	209	3	0	129	21	-1	152
Semi Detached	*Solid*	Wall U-Value	0.17	253	121	0	154	25	-22	278
		Wall U-Value	0.21	256	96	0	156	26	-18	260
		Wall U-Value	0.30a	263	90	0	160	26	-17	259
		Wall U-Value	0.30b	263	97	0	160	26	-18	265
		Window U-value	0.9	341	88	0	204	35	0	327
		Window U-value	1.2	343	74	0	205	35	0	315
		Window U-value	1.4	345	51	0	207	35	0	293
		Window U-value	1.6	347	45	0	208	36	0	289
		Heating Source	ASHP	301	164	23	261	16	-4	459
		Heating Source	Gas + SHW	313	188	33	188	32	-13	428
		Heating Source	Gas 88%	346	97	33	207	35	-1	372
		Roof U-value	0.11	339	5	0	203	35	-1	242

		Roof U-value	0.13	339	5	0	203	35	-1	243
		Roof U-value	0.29	345	4	0	207	35	-1	245
Apartment Block	*Solid*	Wall U-Value	0.17	169	65	0	106	16	-12	175
		Wall U-Value	0.21	170	60	0	107	16	-11	172
		Wall U-Value	0.30a	172	58	0	108	17	-11	172
		Wall U-Value	0.30b	172	57	0	108	17	-11	172
		Window U-value	0.9	189	99	0	117	18	0	235
		Window U-value	1.2	191	84	0	119	19	0	222
		Window U-value	1.4	193	59	0	120	19	0	198
		Window U-value	1.6	196	52	0	121	19	0	193
		Heating Source	Gas + SHW	174	181	66	108	17	-14	358
		Heating Source	ASHP	178	165	27	176	5	-3	370
		Heating Source	Gas 88%	199	105	40	123	20	0	287
		Roof U-value	0.11	197	4	0	122	19	-1	144
		Roof U-value	0.13	197	4	0	122	19	-1	145
		Roof U-value	0.29	201	3	0	124	20	-1	146

Table 5.17a: Financial Costs (Central energy price, 6% discount rate, £/m²)

Dwelling Type	Wall Type	Package	Value	PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Semi Detached	*50mm Cavity*	Wall U-Value	0.14	271	154	0	211	-	-14	350
		Wall U-Value	0.18	274	118	0	213	-	-11	320
		Wall U-Value	0.22a	277	125	0	215	-	-12	329
		Wall U-Value	0.22b	277	110	0	215	-	-10	315
		Wall U-Value	0.24	278	112	0	216	-	-10	318
		Wall U-Value	0.32	284	103	0	220	-	-9	314
		Wall U-Value	0.55	300	8	0	232	-	-1	240
		Window U-value	0.9	346	105	0	265	-	0	370
		Window U-value	1.2	347	89	0	266	-	0	355
		Window U-value	1.4	350	62	0	268	-	0	329
		Window U-value	1.6	352	54	0	269	-	0	324
		Heating Source	ASHP	305	178	21	372	-	-2	567
		Heating Source	Gas + SHW	318	202	30	243	-	-8	467
		Heating Source	Gas 88%	350	106	30	268	-	0	404
		Roof U-value	0.11	343	7	0	263	-	-1	269
		Roof U-value	0.13	344	7	0	264	-	-1	270
		Roof U-value	0.29	350	5	0	268	-	0	272
Apartment Block	*50mm Cavity*	Wall U-Value	0.14	182	83	0	147	-	-8	222
		Wall U-Value	0.18	183	75	0	147	-	-7	215
		Wall U-Value	0.22a	184	75	0	148	-	-7	216
		Wall U-Value	0.22b	184	71	0	148	-	-7	212
		Wall U-Value	0.24	184	72	0	149	-	-7	214
		Wall U-Value	0.32	187	67	0	150	-	-6	211
		Wall U-Value	0.55	193	5	0	154	-	0	159
		Window U-value	0.9	197	119	0	157	-	0	276
		Window U-value	1.2	199	101	0	159	-	0	260
		Window U-value	1.4	201	71	0	161	-	0	232
		Window U-value	1.6	203	63	0	162	-	0	225
		Heating Source	Gas + SHW	181	195	60	144	-	-9	390
		Heating Source	ASHP	184	179	25	262	-	-2	464
		Heating Source	Gas 88%	207	113	36	165	-	0	313
		Roof U-value	0.11	205	4	0	163	-	0	167
		Roof U-value	0.13	205	4	0	164	-	0	168
		Roof U-value	0.29	209	3	0	166	-	0	169
Semi Detached	*Solid*	Wall U-Value	0.17	253	145	0	198	-	-13	330
		Wall U-Value	0.21	256	115	0	200	-	-11	304
		Wall U-Value	0.30a	263	108	0	205	-	-10	303
		Wall U-Value	0.30b	263	117	0	205	-	-11	311
		Window U-value	0.9	341	105	0	261	-	0	366
		Window U-value	1.2	343	89	0	263	-	0	352
		Window U-value	1.4	345	62	0	264	-	0	326
		Window U-value	1.6	347	54	0	266	-	0	320
		Heating Source	ASHP	301	178	21	366	-	-2	562
		Heating Source	Gas + SHW	313	202	30	240	-	-8	464
		Heating Source	Gas 88%	346	106	30	265	-	0	400
		Roof U-value	0.11	339	7	0	260	-	-1	266
		Roof U-value	0.13	339	7	0	260	-	-1	266

		Roof U-value	0.29	345	5	0	264	-	0	269
Apartment Block	*Solid*	Wall U-Value	0.17	169	78	0	137	-	-7	208
		Wall U-Value	0.21	170	72	0	138	-	-7	204
		Wall U-Value	0.30a	172	69	0	140	-	-6	203
		Wall U-Value	0.30b	172	69	0	140	-	-6	202
		Window U-value	0.9	189	119	0	152	-	0	270
		Window U-value	1.2	191	101	0	153	-	0	254
		Window U-value	1.4	193	71	0	155	-	0	226
		Window U-value	1.6	196	63	0	157	-	0	220
		Heating Source	Gas + SHW	174	195	60	139	-	-9	385
		Heating Source	ASHP	178	179	25	254	-	-2	456
		Heating Source	Gas 88%	199	113	36	159	-	0	308
		Roof U-value	0.11	197	4	0	158	-	0	162
		Roof U-value	0.13	197	4	0	158	-	0	162
		Roof U-value	0.29	201	3	0	161	-	0	164

Table 5.17b: Financial Costs (Low energy price, 6% discount rate, £/m²)

Dwelling Type	Wall Type	Package	Value	PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Semi Detached	*50mm Cavity*	Wall U-Value	0.14	271	154	0	172	-	-14	312
		Wall U-Value	0.18	274	118	0	174	-	-11	281
		Wall U-Value	0.22a	277	125	0	176	-	-12	289
		Wall U-Value	0.22b	277	110	0	176	-	-10	275
		Wall U-Value	0.24	278	112	0	177	-	-10	278
		Wall U-Value	0.32	284	103	0	180	-	-9	273
		Wall U-Value	0.55	300	8	0	189	-	-1	197
		Window U-value	0.9	346	105	0	215	-	0	320
		Window U-value	1.2	347	89	0	216	-	0	306
		Window U-value	1.4	350	62	0	217	-	0	279
		Window U-value	1.6	352	54	0	219	-	0	273
		Heating Source	ASHP	305	178	21	338	-	-2	534
		Heating Source	Gas + SHW	318	202	30	197	-	-8	422
		Heating Source	Gas 88%	350	106	30	218	-	0	353
		Roof U-value	0.11	343	7	0	214	-	-1	220
		Roof U-value	0.13	344	7	0	214	-	-1	220
		Roof U-value	0.29	350	5	0	218	-	0	222
Apartment Block	*50mm Cavity*	Wall U-Value	0.14	182	83	0	121	-	-8	196
		Wall U-Value	0.18	183	75	0	122	-	-7	190
		Wall U-Value	0.22a	184	75	0	122	-	-7	190
		Wall U-Value	0.22b	184	71	0	122	-	-7	187
		Wall U-Value	0.24	184	72	0	123	-	-7	188
		Wall U-Value	0.32	187	67	0	124	-	-6	185
		Wall U-Value	0.55	193	5	0	127	-	0	132
		Window U-value	0.9	197	119	0	130	-	0	248
		Window U-value	1.2	199	101	0	131	-	0	232
		Window U-value	1.4	201	71	0	132	-	0	203
		Window U-value	1.6	203	63	0	134	-	0	197
		Heating Source	Gas + SHW	181	195	60	119	-	-9	365
		Heating Source	ASHP	184	179	25	245	-	-2	447
		Heating Source	Gas 88%	207	113	36	135	-	0	284
		Roof U-value	0.11	205	4	0	134	-	0	138
		Roof U-value	0.13	205	4	0	135	-	0	139
		Roof U-value	0.29	209	3	0	137	-	0	140
Semi Detached	*Solid*	Wall U-Value	0.17	253	145	0	162	-	-13	294
		Wall U-Value	0.21	256	115	0	164	-	-11	268
		Wall U-Value	0.30a	263	108	0	168	-	-10	266
		Wall U-Value	0.30b	263	117	0	168	-	-11	274
		Window U-value	0.9	341	105	0	213	-	0	318
		Window U-value	1.2	343	89	0	214	-	0	303
		Window U-value	1.4	345	62	0	215	-	0	276
		Window U-value	1.6	347	54	0	216	-	0	271
		Heating Source	ASHP	301	178	21	333	-	-2	529
		Heating Source	Gas + SHW	313	202	30	195	-	-8	419
		Heating Source	Gas 88%	346	106	30	215	-	0	351
		Roof U-value	0.11	339	7	0	211	-	-1	217
		Roof U-value	0.13	339	7	0	212	-	-1	218

		Roof U-value	0.29	345	5	0	215	-	0	219
Apartment Block	*Solid*	Wall U-Value	0.17	169	78	0	114	-	-7	185
		Wall U-Value	0.21	170	72	0	114	-	-7	180
		Wall U-Value	0.30a	172	69	0	116	-	-6	179
		Wall U-Value	0.30b	172	69	0	116	-	-6	178
		Window U-value	0.9	189	119	0	125	-	0	244
		Window U-value	1.2	191	101	0	126	-	0	228
		Window U-value	1.4	193	71	0	128	-	0	199
		Window U-value	1.6	196	63	0	129	-	0	192
		Heating Source	Gas + SHW	174	195	60	114	-	-9	361
		Heating Source	ASHP	178	179	25	237	-	-2	439
		Heating Source	Gas 88%	199	113	36	131	-	0	280
		Roof U-value	0.11	197	4	0	130	-	0	134
		Roof U-value	0.13	197	4	0	130	-	0	134
		Roof U-value	0.29	201	3	0	132	-	0	135

Table 5.17c: Financial Costs (High energy price, 6% discount rate, £/m²)

Dwelling Type	Wall Type	Package	Value	PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Semi Detached	*50mm Cavity*	Wall U-Value	0.14	271	154	0	255	-	-14	394
		Wall U-Value	0.18	274	118	0	257	-	-11	364
		Wall U-Value	0.22a	277	125	0	260	-	-12	373
		Wall U-Value	0.22b	277	110	0	260	-	-10	359
		Wall U-Value	0.24	278	112	0	261	-	-10	362
		Wall U-Value	0.32	284	103	0	266	-	-9	359
		Wall U-Value	0.55	300	8	0	280	-	-1	288
		Window U-value	0.9	346	105	0	321	-	0	426
		Window U-value	1.2	347	89	0	322	-	0	412
		Window U-value	1.4	350	62	0	324	-	0	386
		Window U-value	1.6	352	54	0	326	-	0	381
		Heating Source	ASHP	305	178	21	405	-	-2	601
		Heating Source	Gas + SHW	318	202	30	294	-	-8	519
		Heating Source	Gas 88%	350	106	30	325	-	0	460
		Roof U-value	0.11	343	7	0	319	-	-1	325
		Roof U-value	0.13	344	7	0	319	-	-1	325
		Roof U-value	0.29	350	5	0	324	-	0	329
Apartment Block	*50mm Cavity*	Wall U-Value	0.14	182	83	0	175	-	-8	250
		Wall U-Value	0.18	183	75	0	176	-	-7	244
		Wall U-Value	0.22a	184	75	0	177	-	-7	245
		Wall U-Value	0.22b	184	71	0	177	-	-7	241
		Wall U-Value	0.24	184	72	0	178	-	-7	243
		Wall U-Value	0.32	187	67	0	180	-	-6	240
		Wall U-Value	0.55	193	5	0	185	-	0	189
		Window U-value	0.9	197	119	0	188	-	0	307
		Window U-value	1.2	199	101	0	190	-	0	292
		Window U-value	1.4	201	71	0	193	-	0	264
		Window U-value	1.6	203	63	0	195	-	0	258
		Heating Source	Gas + SHW	181	195	60	173	-	-9	419
		Heating Source	ASHP	184	179	25	278	-	-2	480
		Heating Source	Gas 88%	207	113	36	197	-	0	346
		Roof U-value	0.11	205	4	0	196	-	0	200
		Roof U-value	0.13	205	4	0	196	-	0	200
		Roof U-value	0.29	209	3	0	199	-	0	202
Semi Detached	*Solid*	Wall U-Value	0.17	253	145	0	239	-	-13	371
		Wall U-Value	0.21	256	115	0	241	-	-11	345
		Wall U-Value	0.30a	263	108	0	247	-	-10	345
		Wall U-Value	0.30b	263	117	0	247	-	-11	353
		Window U-value	0.9	341	105	0	317	-	0	422
		Window U-value	1.2	343	89	0	318	-	0	407
		Window U-value	1.4	345	62	0	320	-	0	382
		Window U-value	1.6	347	54	0	322	-	0	377
		Heating Source	ASHP	301	178	21	400	-	-2	595
		Heating Source	Gas + SHW	313	202	30	290	-	-8	515
		Heating Source	Gas 88%	346	106	30	321	-	0	456
		Roof U-value	0.11	339	7	0	315	-	-1	320
		Roof U-value	0.13	339	7	0	315	-	-1	321

		Roof U-value	0.29	345	5	0	320	-	0	325
Apartment Block	*Solid*	Wall U-Value	0.17	169	78	0	164	-	-7	235
		Wall U-Value	0.21	170	72	0	165	-	-7	230
		Wall U-Value	0.30a	172	69	0	167	-	-6	230
		Wall U-Value	0.30b	172	69	0	167	-	-6	229
		Window U-value	0.9	189	119	0	181	-	0	300
		Window U-value	1.2	191	101	0	183	-	0	284
		Window U-value	1.4	193	71	0	186	-	0	257
		Window U-value	1.6	196	63	0	188	-	0	251
		Heating Source	Gas + SHW	174	195	60	166	-	-9	413
		Heating Source	ASHP	178	179	25	269	-	-2	471
		Heating Source	Gas 88%	199	113	36	191	-	0	340
		Roof U-value	0.11	197	4	0	189	-	0	193
		Roof U-value	0.13	197	4	0	189	-	0	193
		Roof U-value	0.29	201	3	0	192	-	0	195

Table 5.17d: Financial Costs (Central energy price, 10% discount rate, £/m²)

Dwelling Type	Wall Type	Package	Value	PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Semi Detached	*50mm Cavity*	Wall U-Value	0.14	271	154	0	148	-	-5	297
		Wall U-Value	0.18	274	118	0	150	-	-4	264
		Wall U-Value	0.22a	277	125	0	151	-	-4	272
		Wall U-Value	0.22b	277	110	0	151	-	-3	258
		Wall U-Value	0.24	278	112	0	152	-	-4	260
		Wall U-Value	0.32	284	103	0	155	-	-3	254
		Wall U-Value	0.55	300	8	0	163	-	0	171
		Window U-value	0.9	346	105	0	186	-	0	291
		Window U-value	1.2	347	89	0	187	-	0	276
		Window U-value	1.4	350	62	0	188	-	0	250
		Window U-value	1.6	352	54	0	189	-	0	244
		Heating Source	ASHP	305	160	14	261	-	-1	434
		Heating Source	Gas + SHW	318	181	21	171	-	-3	370
		Heating Source	Gas 88%	350	95	21	189	-	0	304
		Roof U-value	0.11	343	7	0	185	-	0	191
		Roof U-value	0.13	344	7	0	185	-	0	192
		Roof U-value	0.29	350	5	0	188	-	0	193
Apartment Block	*50mm Cavity*	Wall U-Value	0.14	182	83	0	103	-	-3	183
		Wall U-Value	0.18	183	75	0	104	-	-2	176
		Wall U-Value	0.22a	184	75	0	104	-	-2	176
		Wall U-Value	0.22b	184	71	0	104	-	-2	173
		Wall U-Value	0.24	184	72	0	104	-	-2	174
		Wall U-Value	0.32	187	67	0	105	-	-2	170
		Wall U-Value	0.55	193	5	0	109	-	0	113
		Window U-value	0.9	197	119	0	111	-	0	229
		Window U-value	1.2	199	101	0	112	-	0	213
		Window U-value	1.4	201	71	0	113	-	0	184
		Window U-value	1.6	203	63	0	114	-	0	177
		Heating Source	Gas + SHW	181	175	42	101	-	-3	315
		Heating Source	ASHP	184	160	17	184	-	-1	361
		Heating Source	Gas 88%	207	101	25	116	-	0	241
		Roof U-value	0.11	205	4	0	115	-	0	119
		Roof U-value	0.13	205	4	0	115	-	0	119
		Roof U-value	0.29	209	3	0	117	-	0	120
Semi Detached	*Solid*	Wall U-Value	0.17	253	145	0	139	-	-5	280
		Wall U-Value	0.21	256	115	0	141	-	-4	252
		Wall U-Value	0.30a	263	108	0	144	-	-3	249
		Wall U-Value	0.30b	263	117	0	144	-	-4	257
		Window U-value	0.9	341	105	0	184	-	0	289
		Window U-value	1.2	343	89	0	185	-	0	274
		Window U-value	1.4	345	62	0	186	-	0	247
		Window U-value	1.6	347	54	0	187	-	0	241
		Heating Source	ASHP	301	160	14	257	-	-1	430
		Heating Source	Gas + SHW	313	181	21	168	-	-3	368
		Heating Source	Gas 88%	346	95	21	186	-	0	302
		Roof U-value	0.11	339	7	0	182	-	0	189
		Roof U-value	0.13	339	7	0	183	-	0	189

		Roof U-value	0.29	345	5	0	186	-	0	191
Apartment Block	*Solid*	Wall U-Value	0.17	169	78	0	97	-	-2	172
		Wall U-Value	0.21	170	72	0	97	-	-2	167
		Wall U-Value	0.30a	172	69	0	98	-	-2	165
		Wall U-Value	0.30b	172	69	0	98	-	-2	165
		Window U-value	0.9	189	119	0	106	-	0	225
		Window U-value	1.2	191	101	0	108	-	0	209
		Window U-value	1.4	193	71	0	109	-	0	180
		Window U-value	1.6	196	63	0	110	-	0	173
		Heating Source	Gas + SHW	174	175	42	98	-	-3	312
		Heating Source	ASHP	178	160	17	178	-	-1	355
		Heating Source	Gas 88%	199	101	25	112	-	0	238
		Roof U-value	0.11	197	4	0	111	-	0	115
		Roof U-value	0.13	197	4	0	111	-	0	115
		Roof U-value	0.29	201	3	0	113	-	0	116

5.4 Existing Buildings – Analysis of Packages

The underpinning costs and assumptions are consistent with that in Section 5.3 but with the addition of Photovoltaics (PV) costs shown in the table below.

Costs for have PV been developed from those published in August 2015 as previously described for new homes in Section 5.2.

These are shown in Table 5.18.

Table 5.18: Cost data for photovoltaic systems of varying sizes

Service type	***Specification***	***Cost (£ per unit)***
		2017
Houses	PV array (0.8kWp) - panels + rooftop installation	£675
	PV array (0.8kWp) - inverter and feed / distribution	£1,000
	PV array (1.6kWp) - panels + rooftop installation	£1,559
	PV array (1.6kWp) - inverter and feed / distribution	£1,000
Flats	PV array (5.3kWp) - panels and rooftop installation	£3,418
	PV array (5.3kWp) - inverters and feed / distribution	£3,000
	PV array (10.6kWp) - panels and rooftop installation	£8,130
	PV array (10.6kWp) - inverters and feed / distribution	£3,000

The following tables summarise the results of the cost calculations for the most cost-optimal packages in each of the four reference buildings. Table 5.19 relates to the macroeconomic calculations and Table 5.20 relate to the financial calculations.

- Table 5.19a / Table 5.20a: Central energy price, central discount factors
- Table 5.19b / Table 5.20b: Low energy price, central discount factors
- Table 5.19c / Table 5.20c: High energy price, central discount factors
- Table 5.19d / Table 5.20d: Central energy price, alternative discount factors
- Table 5.19e: Central energy price, central discount factor, alternative cost of carbon

Table 5.19a: Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Building	Package			PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Semi-detached - Cavity – 30 year calc	All+	ASHP	30%	156	348	23	124	9	-22	481
	All+	Gas + SHW	30%	162	367	33	66	19	-31	453
	All	ASHP	30%	180	256	23	141	10	-6	423
	All+	Gas	30%	181	282	33	73	21	-19	390
	All	Gas + SHW	30%	187	275	33	76	21	-15	390
	Roof + Wall	ASHP	30%	192	211	23	150	11	-6	388
	All	Gas	30%	206	190	33	84	23	-3	327
	Roof + Wall	Gas	30%	218	144	33	89	25	-3	288
	Roof + Wall	Gas	0%	254	110	33	113	26	-3	279
	None	Gas	0%	336	97	33	146	35	-1	310
Apartment block - Cavity – 30 year calc	All+	Gas + SHW	30%	85	314	66	36	10	-26	400
	All	Gas + SHW	30%	94	251	66	40	11	-16	352
	Roof + Wall	Gas + SHW	30%	105	198	66	45	12	-16	306
	All	Gas	30%	132	179	40	57	15	-2	289
	Roof + Wall	Gas	30%	146	127	40	62	16	-2	243
	Roof + Wall	Gas	15%	158	121	40	70	16	-2	246
	Roof + Wall	Gas	0%	170	112	40	78	17	-2	245
	Wall	Gas	0%	181	109	40	83	18	-1	248
	Roof	Gas	0%	193	108	40	88	19	-1	254
	None	Gas	0%	204	105	40	92	20	0	257
Semi-detached - Solid – 30 year calc	All+	ASHP	30%	134	350	23	108	7	-23	466
	All+	Gas + SHW	30%	139	369	33	56	16	-32	443
	All	Gas + SHW	30%	148	357	33	60	17	-31	437
	All+	Gas	30%	158	284	33	64	18	-19	380
	All	Gas	30%	167	272	33	68	19	-18	375
	Roof + Wall	Gas	30%	181	227	33	74	21	-18	336
	Roof + Wall	Gas	0%	217	193	33	98	22	-18	327
	Roof	Gas	30%	277	137	33	112	31	-2	312
	Roof	Gas	0%	313	103	33	136	32	-2	303
	None	Gas	0%	332	97	33	144	34	-1	308
Apartment block - Solid – 30 year calc	All+	Gas + SHW	30%	72	314	66	31	8	-26	394
	All	Gas + SHW	30%	76	305	66	33	9	-26	387
	Roof + Wall	Gas + SHW	30%	89	252	66	38	10	-26	341
	All+	Gas	30%	107	242	40	47	12	-12	328
	All	Gas	30%	112	233	40	49	12	-12	322
	Roof	Gas + SHW	30%	119	195	66	50	13	-15	310
	Roof + Wall	Gas	30%	126	181	40	54	14	-12	277
	Roof	Gas	30%	162	123	40	69	18	-1	248
	Roof	Gas	0%	186	108	40	85	18	-1	250
	None	Gas	0%	197	105	40	89	20	0	253

Table 5.19b: Macroeconomic Costs (Low energy price, 3.5% discount rate, £/m²)

Building	Package			PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Semi-detached - Cavity – 30 year calc	All+	ASHP	30%	156	348	23	107	9	-22	464
	All+	Gas + SHW	30%	162	367	33	42	19	-31	429
	All	ASHP	30%	180	256	23	122	10	-6	405
	All+	Gas	30%	181	282	33	47	21	-19	363
	All	Gas + SHW	30%	187	275	33	48	21	-15	362
	All	Gas	30%	206	190	33	53	23	-3	297
	Roof + Wall	Gas	30%	218	144	33	57	25	-3	256
	Roof + Wall	Gas	0%	254	110	33	79	26	-3	244
	None	Gas	0%	336	97	33	101	35	-1	265
Apartment block - Cavity – 30 year calc	All+	Gas + SHW	30%	85	314	66	24	10	-26	387
	All	Gas + SHW	30%	94	251	66	26	11	-16	338
	Roof + Wall	Gas + SHW	30%	105	198	66	29	12	-16	290
	All	Gas	30%	132	179	40	38	15	-2	269
	Roof + Wall	Gas	30%	146	127	40	41	16	-2	222
	Roof + Wall	Gas	15%	158	121	40	49	16	-2	224
	Roof + Wall	Gas	0%	170	112	40	56	17	-2	223
	Wall	Gas	0%	181	109	40	59	18	-1	224
	Roof	Gas	0%	193	108	40	62	19	-1	228
	None	Gas	0%	204	105	40	65	20	0	230
Semi-detached - Solid – 30 year calc	All+	ASHP	30%	134	350	23	94	7	-23	452
	All+	Gas + SHW	30%	139	369	33	36	16	-32	422
	All	Gas + SHW	30%	148	357	33	38	17	-31	415
	All+	Gas	30%	158	284	33	41	18	-19	357
	All	Gas	30%	167	272	33	43	19	-18	350
	Roof + Wall	Gas	30%	181	227	33	47	21	-18	309
	Roof + Wall	Gas	0%	217	193	33	69	22	-18	298
	Roof	Gas	30%	277	137	33	72	31	-2	272
	Roof	Gas	0%	313	103	33	94	32	-2	260
	None	Gas	0%	332	97	33	99	34	-1	263
Apartment block - Solid – 30 year calc	All+	Gas + SHW	30%	72	314	66	20	8	-26	383
	All	Gas + SHW	30%	76	305	66	21	9	-26	376
	Roof + Wall	Gas + SHW	30%	89	252	66	25	10	-26	328
	All+	Gas	30%	107	242	40	31	12	-12	313
	All	Gas	30%	112	233	40	32	12	-12	306
	Roof	Gas + SHW	30%	119	195	66	33	13	-15	292
	Roof + Wall	Gas	30%	126	181	40	36	14	-12	259
	Roof	Gas	30%	162	123	40	46	18	-1	225
	Roof	Gas	0%	186	108	40	60	18	-1	226
	None	Gas	0%	197	105	40	63	20	0	227

Table 5.19c: Macroeconomic Costs (High energy price, 3.5% discount rate, £/m²)

Building	Package			PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Semi-detached - Cavity – 30 year calc	All+	ASHP	30%	156	348	23	142	9	-22	499
	All+	Gas + SHW	30%	162	367	33	95	19	-31	482
	All	ASHP	30%	180	256	23	162	10	-6	444
	All+	Gas	30%	181	282	33	106	21	-19	422
	Roof + Wall	ASHP	30%	192	211	23	172	11	-6	410
	Roof + Wall	Gas + SHW	30%	200	229	33	117	23	-15	387
	All	Gas	30%	206	190	33	120	23	-3	363
	Roof + Wall	Gas	30%	218	144	33	128	25	-3	327
	Roof + Wall	Gas	0%	254	110	33	154	26	-3	319
	None	Gas	0%	336	97	33	201	35	-1	365
Apartment block - Cavity – 30 year calc	All+	Gas + SHW	30%	85	314	66	52	10	-26	415
	All	Gas + SHW	30%	94	251	66	57	11	-16	369
	Roof + Wall	Gas + SHW	30%	105	198	66	64	12	-16	325
	All	Gas	30%	132	179	40	80	15	-2	312
	Roof + Wall	Gas	30%	146	127	40	88	16	-2	268
	Roof + Wall	Gas	15%	158	121	40	96	16	-2	272
	Roof + Wall	Gas	0%	170	112	40	105	17	-2	272
	Wall	Gas	0%	181	109	40	112	18	-1	277
	Roof	Gas	0%	193	108	40	118	19	-1	285
	None	Gas	0%	204	105	40	125	20	0	289
Semi-detached - Solid – 30 year calc	All+	ASHP	30%	134	350	23	124	7	-23	481
	All+	Gas + SHW	30%	139	369	33	82	16	-32	469
	Roof + Wall	ASHP	30%	157	293	23	142	9	-22	445
	All+	Gas	30%	158	284	33	93	18	-19	409
	All	Gas	30%	167	272	33	98	19	-18	405
	Roof + Wall	Gas	30%	181	227	33	106	21	-18	369
	Roof + Wall	Gas	0%	217	193	33	132	22	-18	362
	Roof	Gas	30%	277	137	33	161	31	-2	360
	Roof	Gas	0%	313	103	33	187	32	-2	353
	None	Gas	0%	332	97	33	198	34	-1	362
Apartment block - Solid – 30 year calc	All+	Gas + SHW	30%	72	314	66	44	8	-26	407
	All	Gas + SHW	30%	76	305	66	47	9	-26	401
	Roof + Wall	Gas + SHW	30%	89	252	66	54	10	-26	357
	All+	Gas	30%	107	242	40	65	12	-12	347
	All	Gas	30%	112	233	40	68	12	-12	342
	Roof	Gas + SHW	30%	119	195	66	71	13	-15	331
	Roof + Wall	Gas	30%	126	181	40	77	14	-12	299
	Roof	Gas	30%	162	123	40	97	18	-1	276
	Roof	Gas	0%	186	108	40	114	18	-1	280
	None	Gas	0%	197	105	40	121	20	0	284

Table 5.19d: Macroeconomic Costs (Central energy price, 3% discount rate, £/m²)

Building	Package			PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Semi-detached - Cavity – 30 year calc	All+	ASHP	30%	156	352	24	132	9	-26	492
	All+	Gas + SHW	30%	162	372	35	70	20	-36	461
	All	ASHP	30%	180	260	24	150	11	-7	438
	All+	Gas	30%	181	284	35	78	23	-22	399
	Roof + Wall	Gas + SHW	30%	200	234	35	86	25	-18	363
	All	Gas	30%	206	192	35	89	26	-3	339
	Roof + Wall	Gas	30%	218	147	35	95	27	-3	300
	Roof + Wall	Gas	0%	254	112	35	120	28	-3	292
	None	Gas	0%	336	100	35	155	38	-1	327
Apartment block - Cavity – 30 year calc	All+	Gas + SHW	30%	85	318	71	39	11	-30	408
	All	Gas + SHW	30%	94	256	71	43	12	-18	362
	Roof + Wall	Gas + SHW	30%	105	203	71	48	13	-18	316
	All	Gas	30%	132	182	42	61	16	-2	298
	Roof + Wall	Gas	30%	146	129	42	66	18	-2	254
	Roof + Wall	Gas	15%	158	124	42	75	18	-2	257
	Roof + Wall	Gas	0%	170	115	42	83	18	-2	257
	Wall	Gas	0%	181	111	42	88	20	-1	260
	Roof	Gas	0%	193	111	42	93	21	-1	266
	None	Gas	0%	204	107	42	98	22	-1	270
Semi-detached - Solid – 30 year calc	All+	ASHP	30%	134	355	24	115	8	-26	476
	All+	Gas + SHW	30%	139	374	35	60	18	-37	451
	Roof + Wall	ASHP	30%	157	298	24	132	9	-25	439
	All+	Gas	30%	158	287	35	68	20	-22	388
	All	Gas	30%	167	275	35	72	21	-21	383
	Roof + Wall	Gas	30%	181	230	35	78	23	-21	345
	Roof + Wall	Gas	0%	217	195	35	104	24	-21	337
	Roof	Gas	30%	277	140	35	120	34	-2	327
	Roof	Gas	0%	313	105	35	145	35	-2	319
	None	Gas	0%	332	100	35	154	37	-1	325
Apartment block - Solid – 30 year calc	All+	Gas + SHW	30%	72	319	71	33	9	-30	401
	All	Gas + SHW	30%	76	310	71	35	10	-30	395
	Roof + Wall	Gas + SHW	30%	89	257	71	40	11	-30	349
	All+	Gas	30%	107	245	42	50	13	-14	336
	All	Gas	30%	112	236	42	52	14	-14	330
	Roof	Gas + SHW	30%	119	199	71	54	15	-17	321
	Roof + Wall	Gas	30%	126	183	42	58	15	-14	285
	Roof	Gas	30%	162	125	42	73	19	-1	259
	Roof	Gas	0%	186	111	42	90	20	-1	262
	None	Gas	0%	197	107	42	95	21	-1	266

Table 5.19e: Macroeconomic Costs (Central energy price, 3.5% discount rate, alternative cost of carbon, £/m²)

Building	Package			PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Semi-detached - Cavity – 30 year calc	All+	ASHP	30%	156	348	23	124	23	-22	495
	All+	Gas + SHW	30%	162	367	33	66	54	-31	489
	All	ASHP	30%	180	256	23	141	26	-6	440
	All+	Gas	30%	181	282	33	73	60	-19	430
	Roof + Wall	ASHP	30%	192	211	23	150	28	-6	405
	Roof + Wall	Gas + SHW	30%	200	229	33	81	66	-15	394
	All	Gas	30%	206	190	33	84	68	-3	371
	Roof + Wall	Gas	30%	218	144	33	89	72	-3	335
	Roof + Wall	Gas	0%	254	110	33	113	74	-3	327
	None	Gas	0%	336	97	33	146	100	-1	375
Apartment block - Cavity – 30 year calc	All+	Gas + SHW	30%	85	314	66	36	28	-26	418
	All	Gas + SHW	30%	94	251	66	40	31	-16	373
	Roof + Wall	Gas + SHW	30%	105	198	66	45	35	-16	328
	All	Gas	30%	132	179	40	57	42	-2	316
	Roof + Wall	Gas	30%	146	127	40	62	46	-2	273
	Roof + Wall	Gas	15%	158	121	40	70	47	-2	277
	Roof + Wall	Gas	0%	170	112	40	78	48	-2	276
	Wall	Gas	0%	181	109	40	83	52	-1	282
	Roof	Gas	0%	193	108	40	88	55	-1	290
	None	Gas	0%	204	105	40	92	59	0	295
Semi-detached - Solid – 30 year calc	All+	ASHP	30%	134	350	23	108	19	-23	478
	All+	Gas + SHW	30%	139	369	33	56	47	-32	474
	All	Gas + SHW	30%	148	357	33	60	50	-31	470
	Roof + Wall	ASHP	30%	157	293	23	124	23	-22	442
	All+	Gas	30%	158	284	33	64	53	-19	415
	All	Gas	30%	167	272	33	68	56	-18	411
	Roof + Wall	Gas	30%	181	227	33	74	60	-18	376
	Roof + Wall	Gas	0%	217	193	33	98	63	-18	368
	Roof	Gas	0%	313	103	33	136	92	-2	363
	None	Gas	0%	332	97	33	144	98	-1	372
Apartment block - Solid – 30 year calc	All+	Gas + SHW	30%	72	314	66	31	24	-26	409
	All	Gas + SHW	30%	76	305	66	33	25	-26	404
	Roof + Wall	Gas + SHW	30%	89	252	66	38	29	-26	360
	All+	Gas	30%	107	242	40	47	34	-12	351
	All	Gas	30%	112	233	40	49	36	-12	346
	Roof	Gas + SHW	30%	119	195	66	50	39	-15	335
	Roof + Wall	Gas	30%	126	181	40	54	40	-12	303
	Roof	Gas	30%	162	123	40	69	51	-1	282
	Roof	Gas	0%	186	108	40	85	53	-1	285
	None	Gas	0%	197	105	40	89	56	0	290

Table 5.20a: Financial Costs (Central energy price, 6% discount rate, £/m²)

Building	Package			PE (KWh/ m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Semi-detached - Cavity – 30 year calc	All+	ASHP	30%	156	397	21	206	-	-13	611
	All+	Gas + SHW	30%	162	417	30	126	-	-19	555
	All	ASHP	30%	180	287	21	234	-	-4	538
	All+	Gas	30%	181	325	30	140	-	-11	484
	All	Gas + SHW	30%	187	307	30	145	-	-9	472
	Roof + Wall	Gas + SHW	30%	200	252	30	154	-	-9	427
	All	Gas	30%	206	215	30	158	-	-2	401
	Roof + Wall	Gas	30%	218	160	30	167	-	-2	356
	Roof + Wall	Gas	0%	254	121	30	197	-	-2	346
	None	Gas	0%	336	106	30	256	-	0	392
Apartment block - Cavity – 30 year calc	All+	Gas + SHW	30%	85	355	60	70	-	-16	470
	All	Gas + SHW	30%	94	280	60	77	-	-9	407
	Roof + Wall	Gas + SHW	30%	105	217	60	85	-	-9	353
	All	Gas	30%	132	202	36	106	-	-1	343
	Roof + Wall	Gas	30%	146	139	36	116	-	-1	290
	Roof + Wall	Gas	15%	158	132	36	126	-	-1	293
	Roof + Wall	Gas	0%	170	122	36	136	-	-1	293
	Wall	Gas	0%	181	118	36	144	-	-1	297
	Roof	Gas	0%	193	117	36	153	-	-1	305
	None	Gas	0%	204	113	36	161	-	0	310
Semi-detached - Solid – 30 year calc	All+	ASHP	30%	134	400	21	181	-	-14	588
	All+	Gas + SHW	30%	139	420	30	110	-	-19	541
	All	Gas + SHW	30%	148	406	30	117	-	-18	534
	All+	Gas	30%	158	328	30	123	-	-12	470
	All	Gas	30%	167	314	30	130	-	-11	464
	Roof + Wall	Gas	30%	181	260	30	140	-	-11	419
	Roof + Wall	Gas	0%	217	220	30	170	-	-11	409
	Roof	Gas	30%	277	152	30	209	-	-1	390
	Roof	Gas	0%	313	112	30	239	-	-1	380
	None	Gas	0%	332	106	30	253	-	0	388
Apartment block - Solid – 30 year calc	All+	Gas + SHW	30%	72	356	60	61	-	-16	461
	All	Gas + SHW	30%	76	345	60	64	-	-15	453
	Roof + Wall	Gas + SHW	30%	89	282	60	73	-	-15	399
	All+	Gas	30%	107	278	36	88	-	-7	394
	All	Gas	30%	112	267	36	91	-	-7	387
	Roof + Wall	Gas	30%	126	204	36	102	-	-7	334
	Roof	Gas	30%	162	134	36	128	-	-1	297
	None	Gas	30%	173	130	36	136	-	0	301
	Roof	Gas	0%	186	117	36	147	-	-1	300
	None	Gas	0%	197	113	36	156	-	0	304

Table 5.20b: Financial Costs (Low energy price, 6% discount rate, £/m²)

Building	Package			PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Semi-detached - Cavity – 30 year calc	All+	ASHP	30%	156	397	21	187	-	-13	591
	All+	Gas + SHW	30%	162	417	30	100	-	-19	528
	All	ASHP	30%	180	287	21	212	-	-4	516
	All+	Gas	30%	181	325	30	111	-	-11	455
	All	Gas + SHW	30%	187	307	30	114	-	-9	442
	Roof + Wall	Gas + SHW	30%	200	252	30	122	-	-9	395
	All	Gas	30%	206	215	30	125	-	-2	368
	Roof + Wall	Gas	30%	218	160	30	133	-	-2	321
	Roof + Wall	Gas	0%	254	121	30	161	-	-2	310
	None	Gas	0%	336	106	30	208	-	0	343
Apartment block - Cavity – 30 year calc	All+	Gas + SHW	30%	85	355	60	56	-	-16	456
	All	Gas + SHW	30%	94	280	60	61	-	-9	392
	Roof + Wall	Gas + SHW	30%	105	217	60	68	-	-9	336
	All	Gas	30%	132	202	36	85	-	-1	322
	Roof + Wall	Gas	30%	146	139	36	93	-	-1	267
	Roof + Wall	Gas	15%	158	132	36	103	-	-1	270
	Roof + Wall	Gas	0%	170	122	36	112	-	-1	269
	Wall	Gas	0%	181	118	36	119	-	-1	272
	Roof	Gas	0%	193	117	36	125	-	-1	278
	None	Gas	0%	204	113	36	132	-	0	281
Semi-detached - Solid – 30 year calc	All+	ASHP	30%	134	400	21	164	-	-14	571
	All+	Gas + SHW	30%	139	420	30	87	-	-19	518
	All	Gas + SHW	30%	148	406	30	92	-	-18	510
	All+	Gas	30%	158	328	30	98	-	-12	444
	All	Gas	30%	167	314	30	103	-	-11	437
	Roof + Wall	Gas	30%	181	260	30	111	-	-11	390
	Roof + Wall	Gas	0%	217	220	30	139	-	-11	379
	Roof	Gas	30%	277	152	30	166	-	-1	347
	Roof	Gas	0%	313	112	30	194	-	-1	336
	None	Gas	0%	332	106	30	205	-	0	341
Apartment block - Solid – 30 year calc	All+	Gas + SHW	30%	72	356	60	49	-	-16	449
	All	Gas + SHW	30%	76	345	60	51	-	-15	440
	Roof + Wall	Gas + SHW	30%	89	282	60	58	-	-15	385
	All+	Gas	30%	107	278	36	71	-	-7	377
	All	Gas	30%	112	267	36	74	-	-7	369
	Roof + Wall	Gas	30%	126	204	36	82	-	-7	315
	Roof	Gas	30%	162	134	36	102	-	-1	272
	None	Gas	30%	173	130	36	109	-	0	275
	Roof	Gas	0%	186	117	36	121	-	-1	274
	None	Gas	0%	197	113	36	128	-	0	276

Table 5.20c: Financial Costs (High energy price, 6% discount rate, £/m²)

Building	Package			PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Semi-detached - Cavity – 30 year calc	All+	ASHP	30%	156	397	21	225	-	-13	630
	All+	Gas + SHW	30%	162	417	30	156	-	-19	585
	All	ASHP	30%	180	287	21	256	-	-4	560
	All+	Gas	30%	181	325	30	173	-	-11	517
	All	Gas + SHW	30%	187	307	30	179	-	-9	506
	Roof + Wall	Gas + SHW	30%	200	252	30	190	-	-9	463
	All	Gas	30%	206	215	30	196	-	-2	439
	Roof + Wall	Gas	30%	218	160	30	207	-	-2	395
	Roof + Wall	Gas	0%	254	121	30	238	-	-2	387
	None	Gas	0%	336	106	30	311	-	0	446
Apartment block - Cavity – 30 year calc	All+	Gas + SHW	30%	85	355	60	86	-	-16	485
	All	Gas + SHW	30%	94	280	60	94	-	-9	425
	Roof + Wall	Gas + SHW	30%	105	217	60	104	-	-9	372
	All	Gas	30%	132	202	36	130	-	-1	367
	Roof + Wall	Gas	30%	146	139	36	142	-	-1	316
	Roof + Wall	Gas	15%	158	132	36	152	-	-1	319
	Roof + Wall	Gas	0%	170	122	36	163	-	-1	320
	Wall	Gas	0%	181	118	36	173	-	-1	326
	Roof	Gas	0%	193	117	36	183	-	-1	336
	None	Gas	0%	204	113	36	193	-	0	342
Semi-detached - Solid – 30 year calc	All+	ASHP	30%	134	400	21	198	-	-14	605
	All+	Gas + SHW	30%	139	420	30	136	-	-19	567
	All	Gas + SHW	30%	148	406	30	144	-	-18	562
	All+	Gas	30%	158	328	30	153	-	-12	499
	All	Gas	30%	167	314	30	161	-	-11	495
	Roof + Wall	Gas	30%	181	260	30	174	-	-11	453
	Roof + Wall	Gas	0%	217	220	30	205	-	-11	444
	Roof	Gas	30%	277	152	30	258	-	-1	439
	Roof	Gas	0%	313	112	30	290	-	-1	431
	None	Gas	0%	332	106	30	307	-	0	442
Apartment block - Solid – 30 year calc	All+	Gas + SHW	30%	72	356	60	74	-	-16	474
	All	Gas + SHW	30%	76	345	60	78	-	-15	468
	Roof + Wall	Gas + SHW	30%	89	282	60	89	-	-15	416
	All+	Gas	30%	107	278	36	107	-	-7	413
	All	Gas	30%	112	267	36	112	-	-7	407
	Roof + Wall	Gas	30%	126	204	36	124	-	-7	357
	Roof	Gas	30%	162	134	36	156	-	-1	326
	None	Gas	30%	173	130	36	166	-	0	332
	Roof	Gas	0%	186	117	36	177	-	-1	330
	None	Gas	0%	197	113	36	187	-	0	336

Table 5.20d: Financial Costs (Central energy price, 10% discount rate, £/m²)

Building	Package			PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Semi-detached - Cavity – 30 year calc	All+	ASHP	30%	156	378	14	145	-	-5	532
	All+	Gas + SHW	30%	162	397	21	89	-	-6	500
	All+	Gas	30%	181	313	21	98	-	-4	428
	All	Gas + SHW	30%	187	286	21	102	-	-3	406
	Roof + Wall	ASHP	30%	192	213	14	175	-	-1	401
	All	Gas	30%	206	203	21	111	-	-1	334
	Roof + Wall	Gas	30%	218	148	21	118	-	-1	286
	Roof + Wall	Gas	15%	236	135	21	128	-	-1	284
	Roof + Wall	Gas	0%	254	110	21	139	-	-1	268
	None	Gas	0%	336	95	21	180	-	0	295
Apartment block - Cavity – 30 year calc	All+	Gas + SHW	30%	85	337	42	49	-	-5	422
	All	Gas + SHW	30%	94	262	42	54	-	-3	354
	Roof + Wall	Gas + SHW	30%	105	199	42	60	-	-3	297
	All	Gas	30%	132	189	25	75	-	0	288
	Roof + Wall	Gas	30%	146	126	25	81	-	0	232
	Roof + Wall	Gas	15%	158	119	25	88	-	0	232
	Roof + Wall	Gas	0%	170	110	25	95	-	0	230
	Wall	Gas	0%	181	105	25	101	-	0	231
	Roof	Gas	0%	193	105	25	107	-	0	237
	None	Gas	0%	204	101	25	113	-	0	238
Semi-detached - Solid – 30 year calc	All+	ASHP	30%	134	381	14	127	-	-5	517
	All+	Gas + SHW	30%	139	400	21	77	-	-7	491
	All+	Gas	30%	158	316	21	87	-	-4	419
	Roof + Wall	Gas	30%	181	247	21	99	-	-4	363
	Roof + Wall	Gas	15%	199	235	21	109	-	-4	361
	Roof + Wall	Gas	0%	217	209	21	120	-	-4	346
	Roof	Gas	30%	277	140	21	147	-	0	307
	Roof	Gas	15%	295	127	21	157	-	0	305
	Roof	Gas	0%	313	101	21	168	-	0	290
	None	Gas	0%	332	95	21	178	-	0	293
Apartment block - Solid – 30 year calc	All+	Gas + SHW	30%	72	337	42	43	-	-5	416
	All	Gas + SHW	30%	76	326	42	45	-	-5	408
	Roof + Wall	Gas + SHW	30%	89	263	42	51	-	-5	351
	All+	Gas	30%	107	265	25	62	-	-3	349
	All	Gas	30%	112	254	25	64	-	-2	341
	Roof	Gas + SHW	30%	119	194	42	67	-	-3	299
	Roof + Wall	Gas	30%	126	191	25	72	-	-2	285
	Roof	Gas	30%	162	121	25	90	-	0	236
	Roof	Gas	0%	186	105	25	103	-	0	233
	None	Gas	0%	197	101	25	109	-	0	235

6. Cost Optimal Level for Reference Buildings

6.1 New Buildings

The cost optimal level has been based on macroeconomic calculations including the cost of greenhouse gas emissions. Macro-economic analysis is used by the Government for the purpose of evaluating different options for technical standards for Building Regulations. Furthermore, the discount rate of 3.5% has been used to mirror that used by the Government policy analysis.

The cost optimal curves for each of the reference buildings are shown in Figure 6.1 (a-b). The costs are based on the central energy price highlighted in Section 5.

For comparison, current UK energy performance standards (weighted average across England, Scotland, Wales and Northern Ireland) are shown.

Figure 6.1a: Results of the cost-optimal analysis (Semi-Detached House, macroeconomic costs)

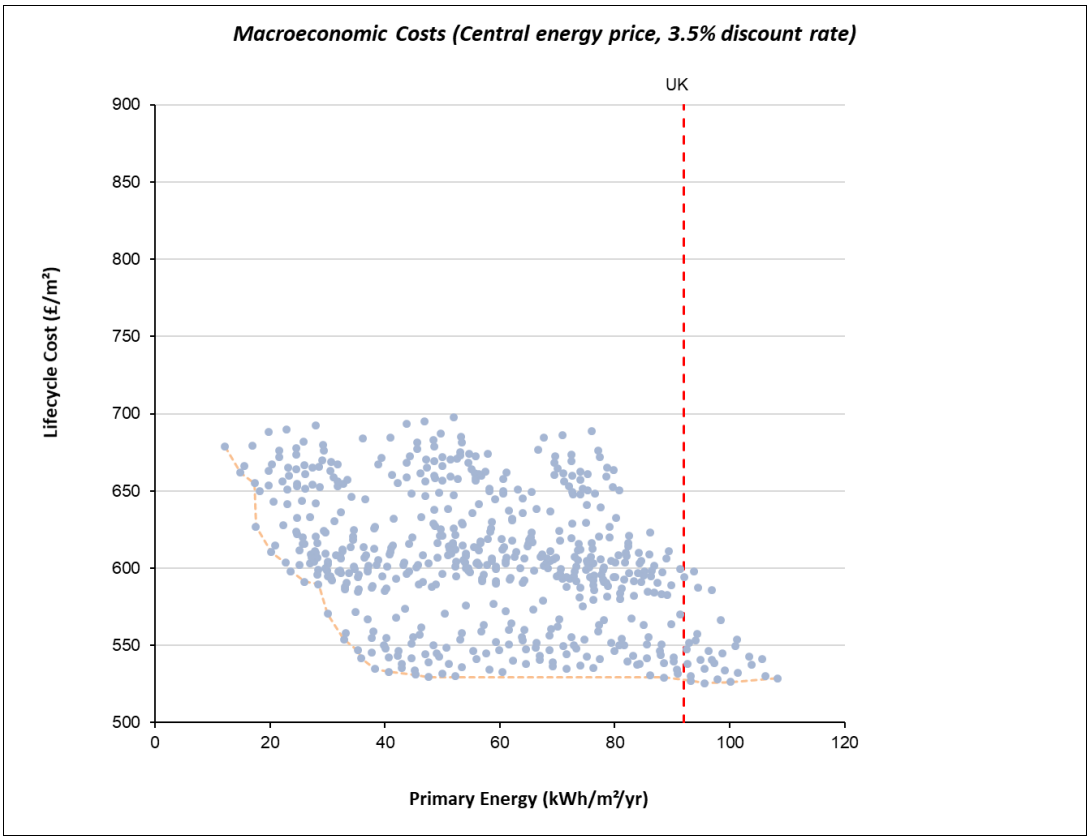
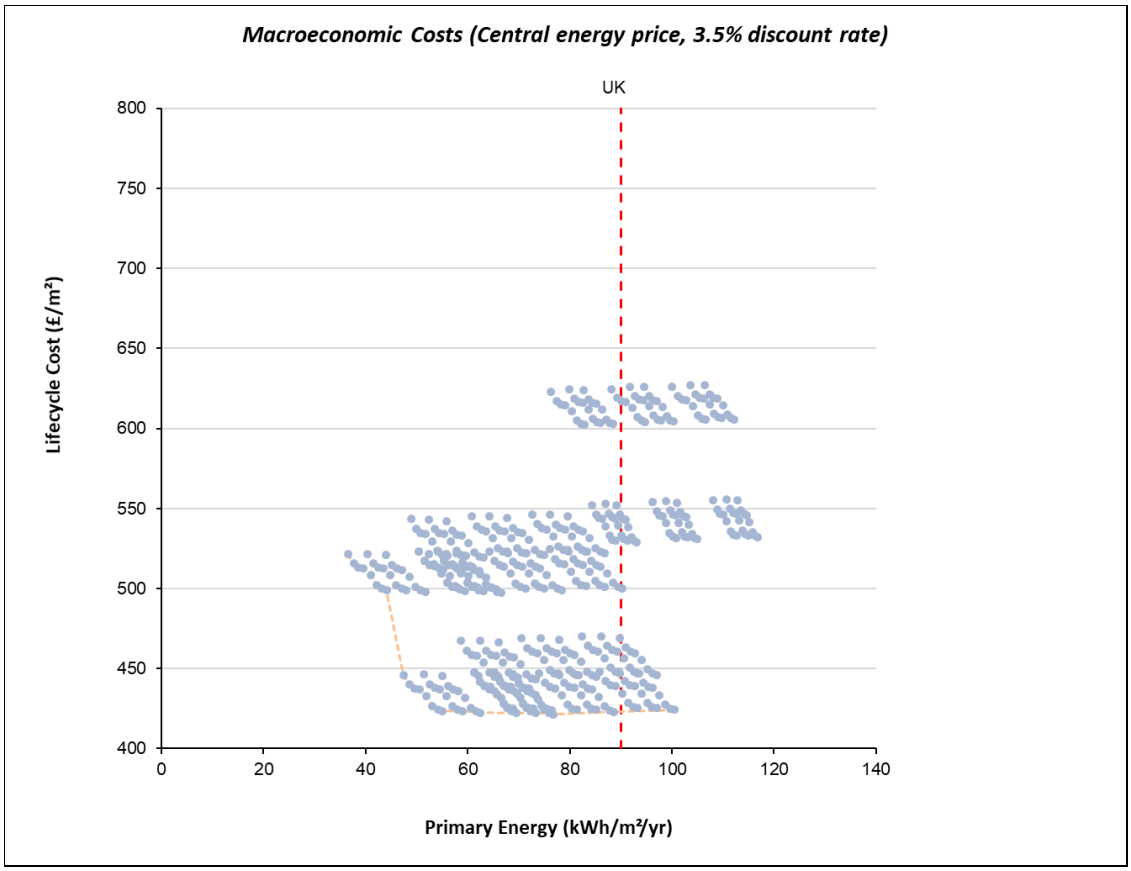


Figure 6.1b: Results of the cost-optimal analysis (Apartment Block, macroeconomic costs)



From these curves, the economic optimal energy performance level in primary energy (kWh/m^2/yr) is shown in Table 6.1. It includes a range to cover the sensitivity cases investigated in Section 5. Furthermore, to allow for some sensitivity in the price of the fabric/services/renewable measures, we have included those primary energies within 5% of the lowest macro-economic cost.

Table 6.1: Economic Optimal Energy Performance Level in Primary Energy

Reference building	*Primary Energy (kWh/m^2/yr)*	*Sensitivity Range (kWh/m^2/yr)*
Semi-detached house	96	35-108
Apartment Building	77	51-101

6.2 Existing Buildings – Elemental Analysis

As for new buildings, the cost optimal level is based on the macroeconomic cost calculations. The cost optimal curves for each of the reference buildings are shown in Figure 6.2 (a–p).The costs are based on the central energy price in Section 5. Again for comparison, current UK energy performance standards (weighted average across England, Scotland, Wales and Northern Ireland) are shown.

Figure 6.2a: Results of the cost-optimal analysis (Walls: Semi-Detached House, Cavity Wall, macroeconomic costs)

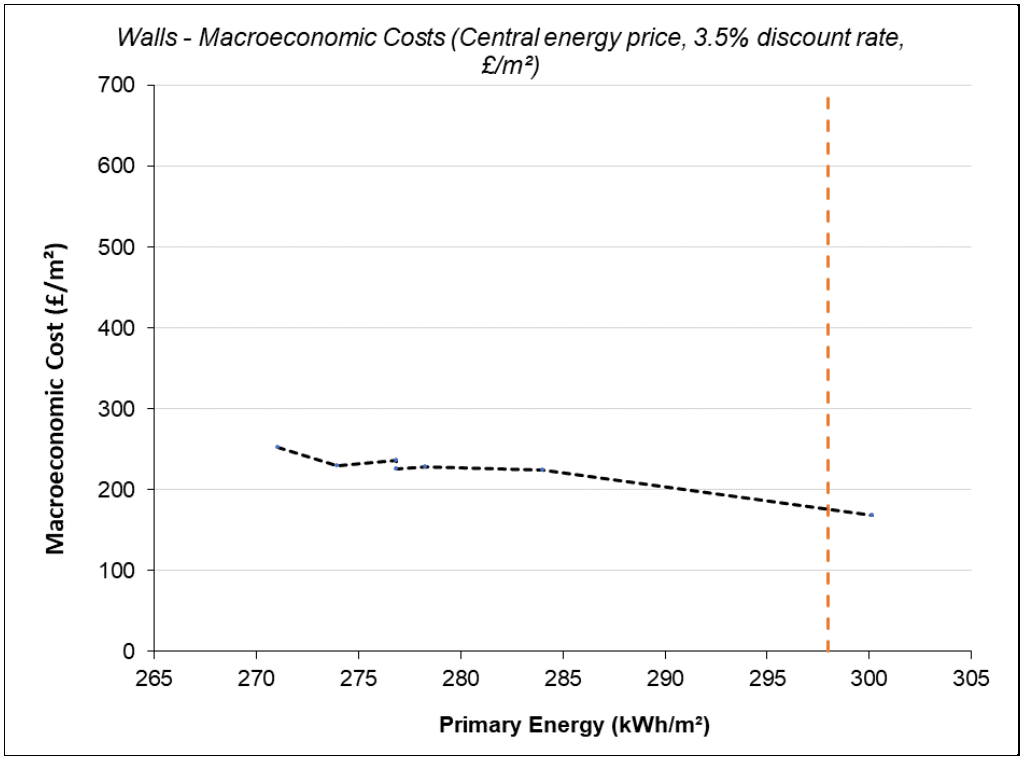


Figure 6.2b: Results of the cost-optimal analysis (Windows: Semi-Detached House, Cavity Wall, macroeconomic costs)

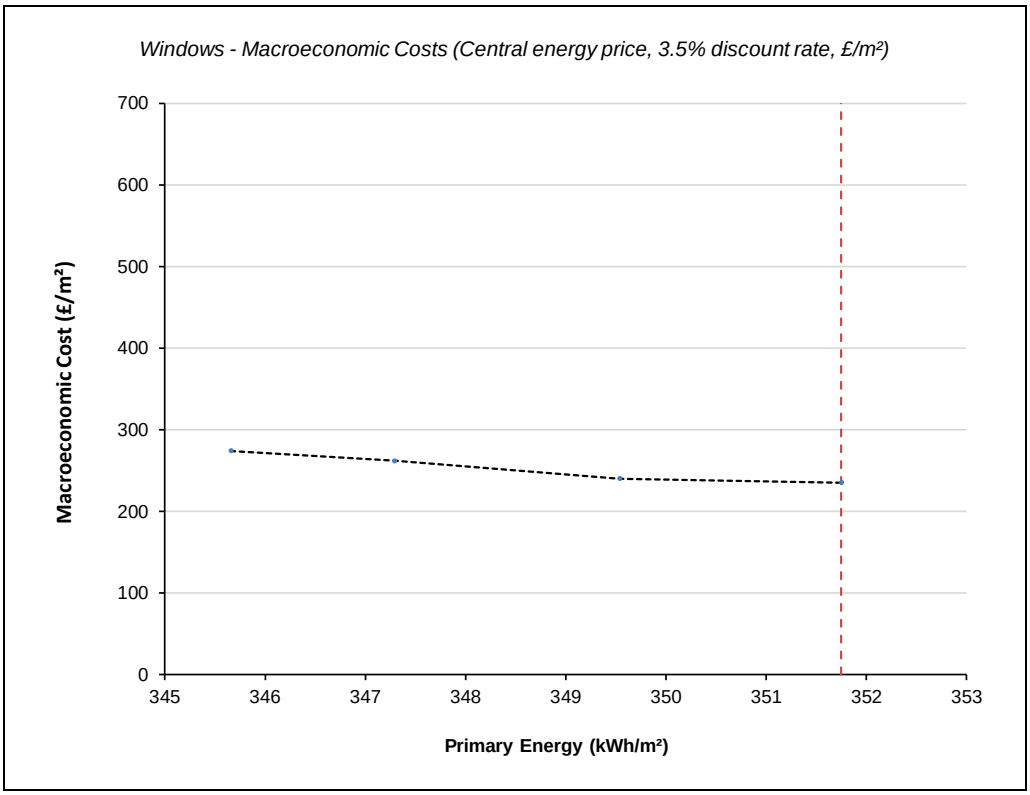


Figure 6.2c: Results of the cost-optimal analysis
(Heating: Semi-Detached House, Cavity Wall, macroeconomic costs)

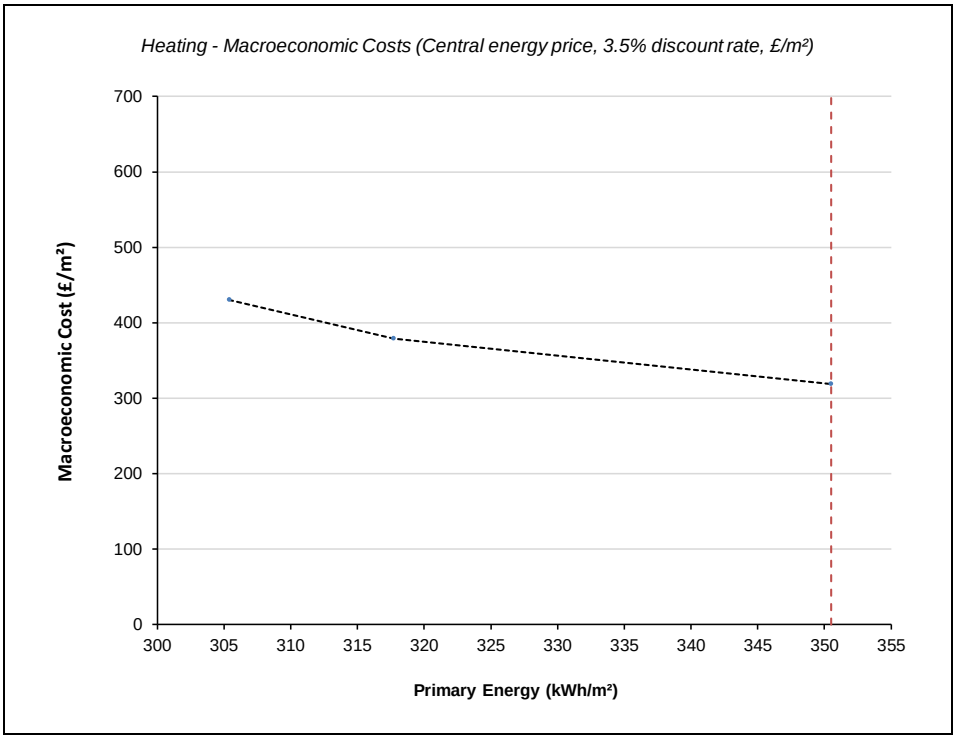


Figure 6.2d: Results of the cost-optimal analysis
(Roof: Semi-Detached House, Cavity Wall, macroeconomic costs)

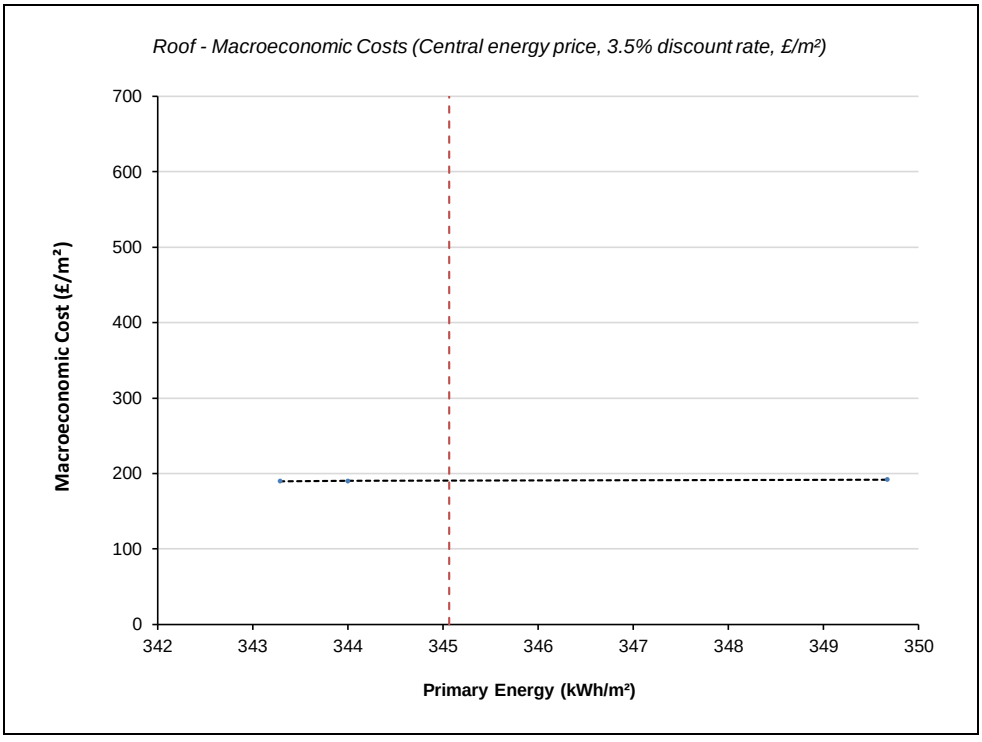


Figure 6.2e: Results of the cost-optimal analysis (Walls: Apartment Block, Cavity Wall, macroeconomic costs)

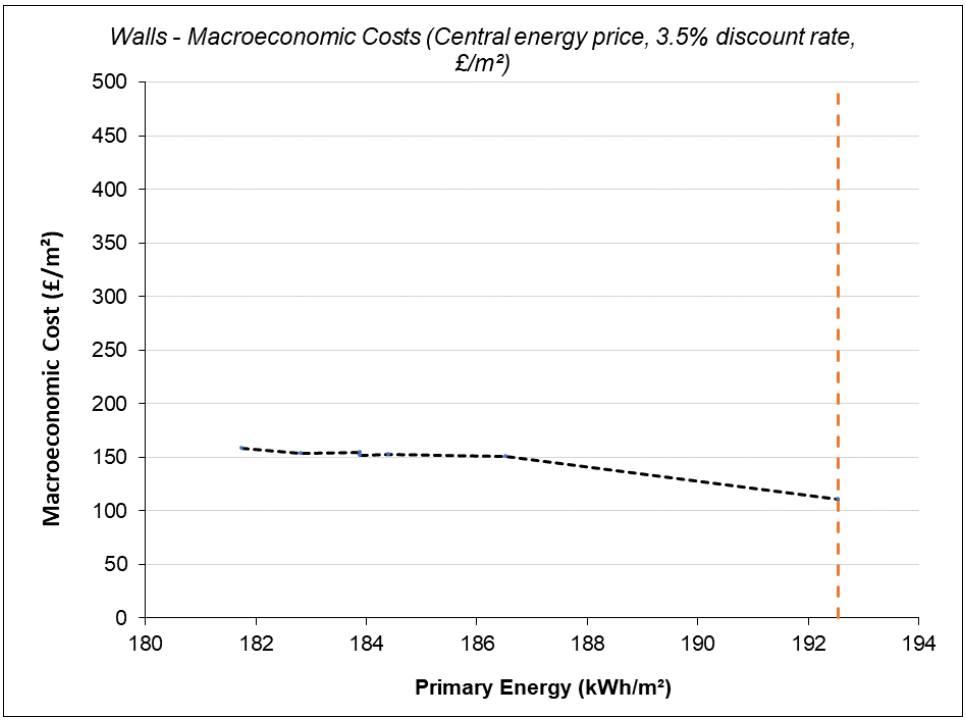


Figure 6.2f: Results of the cost-optimal analysis (Windows: Apartment Block, Cavity Wall, macroeconomic costs)

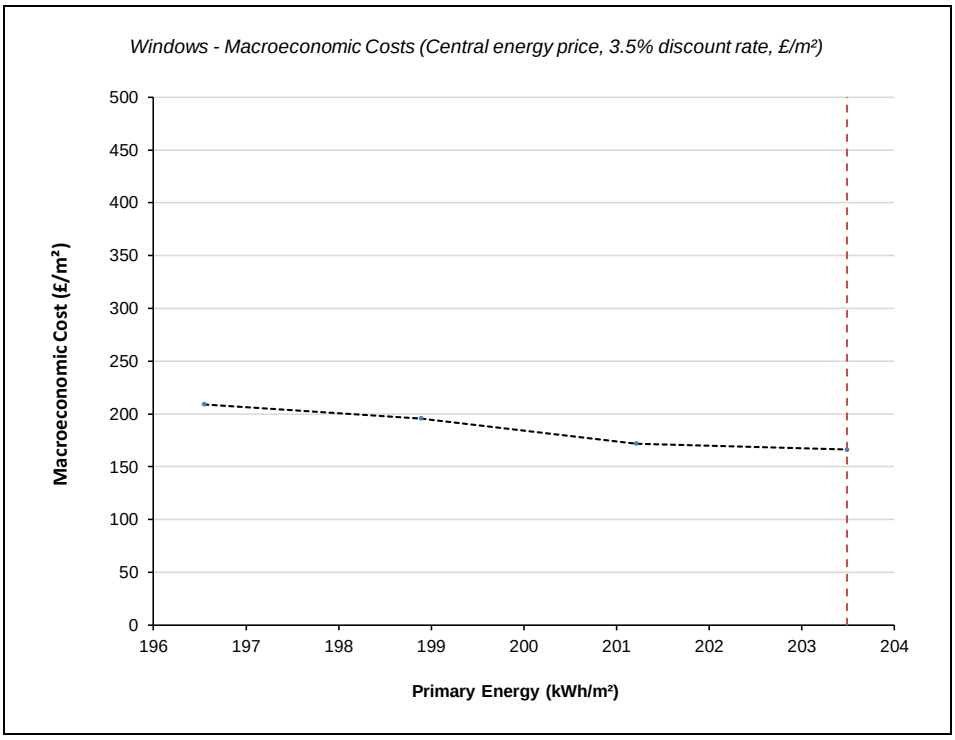


Figure 6.2g: Results of the cost-optimal analysis (Heating: Apartment Block, Cavity Wall, macroeconomic costs)

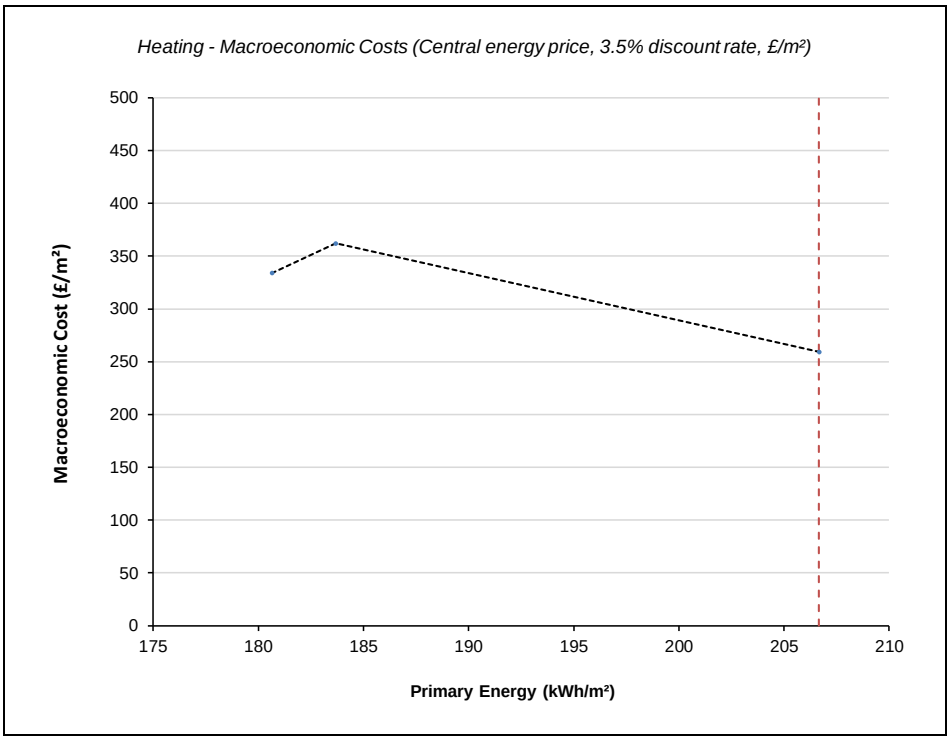


Figure 6.2h: Results of the cost-optimal analysis (Roof: Apartment Block, Cavity Wall, macroeconomic costs)

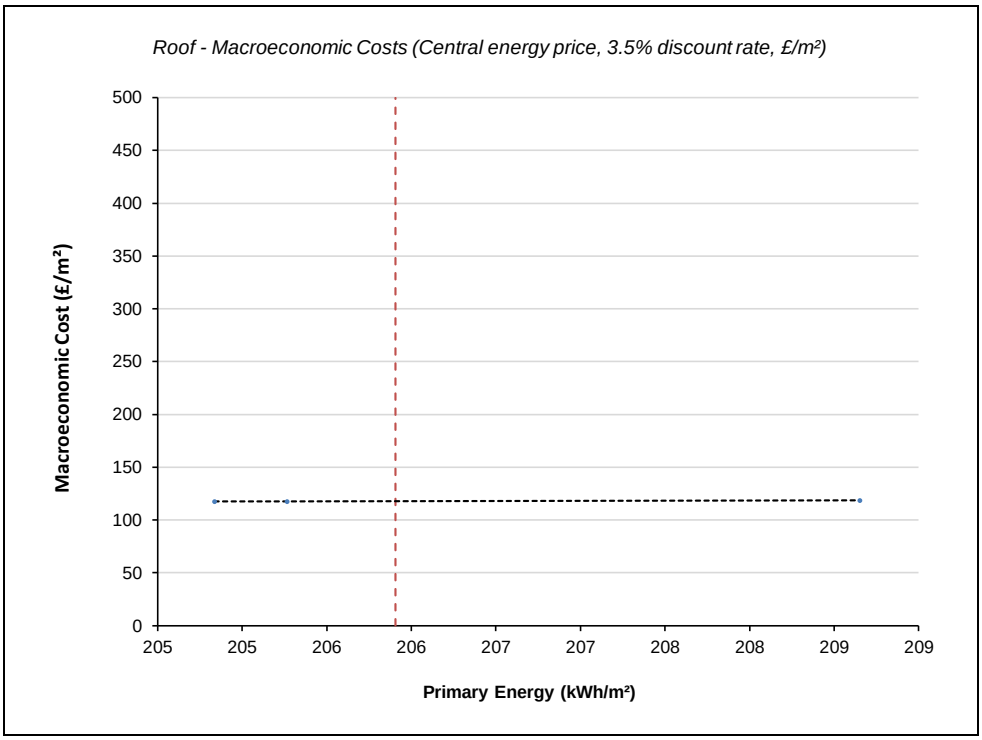


Figure 6.2i: Results of the cost-optimal analysis
(Walls: Semi-Detached House, Solid Wall, macroeconomic costs)

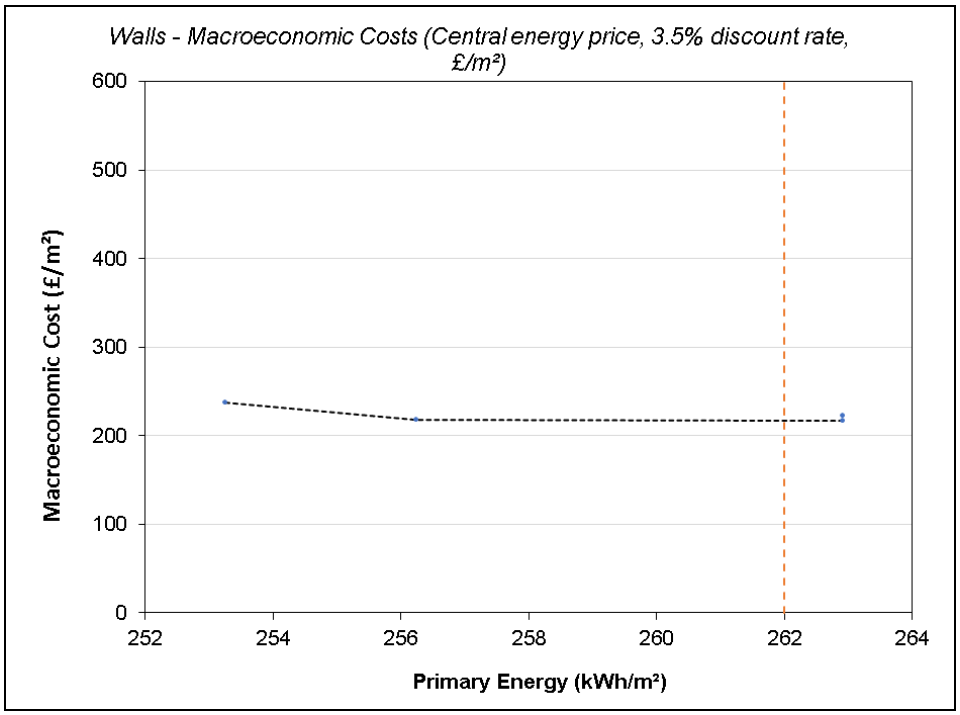


Figure 6.2j: Results of the cost-optimal analysis
(Windows: Semi-Detached House, Solid Wall, macroeconomic costs)

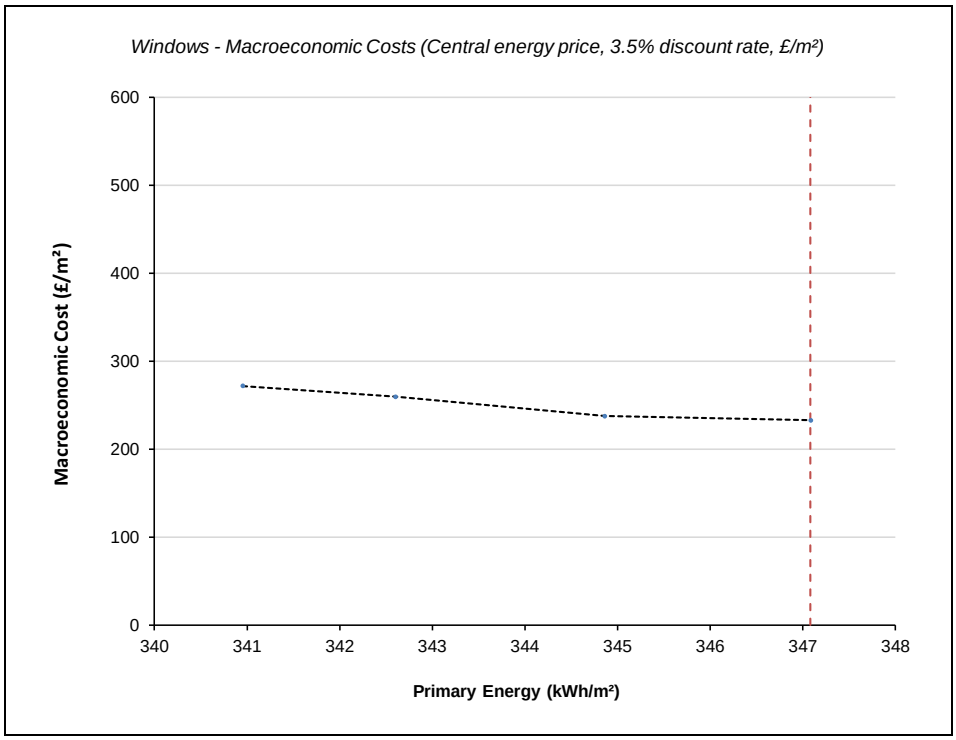


Figure 6.2k: Results of the cost-optimal analysis (Heating: Semi-Detached House, Solid Wall, macroeconomic costs)

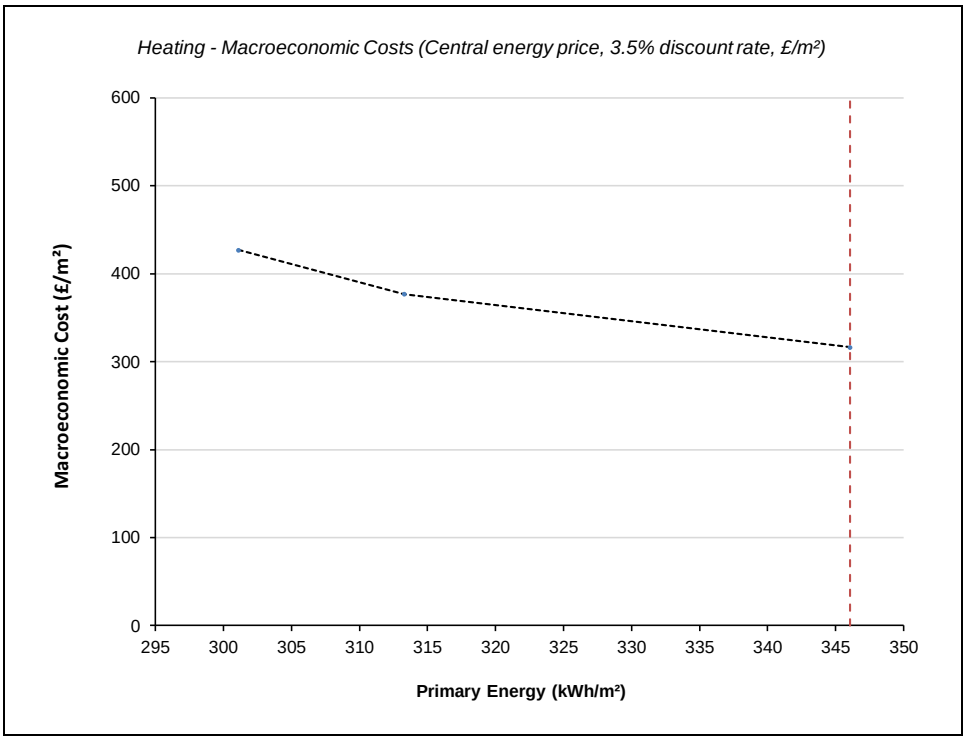


Figure 6.2l: Results of the cost-optimal analysis (Roof: Semi-Detached House, Solid Wall, macroeconomic costs)

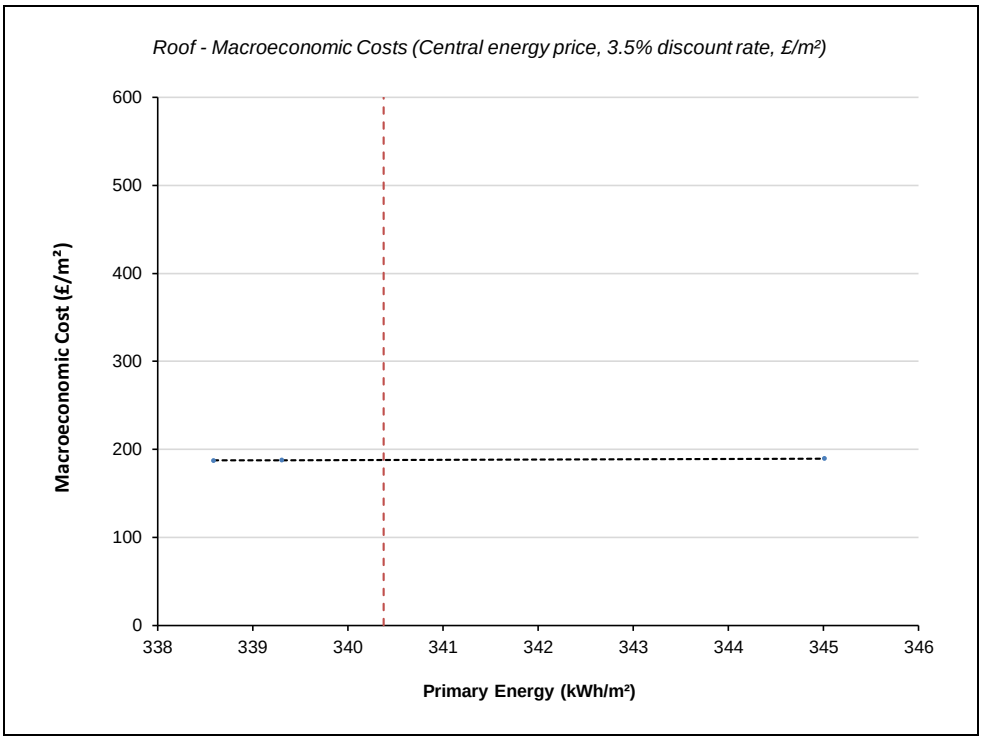


Figure 6.2m: Results of the cost-optimal analysis (Walls: Apartment Block, Solid Wall, macroeconomic costs)

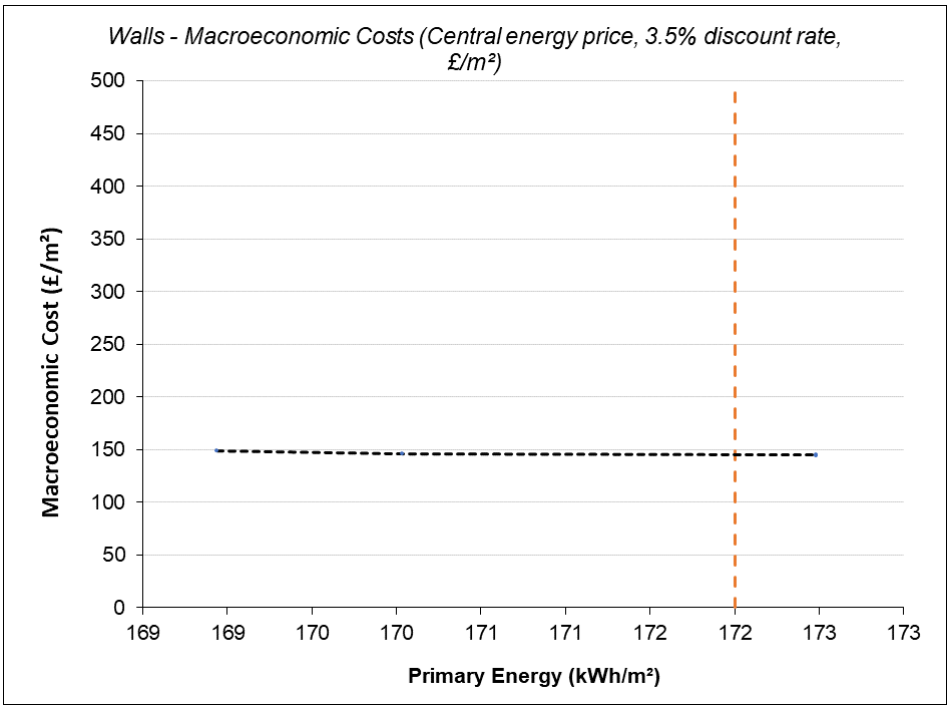


Figure 6.2n: Results of the cost-optimal analysis (Windows: Apartment Block, Solid Wall, macroeconomic costs)

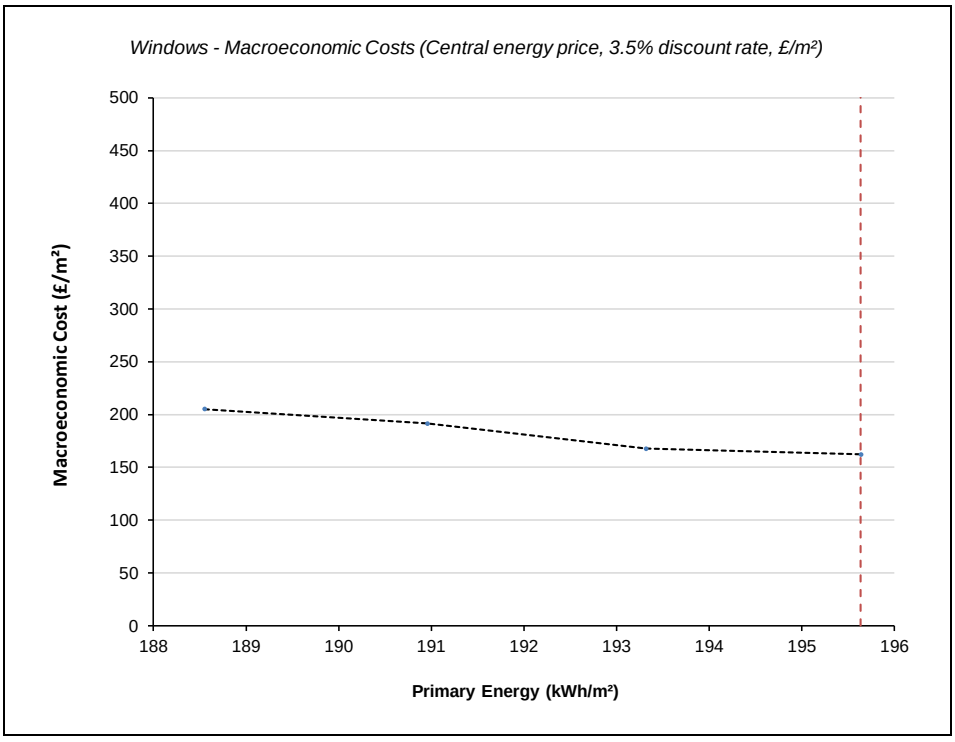


Figure 6.2o: Results of the cost-optimal analysis (Heating: Apartment Block, Solid Wall, macroeconomic costs)

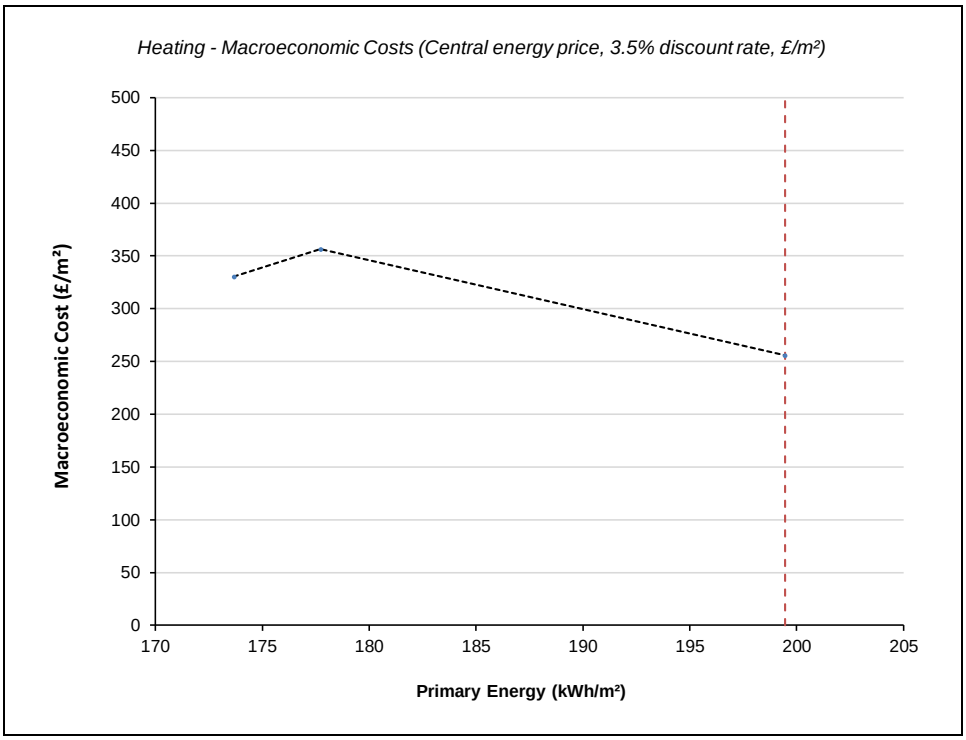
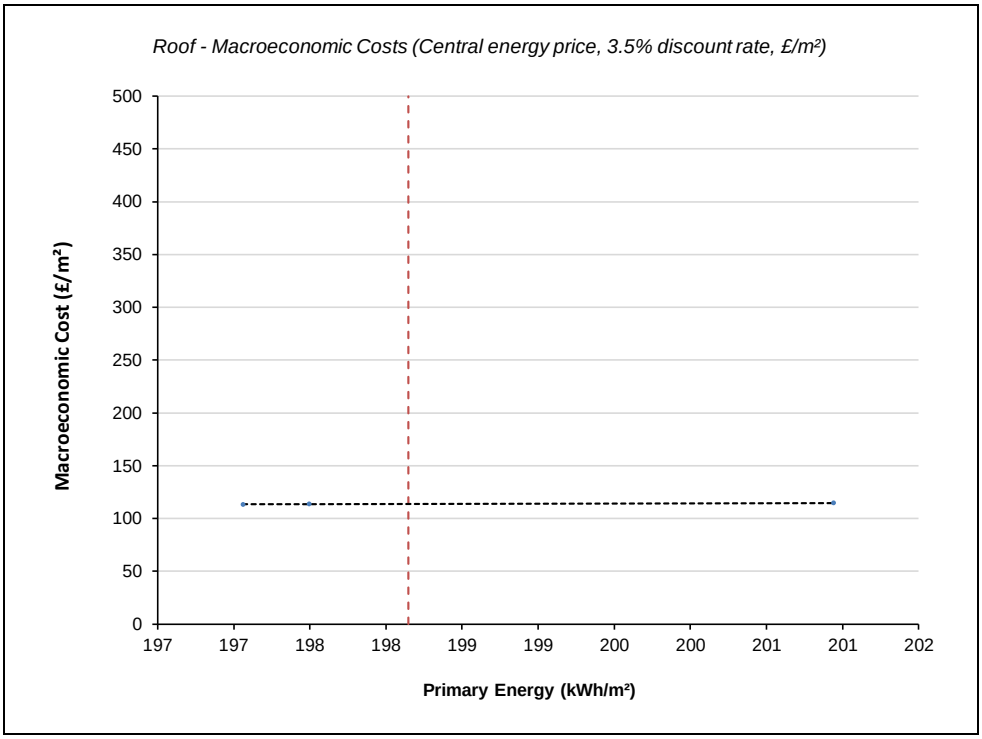


Figure 6.2p: Results of the cost-optimal analysis (Roof: Apartment Block, Solid Wall, macroeconomic costs)



From these curves, the economic optimal building element value is shown in Table 6.2. Where there is a range recorded, it is because the cost associated is the same (to the nearest integer) for multiple building element values.

It also includes a range to cover the macro-economic sensitivity cases investigated in Section 5. Values are only included if they differ from the optimum primary energy in the central case. It does not include sensitivity in the price of the fabric measures as it is assumed that effects on the capital cost will be similar for each scenario on a given curve. Whilst not done here, it may be appropriate to consider cost sensitivity for the different types of heating system.

Table 6.2: Economic Optimal Energy Performance Level in Primary Energy

Reference building	***Cost Optimal***	***Sensitivity***
Semi-Detached Cavity – Walls	U = 0.55 W/m^{2}K	
Semi-Detached Cavity – Windows	U = 1.6 W/m^{2}K	
Semi-Detached Cavity – Heating	88% (gas boiler)	
Semi-Detached Cavity – Roof	U = 0.11 W/m^{2}K to 0.13 W/m^{2}K	
Apartment Building Cavity – Walls	U = 0.55 W/m^{2}K	
Apartment Building Cavity – Windows	U = 1.6 W/m^{2}K	
Apartment Building Cavity – Heating	88% (gas boiler)	
Apartment Building Cavity – Roof	U = 0.11 W/m^{2}K	U = 0.11 W/m^{2}K to 0.13 W/m^{2}K
Semi-Detached Solid – Walls	U = 0.30 W/m^{2}K	U = 0.21 W/m^{2}K to 0.30 W/m^{2}K
Semi-Detached Solid – Windows	U = 1.6 W/m^{2}K	
Semi-Detached Solid – Heating	88% (gas boiler)	
Semi-Detached Solid – Roof	U = 0.11 W/m^{2}K	U = 0.11 W/m^{2}K to 0.13 W/m^{2}K
Apartment Building Solid – Walls	U = 0.30 W/m^{2}K	U = 0.21 W/m^{2}K to 0.30 W/m^{2}K
Apartment Building Solid – Windows	U = 1.6 W/m^{2}K	
Apartment Building Solid – Heating	88% (gas boiler)	
Apartment Building Solid – Roof	U = 0.11 W/m^{2}K	U = 0.11 W/m^{2}K to 0.13 W/m^{2}K

6.3 Existing Buildings – Analysis of Packages

As for new buildings, the cost optimal level is based on the macroeconomic cost calculations. The cost optimal curves for each of the reference buildings are shown in Figure 6.3 (a–d). The costs are based on the central energy price in Section 5.

The results are summarised in Table 6.3. The sensitivity highlighted alternative options either within 5% of the macroeconomic cost in the central case or the optimum solution in any of the sensitivity analyses.

There is no comparison with current energy performance requirements provided in Figure 6.3 (a-d). In the UK energy performance requirements for existing buildings undergoing renovation are applied to the individual building elements as permitted under Article 7 of the Directive.

In summary, the results show that in all cases the cost optimal package has a gas boiler and roof improvements for all dwelling types. For the cavity wall buildings, the cost optimal package also included improvement to the wall. For the apartment building, the cost optimal package also included the installation of PV. The sensitivity analyses also included additional options for fabric upgrade and installation of PV.

Table 6.3: Economic Optimal Energy Performance Level in Primary Energy

Reference building	*Optimal Solution*	*Sensitivity Range*
Semi-detached house – Cavity	Roof and wall improvements to cost optimum, gas boiler (Primary Energy = 254 KWh/m²)	Roof and wall improvements to cost optimum, gas boiler, 30% PV
Apartment Building – Cavity	Roof and wall improvements to cost optimum, gas boiler, 30% PV (Primary Energy = 146 KWh/m²)	Roof and wall improvements to cost optimum, gas boiler Roof and wall improvements to cost optimum, gas boiler, 15% PV Wall improvements to cost optimum, gas boiler Roof improvements to cost optimum, gas boiler
Semi-detached house – Solid	Roof improvement to cost optimum, gas boiler (Primary Energy = 313 KWh/m²)	Roof improvement to cost optimum, gas boiler, 30% PV No fabric upgrade, gas boiler
Apartment Building – Solid	Roof improvement to cost optimum, gas boiler, 30% PV (Primary Energy = 162 KWh/m²)	Roof improvement to cost optimum, gas boiler No fabric upgrade, gas boiler

Figure 6.3a: Semi-Detached House – Cavity Wall

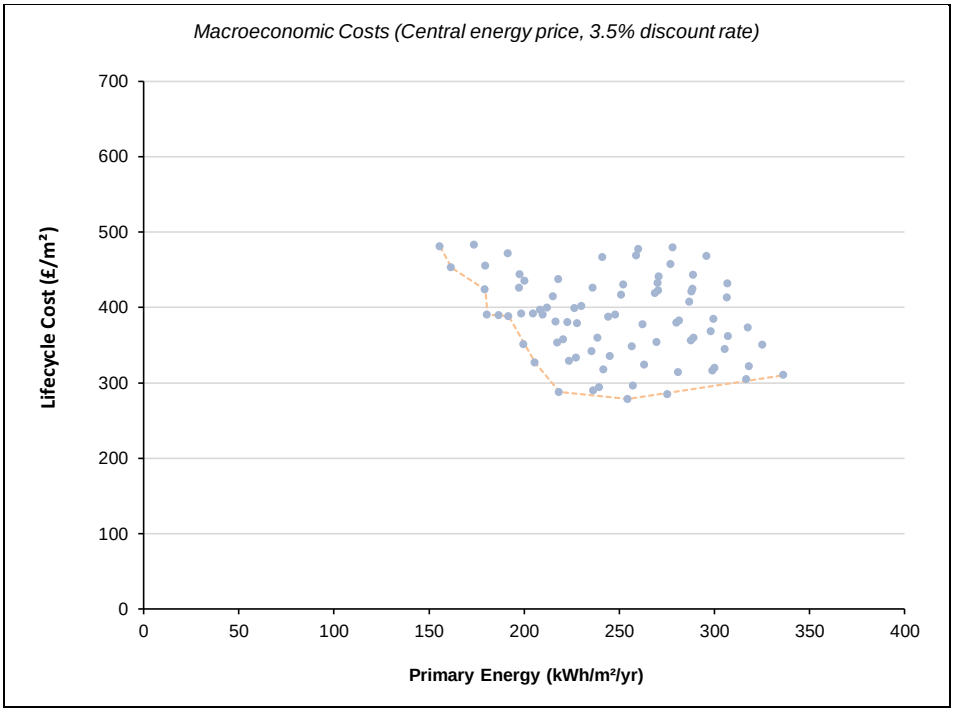


Figure 6.3b: Apartment Block – Cavity Wall

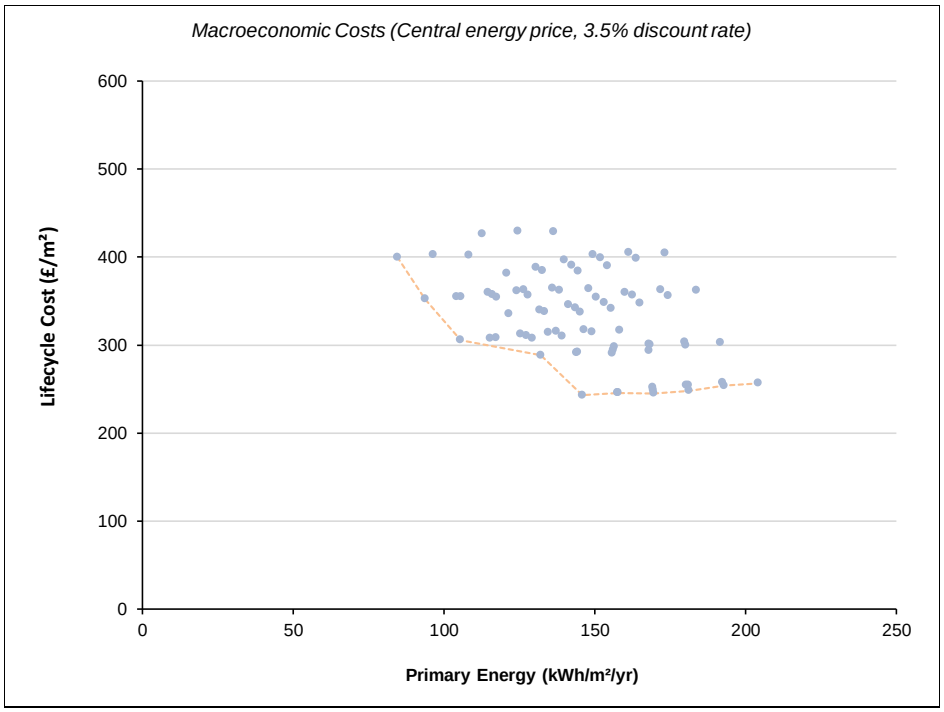


Figure 6.3c: Semi-Detached House – Solid Wall

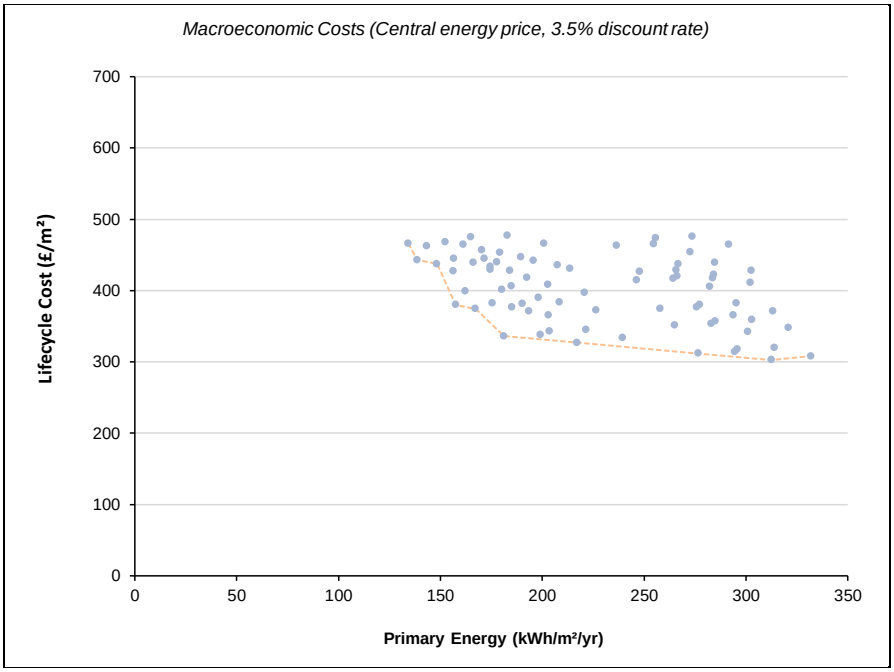
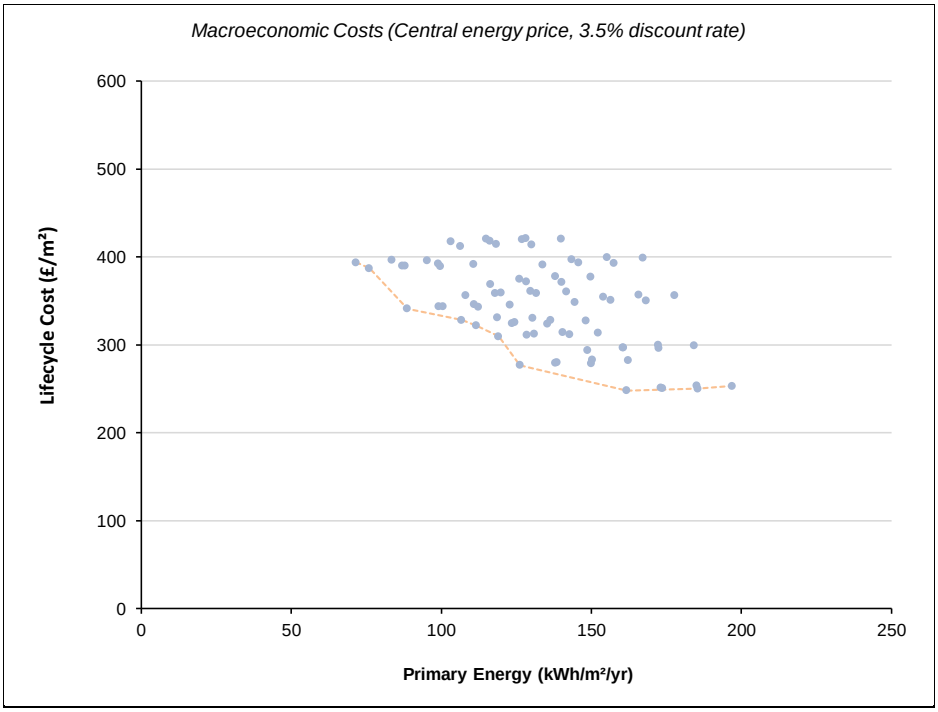


Figure 6.3d: Apartment Block – Solid Wall



7. Comparison of Current Regulations and Cost Optimal Level

7.1 New Buildings

7.1.1 Single family buildings

For single family buildings, Table 7.1 shows the current energy requirements in national regulations compared to the cost optimal level for a semi detached house.

A positive percentage gap denotes that the national energy requirements are better than the cost optimal level whilst a negative gap denotes that they are poorer than the cost optimal level.

Table 7.1 Comparison Table, New Semi-Detached House

Reference building	*Cost Optimal Level ($kWh/m^2/yr$)*	*Current Requirements ($kWh/m^2/yr$)*	*Gap (%)*
Semi-Detached House (England)	96	93	+ 2%
Semi-Detached House (Wales)	96	93	+ 3%
Semi-Detached House (Scotland)	96	74	+ 23%
Semi-Detached House (Nortern Ireland)	96	101	- 6%
Semi-Detached House (UK average)	**96**	**92**	**+ 4%**

The current national energy requirements weighted across the UK as a whole are better than the cost optimal level. Although requirements in Northern Ireland are poorer than the cost optimal level they are well within the 15% range described in the cost optimal methodology so there is no significant discrepancy. It is also worth considering the sensitivity results. If the minimum in the range was taken, the current energy requirements in all countries would be better than the cost optimal levels.

7.1.2 Apartment blocks and multi-family buildings

For multi family buildings, Table 7.2 shows the current national regulations compared to the cost optimal level for the reference apartment building.

Table 7.2 Comparison Table, New Apartment Building

Reference building	*Cost Optimal Level (kWh/m^2/yr)*	*Current Requirements (kWh/m^2/yr)*	*Gap (%)*
Apartment Building (England)	77	92	- 20%
Apartment Building (Wales)	77	92	- 20%
Apartment Building (Scotland)	77	71	+ 8%
Apartment Building (Northern Ireland)	77	92	- 20%
Apartment Building (UK average)	**77**	**90**	**- 14%**

The current national energy requirements weighted across the UK as a whole are are poorer than the cost optimal level but within the 15% threshold described in the cost optimal methodology. Requirements in Scotland are better than the cost optimal level. If the the minimum in the range of sensitivity results are taken into consideration, then the current energy requirements in all countries would be better than the cost optimal levels.

7.2 Existing Buildings – Elemental Analysis

7.2.1 Single family buildings

For each improvement measure to an existing semi detached house, Table 7.3 shows the current national regulations compared to the cost optimal level. Due to the different construction types, houses with cavity wall construction and solid wall construction have been considered separately.

Table 7.3 Comparison Table, Existing Semi-Detached House

Reference building	*Cost Optimal Level*	*Current Requirements*	*Gap*
Semi-Detached House, Cavity Wall Insulation	U = 0.55 W/m^{2}K	U = 0.52 W/m^{2}K to 0.22 W/m^{2}K	+ 5%
UK Average	U = 0.55 W/m^{2}K *	U = 0.52 W/m^{2}K	
Semi-Detached House, Solid Wall Insulation	U = 0.30 W/m^{2}K	U = 0.30 W/m^{2}K to 0.22 W/m^{2}K	+ 3%
UK Average	U = 0.30 W/m^{2}K	U = 0.29 W/m^{2}K	
Semi-Detached House, Cavity Wall – Windows	U = 1.6 W/m^{2}K	U = 1.6 W/m^{2}K	Cost optimal
Semi-Detached House, Solid Wall – Windows	U = 1.6 W/m^{2}K	U = 1.6 W/m^{2}K	
UK Average	U = 1.6 W/m^{2}K	U = 1.6 W/m^{2}K	
Semi-Detached House, Cavity Wall – Roof	U = 0.11 W/m^{2}K to 0.13 W/m^{2}K	U = 0.18 W/m^{2}K	- 64%
Semi-Detached House, Solid Wall – Roof	U = 0.11 W/m^{2}K	U = 0.18 W/m^{2}K	
UK Average	U = 0.11 W/m^{2}K	U = 0.18 W/m^{2}K	
Semi-Detached House, Cavity Wall – Heating	88% (gas boiler)	88% (gas boiler)	Cost optimal
Semi-Detached House, Solid Wall – Heating	88% (gas boiler)	88% (gas boiler)	
UK Average	88% (gas boiler)	88% (gas boiler)	

* Current cavity wall insulation standards are based on fully filling a 50mm cavity, which is a typical cavity size for older properties. Many buildings in the UK have cavity walls with empty 50mm cavities. The cost-optimal level has been calculated based on a 100mm cavity, which is found in more modern buildings. It appears reasonable and can be argued that fully filling a 50mm cavity is very cost effective and worthwhile.

The current energy requirements weighted across the UK for solid wall insulation, windows and heating are cost optimal level or better. The current energy requirements for roof insulation are less efficient than the theoretical cost optimal level. However, the Directive says that these requirements should also be technically and functionally feasible and we will need to be mindful of the potential impacts of increasing loft insulation thicknesses upon roof detailing and provision of adequate ventilation to the roof space. We will consider how this gap can be addressed as part of the next planned review of energy requirements.

7.2.2 Apartment blocks and multi-family buildings

For each improvement measure to an existing apartment building, Table 7.4 shows the current national regulations compared to the cost optimal level. Due to the different construction types, apartment buildings with cavity wall construction and solid wall construction have been considered separately.

Table 7.4 Comparison Table, Existing Apartment Building

Reference building	*Cost Optimal Level*	*Current Requirements*	*Gap*
Apartment Building, Cavity Wall Insulation	U = 0.55 W/m^{2}K	U = 0.55 W/m^{2}K to 0.22 W/m^{2}K	+ 4%
UK Average	U = 0.55 W/m^{2}K *	U = 0.53 W/m^{2}K	
Apartment Building, Solid Wall Insulation	U = 0.30 W/m^{2}K	U = 0.30 W/m^{2}K to 0.22 W/m^{2}K	Cost optimal
UK Average	U = 0.30 W/m^{2}K	U = 0.30 W/m^{2}K	
Apartment Building, Cavity Wall - Windows	U = 1.6 W/m^{2}K	U = 1.6 W/m^{2}K	Cost optimal
Apartment Building, Solid Wall – Windows	U = 1.6 W/m^{2}K	U = 1.6 W/m^{2}K	
UK Average	U = 1.6 W/m^{2}K	U = 1.6 W/m^{2}K	
Apartment Building, Cavity Wall – Roof	U = 0.11 W/m^{2}K	U = 0.18 W/m^{2}K	- 64%
Apartment Building, Solid Wall – Roof	U = 0.11 W/m^{2}K	U = 0.18 W/m^{2}K	
UK Average	U = 0.11 W/m^{2}K	U = 0.18 W/m^{2}K	
Apartment Building, Cavity Wall – Heating	88% (gas boiler)	88% (gas boiler)	Cost optimal
Apartment Building, Solid Wall – Heating	88% (gas boiler)	88% (gas boiler)	
UK Average	88% (gas boiler)	88% (gas boiler)	

* Current cavity wall insulation standards are based on fully filling a 50mm cavity, which is a typical cavity size for older properties. Many buildings in the UK have cavity walls with empty 50mm cavities. The cost-optimal level has been calculated based on a 100mm cavity, which is found in more modern buildings. It appears reasonable and can be argued that fully filling a 50mm cavity is very cost effective and worthwhile.

The current energy requirements weighted across the UK for solid wall insulation, windows and heating are cost optimal level or better. The current energy requirements for roof insulation are less efficient than the theoretical cost optimal level. However, the Directive says that these requirements should also be technically and functionally feasible and we will need to be mindful of the potential impacts of increasing loft insulation thicknesses upon roof detailing and provision of adequate ventilation to the roof space. We will consider how this gap can be addressed as part of the next planned review of energy requirements.

7.3 Existing Buildings – Analysis of Packages

As permitted under Article 7 of the Directive, energy requirements for the renovation of existing buildings in the UK are applied to the individual elements that are undergoing renovation or replacement. Energy requirements are not applied at the building level to existing buildings undergoing renovation so no comparison with current energy performance requirements for packages of work is provided.

The energy performance of existing buildings in the case of a major renovation is based upon the sum of component performances of the individual elements e.g. the roof, wall, window, heating boiler etc. that undergo renovation or replacement. If a renovation is carried out as smaller tasks then the same component performance requirements for individual elements are applied.

Part B: Non-Domestic Buildings

8. Reference Buildings

8.1 New Buildings

According to the Cost Optimal Methodology, Member States should establish at least one reference building for office buildings and also establish reference buildings for other non-residential building categories listed in Annex I of the EPBD for which specific energy performance requirements exist. In each administration of the UK, energy performance requirements are set for all non-residential buildings. Hence, we have considered the wider list of non-residential buildings included in the EPBD. We have selected reference buildings based on the following five building categories.

- Office buildings
- Educational buildings
- Hotels and restaurants
- Wholesale and retail services buildings
- Hospitals and healthcare facilities

Sport facilities are also included in Annex I of the EPBD. We have chosen not to analyse such buildings in this work. The main reason for this is that the other buildings in the list above encompass a wide range of servicing strategies and are considered representative of the significant majority of the non-domestic building stock. Hence, this provides a sufficient understanding of the gap between current regulations and the Cost Optimal Level. In addition, restricting the number of buildings allows for a more detailed analysis, so that a greater number of measures can be included in the cost-optimal calculations.

For the office buildings and hotel and restaurants building categories we have used building models constructed for the development of Building Regulations for energy performance requirements within the UK. These are typical building models and not actual buildings. For the other three categories, we have used actual building models taken from construction projects. These again have been used for the development of Building Regulations for energy performance requirements within the UK. In all cases, these models have previously been agreed as being sufficiently representative for such work.

A summary of the buildings, construction type and servicing strategy are shown in Table 8.1.

In total seven reference buildings have been considered. Both naturally ventilated and air conditioned serviced buildings have been considered – including splitting office buildings between both types. Furthermore both cavity wall and steel frame constructed buildings have been considered with the most appropriate construction type selected for each building category. This should provide a good estimate of the difference between national regulations and cost optimal levels.

Table 8.1: New Non Domestic Reference Buildings

Building Category	***Construction type***	
	Cavity Wall	***Steel Frame***
Office (AC)		30,000 m²
Office (NV)		4,500 m²
Secondary School	11,200 m²	
Hospital		18,500 m²
Hotel (AC)		15,200 m²
Distribution Warehouse		5,200 m²
Retail Warehouse		5,200 m²

Please note that the floor areas are calculated by taking linear measurements between the finished internal faces of the walls.

For the purpose of this work, it has been assumed that the buildings will be constructed in South-East England. This area is the greatest focus of current construction activities within the UK. Hence, we have considered climate and cost data relevant for the South-East England geographical area.

Table 8.2 provides a more detailed summary of the reference buildings using the template provided with the Cost Optimal Methodology. It includes the primary energy associated with building specifications that comply with national regulations based on Part L 2013 of the Building Regulations (England), Technical Handbook Section 6 of the Scottish Building Regulations (2015), Part L 2014 of the Building Regulations (Wales) and Part F 2012 of the Building Regulations (Northern Ireland). It is noted that for all four countries (England, Wales, Scotland and Northern Ireland) the national standard is performance based, against a carbon dioxide (CO_2) metric. Different compliant solutions may have different primary energies. We have selected a typical compliant solution in determining the primary energy associated with the national regulations.

Table 8.3 (a-g) provides a summary of the energy performance relevant data used in the modelling for each of the seven reference buildings.

Table 8.2: Reference Buildings for New Non Domestic Buildings

Building Category	***Building Geometry***		***Shares of window area on the building envelope and windows with no solar access***	***Floor area m^2 as used in building code***	***Typical energy performance kWh/m^2/yr***				***Component level requirements***
	Area of N/W/S/E facade (m^2)	***Volume (m^3)***	***Ratio of window area over total building envelope area separately for N/W/S/E facades***		***Primary energy for each building model according to current national regulations***				
					E	***W***	***S***	***NI***	
Office (AC)	3,600 / 3,600 / 3,600 / 3,600	111,000	0.8 / 0.8 / 0.8 / 0.8	30,000	115	97	101	125	There are recommended minimum component performance levels but currently these are not mandated. In this work we have always ensured that all component measures are at least as good as the recommended levels.
Office (NV)	340 / 560 / 340 / 560	16,875	0.4 / 0.4 / 0.4 / 0.4	4,500	66	50	59	76	
Secondary School	1000 / 2000 / 1000 / 2000	22,400	0.2 / 0.2 /0.2 / 0.2	11,200	122	107	121	135	
Hospital	1380 / 2760 / 1380 / 2760	19,800	0.22 / 0.22 / 0.22 / 0.22	18,500	237	219	225	260	
Hotel (AC)	3750 / 1875 / 3750 / 1875	15,000	0.35 / 0.35 / 0.35 / 0.35	15,200	395	386	399	461	
Distribution Warehouse	270 / 750 / 430 / 750	40,000	0 / 0 / 0 / 0 (Rooflights = 0.12)	5,200	112	104	134	130	
Retail Warehouse	270 / 750 / 430 / 750	40,000	0 / 0 / 0 / 0 (Rooflights = 0.12)	5,200	184	168	175	194	

Table 8.3a: Energy Performance Relevant Data – New Office (AC)

						Quantity	***Unit***
Calculation	Method and tool(s)	SBEM v.5.2.g					
	Primary energy conversion factors (averaged over calculation period):	Gas				1.127	kWh/kWh
		Grid Supplied Electricity				2.364	
		On-site Generated Electricity				-2.364	
Climate	Location	London					
	Climate data	SBEM v.5.2.g climate data file					
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.					
Geometry	Length x Width x Height					55 x 55 x 38	m
Systems	Ventilation system	Air changes per hour				1	1/hr
		Heat recovery efficiency				70	%
	Heating system	Generation				86	%
		Distribution				95	%
		Emission				-	%
		Control				-	%
	Cooling system	Generation				350	%
		Distribution				66	%
		Emission				-	%
		Control				-	%
	DHW system	Generation				75	%
		Distribution				60	%
		Emission				-	%
		Control				-	%
Setpoints and Schedules	Temperature setpoint	Winter				20	ºC
		Summer				23	ºC
	Operation schedules	All schedules are defined by the SBEM v.5.2.g activity database.					
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.				
		Daylight lighting control					
			E	W	NI	S	
	Heating energy		4	6	8	5	kWh/m²/yr
	Cooling energy		10	9	8	10	kWh/m²/yr
	DHW energy		3	3	3	3	kWh/m²/yr
	Lighting energy		22	21	21	21	kWh/m²/yr
	Auxiliary energy		13	13	18	14	kWh/m²/yr
Energy Generation	Photovoltaics		0	6	0	5	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	7	9	12	8	kWh/m²/yr
		Electricity	45	43	47	44	
		Other	0	0	0	0	kWh/m²/yr
	Primary energy		115	97	125	101	kWh/m²/yr

Table 8.3b: Energy Performance Relevant Data – New Office (NV)

						Quantity	***Unit***
Calculation	Method and tool(s)	SBEM v.5.2.g					
	Primary energy conversion factors (averaged over calculation period):	Gas				1.127	kWh/kWh
		Grid Supplied Electricity				2.364	
		On-site Generated Electricity				-2.364	
Climate	Location	London					
	Climate data	SBEM v.5.2.g climate data file					
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.					
Geometry	Length x Width x Height					30 x 50 x 11	m
Systems	Ventilation system	Air changes per hour				-	1/hr
		Heat recovery efficiency				-	%
	Heating system	Generation				86	%
		Distribution				95	%
		Emission				-	%
		Control				-	%
	Cooling system	Generation				-	%
		Distribution				-	%
		Emission				-	%
		Control				-	%
	DHW system	Generation				75	%
		Distribution				60	%
		Emission				-	%
		Control				-	%
Setpoints and Schedules	Temperature setpoint	Winter				20	ºC
		Summer				-	ºC
	Operation schedules	All schedules are defined by the SBEM v.5.2.g activity database.					
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.				
		Daylight lighting control					
			E	W	NI	S	
	Heating energy		10	11	20	13	kWh/m²/yr
	Cooling energy		0	0	0	0	kWh/m²/yr
	DHW energy		3	3	3	3	kWh/m²/yr
	Lighting energy		18	17	17	18	kWh/m²/yr
	Auxiliary energy		4	4	4	4	kWh/m²/yr
Energy Generation	Photovoltaics		0	6	0	5	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	13	14	23	13	kWh/m²/yr
		Electricity	22	21	21	24	kWh/m²/yr
		Other	0	0	0	0	kWh/m²/yr
	Primary energy		66	50	76	59	kWh/m²/yr

Table 8.3c: Energy Performance Relevant Data – New Secondary School

								Quantity	**Unit**
Calculation	Method and tool(s)		SBEM v.5.2.g						
	Primary energy conversion factors (averaged over calculation period):		Gas					1.127	kWh/kWh
			Grid Supplied Electricity					2.364	
			On-site Generated Electricity					-2.364	
Climate	Location		London						
	Climate data		SBEM v.5.2.g climate data file						
	Terrain location		Sub-urban. The impact of surrounding buildings has not been included.						
Geometry	Length x Width x Height							56 x 100 x 8	m
Systems	Ventilation system		Air changes per hour					-	1/hr
			Heat recovery efficiency					-	%
	Heating system		Generation					86	%
			Distribution					95	%
			Emission					-	%
			Control					-	%
	Cooling system		Generation					350	%
			Distribution					66	%
			Emission					-	%
			Control					-	%
	DHW system		Generation					75	%
			Distribution					60	%
			Emission					-	%
			Control					-	%
Setpoints and Schedules	Temperature setpoint		Winter					20	ºC
			Summer					23	ºC
	Operation schedules		All schedules are defined by the SBEM v.5.2.g activity database.						
Energy Use	Energy contribution of main passive strategies		Natural ventilation	These energy savings are not reported separately.					
			Daylight lighting control						
				E		W	NI	S	
	Heating energy			20		22	31	30	kWh/m²/yr
	Cooling energy			0		0	0	0	kWh/m²/yr
	DHW energy			58		58	60	58	kWh/m²/yr
	Lighting energy			13		12	12	13	kWh/m²/yr
	Auxiliary energy			1		1	1	1	kWh/m²/yr
Energy Generation	Photovoltaics			0		6	0	5	kWh/m²/yr
Energy Consumption	Delivered energy		Fossil fuel	78		80	91	88	kWh/m²/yr
			Electricity	14		14	13	14	kWh/m²/yr
			Other	0		0	0	0	kWh/m²/yr
	Primary energy			122		108	135	121	kWh/m²/yr

Table 8.3d: Energy Performance Relevant Data – New Hospital

							Quantity	**Unit**
Calculation	Method and tool(s)	SBEM v.5.2.g						
	Primary energy conversion factors (averaged over calculation period):	Gas					1.127	kWh/kWh
		Grid Supplied Electricity					2.364	
		On-site Generated Electricity					-2.364	
Climate	Location	London						
	Climate data	SBEM v.5.2.g climate data file						
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.						
Geometry	Length x Width x Height						33 x 100 x 23	m
Systems	Ventilation system	Air changes per hour					6	1/hr
		Heat recovery efficiency					70	%
	Heating system	Generation					86	%
		Distribution					95	%
		Emission					-	%
		Control					-	%
	Cooling system	Generation					-	%
		Distribution					-	%
		Emission					-	%
		Control					-	%
	DHW system	Generation					75	%
		Distribution					60	%
		Emission					-	%
		Control					-	%
Setpoints and Schedules	Temperature setpoint	Winter					20	ºC
		Summer					-	ºC
	Operation schedules	All schedules are defined by the SBEM v.5.2.g activity database.						
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.					
		Daylight lighting control						
			E	W	NI	S		
	Heating energy		7	10	14	9		kWh/m²/yr
	Cooling energy		17	15	14	15		kWh/m²/yr
	DHW energy		52	52	53	53		kWh/m²/yr
	Lighting energy		26	24	25	20		kWh/m²/yr
	Auxiliary energy		30	30	38	15		kWh/m²/yr
Energy Generation	Photovoltaics		0	6	0	5		kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	59	62	68	62		kWh/m²/yr
		Electricity	72	69	78	71		kWh/m²/yr
		Other	0	0	0	0		kWh/m²/yr
	Primary energy		237	219	260	225		kWh/m²/yr

Table 8.3e: Energy Performance Relevant Data – New Hotel (AC)

							Quantity	**Unit**
Calculation	Method and tool(s)		SBEM v.5.2.g					
	Primary energy conversion factors (averaged over calculation period):		Gas				1.127	kWh/kWh
			Grid Supplied Electricity				2.364	
			On-site Generated Electricity				-2.364	
Climate	Location		London					
	Climate data		SBEM v.5.2.g climate data file					
	Terrain location		Sub-urban. The impact of surrounding buildings has not been included.					
Geometry	Length x Width x Height						100 x 50 x 38	m
Systems	Ventilation system		Air changes per hour				1.2	1/hr
			Heat recovery efficiency				70	%
	Heating system		Generation				86	%
			Distribution				95	%
			Emission				-	%
			Control				-	%
	Cooling system		Generation				350	%
			Distribution				66	%
			Emission				-	%
			Control				-	%
	DHW system		Generation				75	%
			Distribution				60	%
			Emission				-	%
			Control				-	%
Setpoints and Schedules	Temperature setpoint		Winter				20	ºC
			Summer				23	ºC
	Operation schedules		All schedules are defined by the SBEM v.5.2.g activity database.					
Energy Use	Energy contribution of main passive strategies		Natural ventilation	These energy savings are not reported separately.				
			Daylight lighting control					
				E	W	NI	S	
	Heating energy			37	45	65	50	kWh/m²/yr
	Cooling energy			7	6	5	7	kWh/m²/yr
	DHW energy			204	204	211	204	kWh/m²/yr
	Lighting energy			21	20	22	20	kWh/m²/yr
	Auxiliary energy			24	24	36	26	kWh/m²/yr
Energy Generation	Photovoltaics			0	6	0	5	kWh/m²/yr
Energy Consumption	Delivered energy		Fossil fuel	240	249	276	254	kWh/m²/yr
			Electricity	52	50	63	53	kWh/m²/yr
			Other	0	0	0	0	kWh/m²/yr
	Primary energy			395	386	461	399	kWh/m²/yr

Table 8.3f: Energy Performance Relevant Data – New Distribution Warehouse

					Quantity		***Unit***
Calculation	Method and tool(s)	SBEM v.5.2.g					
	Primary energy conversion factors (averaged over calculation period):	Gas			1.127		kWh/kWh
		Grid Supplied Electricity			2.364		
		On-site Generated Electricity			-2.364		
Climate	Location	London					
	Climate data	SBEM v.5.2.g climate data file					
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.					
Geometry	Length x Width x Height				44 x 105 x 8		m
Systems	Ventilation system	Air changes per hour			-		1/hr
		Heat recovery efficiency			-		%
	Heating system	Generation			86		%
		Distribution			95		%
		Emission			-		%
		Control			-		%
	Cooling system	Generation			350		%
		Distribution			66		%
		Emission			-		%
		Control			-		%
	DHW system	Generation			75		%
		Distribution			60		%
		Emission			-		%
		Control			-		%
Setpoints and Schedules	Temperature setpoint	Winter			20		ºC
		Summer			23		ºC
	Operation schedules	All schedules are defined by the SBEM v.5.2.g activity database.					
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.				
		Daylight lighting control					
			E	W	NI	S	
	Heating energy		33	42	52	49	kWh/m²/yr
	Cooling energy		0	0	0	0	kWh/m²/yr
	DHW energy		18	18	19	16	kWh/m²/yr
	Lighting energy		18	16	16	17	kWh/m²/yr
	Auxiliary energy		5	5	5	5	kWh/m²/yr
Energy Generation	Photovoltaics		0	6	0	5	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	51	60	70	49	kWh/m²/yr
		Electricity	23	22	21	39	kWh/m²/yr
		Other	0	0	0	0	kWh/m²/yr
	Primary energy		112	104	130	134	kWh/m²/yr

Table 8.3g: Energy Performance Relevant Data – New Retail Warehouse

					Quantity		***Unit***
Calculation	Method and tool(s)	SBEM v.5.2.g					
	Primary energy conversion factors (averaged over calculation period):	Gas			1.127		kWh/kWh
		Grid Supplied Electricity			2.364		
		On-site Generated Electricity			-2.364		
Climate	Location	London					
	Climate data	SBEM v.5.2.g climate data file					
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.					
Geometry	Length x Width x Height				44 x 105 x 8		m
Systems	Ventilation system	Air changes per hour			0.5		1/hr
		Heat recovery efficiency			70		%
	Heating system	Generation			86		%
		Distribution			95		%
		Emission			-		%
		Control			-		%
	Cooling system	Generation			350		%
		Distribution			66		%
		Emission			-		%
		Control			-		%
	DHW system	Generation			75		%
		Distribution			60		%
		Emission			-		%
		Control			-		%
Setpoints and Schedules	Temperature setpoint	Winter			20		ºC
		Summer			23		ºC
	Operation schedules	All schedules are defined by the SBEM v.5.2.g activity database.					
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.				
		Daylight lighting control					
			E	W	NI	S	
	Heating energy		20	25	33	28	kWh/m²/yr
	Cooling energy		15	14	10	12	kWh/m²/yr
	DHW energy		2	2	2	2	kWh/m²/yr
	Lighting energy		35	34	34	35	kWh/m²/yr
	Auxiliary energy		17	17	22	17	kWh/m²/yr
Energy Generation	Photovoltaics		0	6	0	5	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	22	27	35	28	kWh/m²/yr
		Electricity	67	65	66	66	kWh/m²/yr
		Other	0	0	0	0	kWh/m²/yr
	Primary energy		184	168	194	175	kWh/m²/yr

8.2 Existing Buildings

According to the Cost Optimal Methodology, Member States should establish at least two reference buildings for each building category. Hence, we have considered two reference buildings for each of the five building categories considered for new buildings in Section 8.1.

We have chosen to adopt five of the seven building models used for new build (i.e. same size and geometry). The principal reason for the choice of adopting the new build models is that it provides a useful comparison with the new-build results. Furthermore, it would be expected that the new-build floor areas selected are not significantly different to existing building floor areas and that the floor area is much less significant in determining the cost optimum level than the initial energy efficiencies assumed in the base case (i.e. current) existing building models. In selecting the five of the original seven building models, we have chosen to assess only one of the two office buildings (naturally ventilated option) and one of the two warehouse buildings (retail warehouse). Based on the results for new non-domestic buildings (which we analysed first), adopting five rather than seven buildings should be suitable for comparing current technical standards to the cost optimal level.

For each of the five building models, we have assumed two different initial energy performance levels i.e. we have considered two reference buildings for each building category. For the purpose of this discussion, we have defined these here as Energy Efficiency 1 (EE1) and Energy Efficiency 2 (EE2) where EE2 is of a higher standard than EE1.

We have principally used energy data for existing buildings published in the Energy Conservation Guides (ECON)[37,38,39,40] to derive EE1 and EE2. These ECON publications were produced following extensive surveys of existing buildings covering four of the five building types (offices, schools, hospitals and hotels). This data has the advantage of representing the consolidation of measured data from a wide variety of actual buildings. We note that some buildings will have improved performance since this survey was carried out but such buildings are less likely to require renovation or replacement in the next few years – which is the focus of this cost optimal study.

[37] ECON 19: Energy use in Offices, BRECSU, 2000.
[38] ECON 36: Energy Efficiency in Hotels, BRECSU, 1993.
[39] ECON 73: Saving Energy in Schools, BRECSU, 1998.
[40] ECON 72: Saving Energy in Hospitals BRECSU, 1999.

There are two sets of data provided by ECON – 'typical' energy data and 'good practice' energy data. The energy data is sub-divided into energy end uses e.g. heating, cooling etc. We have used these two sets of data to derive the specifications for EE1 and EE2 respectively. We have determined fabric and services specifications for EE1 and EE2 to deliver the energy end uses provided by the ECON guides.

The offices ECON guide includes benchmark data for four different office types (two naturally ventilated and two air conditioned). We have used the average of the 'Naturally Ventilated Cellular' and 'Naturally Ventilated Open-Plan' benchmarks for the 'Office (NV)' building model. Similarly, the ECON guide for hotels includes benchmark data for three different hotel types. Based on the floor area in Table 8.1 and the description in the ECON guide, we have used the 'Type 1: Luxury Hotel' benchmark for the 'Hotel' model. The other benchmark data were for 'smaller hotels' and 'business hotels'.

Since there is not an ECON guide for Warehouse buildings, we have used the benchmarks published in CIBSE Guide F[41]. These are taken from a report on energy consumption in retail buildings published in 2000 and are representative of the current existing building stock. As with the ECON data, the benchmarks include both 'typical' and 'good practice' energy data.

In some cases the benchmarks, do not include a breakdown of the energy end-uses. Therefore, where necessary we have apportioned the benchmark energy data by energy end use as follows:

- We have used the 'typical' building specifications included in the 2008 England and Wales National Calculation Methodology (NCM). These 'typical' values reflect England and Wales Part L 1995 standards.
- We have used the percentage of energy use by each end-use (e.g. heating, cooling etc.) from these calculation runs to apportion the energy end-use for the school and retail benchmarks.

Table 8.4 provides a summary of the reference buildings using the template provided in the Cost Optimal Methodology. We have omitted information on the building geometry, window and floor area which are already provided in Tables 8.2 and 8.3.

Table 8.5 (a-e)provides a summary of the energy performance data. Again, we have omitted information on the buildings themselves which were provided in Tables 8.2 and 8.3.

[41] Guide F: Energy Efficiency in Buildings, CIBSE, 2012.

Table 8.4: Existing Non Domestic Building Models

Building Category	*Energy Efficiency Level*	*Construction type*	*Typical energy performance kWh/m²/yr*	*Component level requirements*
Office (NV)	EE1	Steel Frame	334	The relevant component level standards for existing non-domestic buildings are included in Table 9.2.
	EE2	Steel Frame	229	
Secondary School	EE1	Cavity Wall	280	
	EE2	Cavity Wall	225	
Hospital	EE1	Steel Frame	558	
	EE2	Steel Frame	472	
Hotel (AC)	EE1	Steel Frame	775	
	EE2	Steel Frame	650	
Retail Warehouse	EE1	Steel Frame	389	
	EE2	Steel Frame	364	

Table 8.5a: Energy Performance Relevant Data – Existing Office (NV)

			Quantity		*Unit*
			EE1	*EE2*	
Systems	Ventilation system	Air changes per hour	-	-	1/hr
		Heat recovery efficiency	-	-	%
	Heating system	Generation	70	70	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
	Cooling system	Generation	-	-	%
		Distribution	-	-	%
		Emission	-	-	%
		Control	-	-	%
	DHW system	Generation	70	90	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
Building Elements	Average U-value	Walls	0.6	0.45	W/m²K
		Roof	0.6	0.6	W/m²K
		Floor	0.6	0.45	W/m²K
		Windows	4.8	4.8	W/m²K
	Average g-value of glazing		0.7	0.7	-
	Air permeability		20	15	m³/m².hr
	Lighting	Efficacy	15	25	llm/cW
		Daylight controls	NO	NO	-
		Occupancy controls	NO	NO	-
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.		
		Daylight lighting control			
	Heating energy		48	52	kWh/m²/yr
	Cooling energy		0	0	kWh/m²/yr
	DHW energy		4	3	kWh/m²/yr
	Lighting energy		114	68	kWh/m²/yr
	Auxiliary energy		1	1	kWh/m²/yr

Table 8.5b: Energy Performance Relevant Data – Existing Secondary School

			Quantity		***Unit***
			EE1	***EE2***	
Systems	Ventilation system	Air changes per hour	-	-	1/hr
		Heat recovery efficiency	-	-	%
	Heating system	Generation	70	70	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
	Cooling system	Generation	-	-	%
		Distribution	-	-	%
		Emission	-	-	%
		Control	-	-	%
	DHW system	Generation	45	60	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
Building Elements	Average U-value	Walls	0.6	0.45	W/m²K
		Roof	0.6	0.6	W/m²K
		Floor	0.6	0.45	W/m²K
		Windows	4.8	4.8	W/m²K
	Average g-value of glazing		0.7	0.7	-
	Air permeability		20	15	m³/m².hr
	Lighting	Efficacy	30	35	llm/cW
		Daylight controls	NO	NO	-
		Occupancy controls	NO	NO	-
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.		
		Daylight lighting control			
	Heating energy		58	49	kWh/m²/yr
	Cooling energy		0	0	kWh/m²/yr
	DHW energy		118	88	kWh/m²/yr
	Lighting energy		33	28	kWh/m²/yr
	Auxiliary energy		2	2	kWh/m²/yr

Table 8.5c: Energy Performance Relevant Data – Existing Hospital

			Quantity		Unit
			EE1	EE2	
Systems	Ventilation system	Air changes per hour	6	6	1/hr
		Heat recovery efficiency	-	-	%
	Heating system	Generation	70	70	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
	Cooling system	Generation	-	-	%
		Distribution	-	-	%
		Emission	-	-	%
		Control	-	-	%
	DHW system	Generation	45	45	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
Building Elements	Average U-value	Walls	0.6	0.45	W/m²K
		Roof	0.6	0.6	W/m²K
		Floor	0.6	0.45	W/m²K
		Windows	4.8	4.8	W/m²K
	Average g-value of glazing		0.7	0.7	-
	Air permeability		20	15	m³/m².hr
	Lighting	Efficacy	20	25	llm/cW
		Daylight controls	NO	NO	-
		Occupancy controls	NO	NO	-
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.		
		Daylight lighting control			
	Heating energy		58	54	kWh/m²/yr
	Cooling energy		45	35	kWh/m²/yr
	DHW energy		105	105	kWh/m²/yr
	Lighting energy		87	70	kWh/m²/yr
	Auxiliary energy		26	19	kWh/m²/yr

Table 8.5d: Energy Performance Relevant Data – Existing Hotel (AC)

			Quantity		Unit
			EE1	EE2	
Systems	Ventilation system	Air changes per hour	1.2	1.2	1/hr
		Heat recovery efficiency	-	-	%
	Heating system	Generation	70	78	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
	Cooling system	Generation	200	220	%
		Distribution	66	66	%
		Emission	-	-	%
		Control	-	-	%
	DHW system	Generation	65	74	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
Building Elements	Average U-value	Walls	0.6	0.45	W/m²K
		Roof	0.6	0.6	W/m²K
		Floor	0.6	0.45	W/m²K
		Windows	3.3	3.3	W/m²K
	Average g-value of glazing		0.7	0.7	-
	Air permeability		20	15	m³/m².hr
	Lighting	Efficacy	35	40	llm/cW
		Daylight controls	NO	YES	-
		Occupancy controls	NO	NO	-
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.		
		Daylight lighting control			
	Heating energy		154	130	kWh/m²/yr
	Cooling energy		18	14	kWh/m²/yr
	DHW energy		239	210	kWh/m²/yr
	Lighting energy		47	32	kWh/m²/yr
	Auxiliary energy		75	67	kWh/m²/yr

Table 8.5e: Energy Performance Relevant Data – Existing Retail Warehouse

			Quantity		Unit
			EE1	EE2	
Systems	Ventilation system	Air changes per hour	0.5	0.5	1/hr
		Heat recovery efficiency	-	-	%
	Heating system	Generation	70	70	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
	Cooling system	Generation	200	200	%
		Distribution	66	66	%
		Emission	-	-	%
		Control	-	-	%
	DHW system	Generation	70	90	%
		Distribution	90	90	%
		Emission	-	-	%
		Control	-	-	%
Building Elements	Average U-value	Walls	0.6	0.45	W/m²K
		Roof	0.6	0.6	W/m²K
		Floor	0.6	0.45	W/m²K
		Windows	3.3	3.3	W/m²K
	Average g-value of glazing		0.7	0.7	-
	Air permeability		20	15	m³/m².hr
	Lighting	Efficacy	35	40	llm/cW
		Daylight controls	YES	YES	-
		Occupancy controls	NO	NO	-
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.		
		Daylight lighting control			
	Heating energy		68	62	kWh/m²/yr
	Cooling energy		39	37	kWh/m²/yr
	DHW energy		2	2	kWh/m²/yr
	Lighting energy		41	38	kWh/m²/yr
	Auxiliary energy		51	48	kWh/m²/yr

9. Measures and Packages

9.1 New Buildings

A list of potential measures has been compiled using the Cost Optimal Methodology Guidelines document and design experience. Since it is impractical to evaluate every permutation of the selected measures, we have grouped the measures into packages. These packages are listed in Tables 9.1a and 9.1b. The packages represent four different components of a building design (fabric, services, heating and photovoltaics (PV)), so that selecting one package from each component forms a complete building design. In total, we have considered 135 packages for each building (3 fabric x 3 services x 5 heating x 3 PV).

The values selected for each of the measures (e.g. the fabric U-values and building services efficiencies) within the packages have been chosen to give a large spread of primary energies and lifecycle costs. This helps to obtain a clear cost optimal front and identification of the optimum point. It includes solutions that together might comprise a building model that performs more poorly than the primary energy target reflected by the current regulations.

It should be noted that some possible measures have been omitted from these packages. There are a number of reasons for this:

- Site specific measures: Various measures are particularly dependant on site constraints. For example, building orientation, the availability of biomass and feasibility of wind turbines are all likely to depend on the site and the surrounding context. Our assumption is that the cost optimal point should be based on measures that any designer can typically adopt, if not the cost optimal point may be unrealistic to achieve in many real cases.

- Design measures: Some measures impact on design constraints that are not incorporated in the building primary energy requirement. In particular, our concern is that by modifying the percentage of glazing or introducing shading to optimise on primary energy, it may result in inadequate daylight levels. Furthermore, this is building dependent – a particular percentage of glazing may provide appropriate day lighting in one building design but not another. Therefore we have not considered these two measures in the list of packages.

- Default measures: There are other measures that are likely to be included in new buildings by default, for example, monitoring and metering, variable speed pumps and power factor correction. These have not been treated as options - they are simply be added into the base building models assumed in all cases. Since these measures do not vary, there is no need to identify separately costs for them.

Table 9.1c gives the details of the baseline and improved thermal bridging cases. In addition, Tables 9.1 (d-e) show example compliant specifications to meet current national Regulations for all building types. As the national regulations are performance-based, a building may comply by adopting alternative measures.

Table 9.1a: Measures to be included in analysis (naturally ventilated buildings)

Fabric (3 options)	***A***	***B***	***C***
Wall U-value (W/m²K)	0.3	0.21	0.15
Roof U-value (W/m²K)	0.25	0.2	0.15
Floor U-value (W/m²K)	0.25	0.2	0.15
Window U-value (W/m²K)	1.8	1.4	0.9
Improved Thermal Bridging	NO	YES	YES
Air Tightness (m³/m².hr @ 50 Pa)	7	5	3

Services (3 options)	***1***	***2***	***3***
Lighting (llm/cW)	60	75	95
Daylight Lighting Control	NO	YES	YES
Occupancy Lighting Control	NO	YES	YES

Heating (5 options)					
Heating Source	Gas boiler (86% efficiency)	Gas boiler (91% efficiency) + Solar Hot Water	Combined Heat and Power (45% heat efficiency)	Ground Source Heat Pump (4.0 CoP)	Ground Source Heat Pump (4.0 CoP) + Solar Hot Water

PV (3 options)			
PV Installation (percentage of foundation area)	0%	20%	40%

Table 9.1b: Measures to be included in analysis (air conditioned buildings)

Fabric (3 options)	***A***	***B***	***C***
Wall U-value (W/m²K)	0.3	0.25	0.2
Roof U-value (W/m²K)	0.25	0.2	0.15
Floor U-value (W/m²K)	0.25	0.2	0.15
Window U-value (W/m²K)	1.8	1.4	0.9
Improved Thermal Bridging	NO	YES	YES
Air Tightness (m³/m².hr @ 50 Pa)	7	5	3

Services (3 options)	***1***	***2***	***3***
Lighting (llm/cW)	60	75	95
Daylight Lighting Control	NO	YES	YES
Occupancy Lighting Control	NO	YES	YES
Heat Recovery	NO	45%	70%
Chiller Efficiency (SEER)	3.9	4.5	5.5
AHU SFP	2.2	2	1.8
FCU SFP	0.6	0.3	0.2
Demand Control Ventilation	NO	YES	YES

Heating (5 options)					
Heating Source	Gas boiler (86% efficient)	Gas boiler (91% efficient) + Solar Hot Water	Combined Heat and Power (45% heat efficiency)	Ground Source Heat Pump (4.0 CoP)	Ground Source Heat Pump (4.0 CoP) + Solar Hot Water

PV (3 options)			
PV Installation (percentage of foundation area)	0%	20%	40%

Table 9.1c: Thermal Bridging Details (W/mK)

Junction	***Baseline***	***Improved***
Roof – Wall	0.18	0.12
Wall – Ground	0.24	0.16
Wall – Wall	0.14	0.09
Wall – Floor	0.11	0.07
Lintel	0.45	0.3
Sill	0.08	0.04
Jamb	0.09	0.05
Roof – Wall (Metal Cladding)	0.42	0.28
Wall – Ground (Metal Cladding)	1.73	1.0
Wall – Wall (Metal Cladding)	0.38	0.2
Wall – Floor (Metal Cladding)	0.04	0.00
Lintel (Metal Cladding)	1.91	1.0
Sill (Metal Cladding)	1.91	0.95
Jamb (Metal Cladding)	1.91	0.95

Table 9.1d: Compliant specification to meet current English, Welsh and Northern Irish Regulations

Fabric	***E***	***W***	***NI***
Wall U-value (W/m²K)	0.26	0.26	0.26
Roof U-value (W/m²K)	0.18	0.18	0.18
Floor U-value (W/m²K)	0.22	0.22	0.22
Window U-value (W/m²K)	1.6	1.6	1.8
Thermal Bridging (additional heat loss, %)	Improved	Improved	Improved
Air Tightness (m³/m².hr @ 50 Pa): - GIA less than or equal 250m² o Side-lit or unlit o Top-lit - GIA more than 250m² and less than 3,500m² o Side-lit or unlit o Top-lit - GIA more than 3,500m² and less than 10,000m² o Side-lit or unlit o Top-lit - GIA more than 250m² and less than 10,000m² o Side-lit or unlit o Top-lit	 5 7 3 7 3 5 3 3	 5 7 3 or 5 if includes cooling 7 3 or 5 if includes cooling 5 3 or 5 if includes cooling 3	 5

Services	***E***	***W***	***NI***
Lighting (llm/cW)	60	65	55
Daylight Lighting Control	YES	YES	YES
Occupancy Lighting Control	YES	YES	NO
Heat Recovery	YES	YES	YES
Chiller Efficiency (SEER)	4.5	4.5	4.5
AHU SFP (W/l/s)	1.8	1.8	1.8
FCU SFP (W/l/s)	0.3	0.3	0.5
Demand Control Ventilation	YES	YES	NO

Heating	***E***	***W***	***NI***
Space heating (SCoP)	81.9%	81.9%	79.2%
Hot water (SCoP)	86.45%	86.45%	83.6%

PV	***E***	***W***	***NI***
PV Installation	0%	Lesser of 5.3% x GIA, or 50% x roof area x 120kWh/m²	0%

Note: GIA = Gross Internal Area

Table 9.1e: Compliant specification to meet current Scottish Regulations

	Heated and naturally ventilated (Office NV, School, Distribution Warehouse)	***Heated and cooled or mechanically ventilated (Office AC, Hotel, Retail Warehouse, Hospital)***
Fabric		
Wall U-value (W/m²K)	0.23	0.2
Roof U-value (W/m²K)	0.18	0.16
Floor U-value (W/m²K)	0.22	0.2
Window U-value (W/m²K)	1.8	1.6
Thermal Bridging (additional heat loss, %)	Improved	Improved
Air Tightness (m³/m².hr @ 50 Pa)		
Services		
Lighting (llm/cW)	60	65
Daylight Lighting Control	YES	YES
Occupancy Lighting Control	YES	YES
Heat Recovery	-	YES
Chiller Efficiency (SEER)	-	4.5
AHU SFP (W/l/s)	-	1.8
FCU SFP (W/l/s)	-	0.3
Demand Control Ventilation	-	YES
Heating		
Gas Boiler (efficiency)	91%	91%
PV		
PV Installation	Lesser of 4.5% x GIA, or 50% x roof area x 120kWh/m²	Lesser of 4.5% x GIA, or 50% x roof area x 120kWh/m²

Note: GIA = Gross Internal Area

9.2 Existing Buildings – Elemental Analysis

We have considered the following building measures. These cover the most common renovation and replacement activities, focussing on those which have the most significant impact on energy use. We have investigated the cost optimum level of changing each component in isolation at different levels of energy efficiency. We have undertaken this approach as it is most common to retrofit building components independent of each other and national standards for existing buildings are based on a building component level.

Renovation Measures:

- Floors: We have investigated the resurfacing of external floors, including varying levels of insulation.
- Walls: There are a number of means of improving the thermal performance of external walls. We have considered including cavity wall insulation where appropriate, as well as internal insulation and the addition of external cladding.
- Roofs: We have considered the impact of varying levels of insulation in the roof-space.
- Heating system: We have included changes to the whole heating system in the building.

Replacement Measures:

- Windows
- Packaged chillers
- Central ventilation air handling units (AHUs)
- Fan coil units (FCUs)
- Light sources (lamp efficacy)

The different levels of energy efficiency investigated are provided in Table 9.2. Additional details of the fabric improvement measures are given in Table 9.3 (a-e).

Table 9.2: Measures included in analysis

		Standard											
Renovation	***Building Types***	***E***	***W***	***NI***	***S***								
Floors (W/m²K)	All	0.25	0.25	0.25	0.25	0.25	0.20	0.15	0.10				
Cavity Walls (W/m²K)	School	0.55	0.55	0.55	0.3	0.30	0.19	0.14	0.16	0.10	0.39	0.21	
Metal Frame Walls (W/m²K)	Office, Hospital, Hotel, Warehouse	0.3	0.3	0.3	0.3	0.47	0.36	0.27	0.21	0.20	0.15	0.15	0.11
Flat Roof (W/m²K)	School, Office, Hospital, Hotel	0.18	0.18	0.18	0.25	0.25	0.20	0.15					
Metal Seam Roof (W/m²K)	Warehouse	0.18	0.18	0.18	0.25	0.29	0.18	0.14					
Heating system	All	84%	84%	84%	86%	Gas (86%)	Gas (91%) + SHW	Gas CHP					

Replacement	***Building Types***	***E***	***W***	***NI***	***S***								
Windows (W/m²K)	All	1.8	1.8	1.8	1.6	1.8	1.4	1.1	0.9				
Chiller Efficiency (SEER)	Hospital, Hotel, Warehouse	3.6	3.6	3.6	3.6	3.9	4.5	5.5					
AHU SFP (W/l/s)	Hospital, Hotel, Warehouse	2.2	2.2	2.2	2.2	2.2	2.0	1.8					
Lighting (llm/cW)	All	60	60	60	60	55	60	65					

Table 9.3a: Details of the improvement measures to solid floors

Measure	***U-Value (W/m²K)***
Concrete screed (70mm) Rigid PIR board (60mm) (λ=0.022) 25mm edge insulation (1000 wide along perimeter, rigid PU (λ=0.022))	0.25
Concrete screed (70mm) Rigid PIR board (85mm) (λ=0.022) 25mm edge insulation (1000 wide along perimeter, rigid PU (λ=0.022))	0.20
Concrete screed (70mm) Rigid PIR board (120mm) (λ=0.022) 25mm edge insulation (1000 wide along perimeter, rigid PU (λ=0.022))	0.15
Concrete screed (70mm) Rigid PIR board (180mm) (λ=0.022) 25mm edge insulation (1000 wide along perimeter, rigid PU (λ=0.022))	0.10

Table 9.3b: Details of the improvement measures to cavity walls

Measure	***U-Value (W/m²K)***
Fully filled cavity (100mm)	0.30
Fully filled cavity and 50mm internal insulation	0.19
Fully filled cavity and 100mm internal insulation	0.14
Fully filled cavity and 100mm external insulation	0.16
Fully filled cavity and 200mm external insulation	0.10
50mm internal insulation (unfilled cavity)	0.39
100mm internal insulation (unfilled cavity)	0.21

Table 9.3c: Details of the improvement measures to metal frame walls

Measure	***U-Value (W/m²K)***
50mm external insulation (EPS/mw (λ=0.031W/mK))	0.47
100mm external insulation (EPS/mw (λ=0.031W/mK))	0.27
150mm external insulation (EPS/mw (λ=0.031W/mK))	0.20
200mm external insulation (EPS/mw (λ=0.031W/mK))	0.15
50mm external insulation (PIR (λ=0.022W/mK))	0.36
100mm external insulation (PIR (λ=0.022W/mK))	0.21
150mm external insulation (PIR (λ=0.022W/mK))	0.15 (b)
200mm external insulation (PIR (λ=0.022W/mK))	0.11

Table 9.3d: Details of the improvement measures to flat roofs

Measure	***U-Value (W/m²K)***
Polymer WP lining 85mm PIR insulation (λ=0.022) VCL Deck (single ply/concrete/metal trough)	0.25
Polymer WP lining 110mm PIR insulation (λ=0.022) VCL Deck (single ply/concrete/metal trough)	0.20
Polymer WP lining 150mm PIR insulation (λ=0.022) VCL Deck (single ply/concrete/metal trough)	0.15

Table 9.3e: Details of the improvement measures to metal seam roofs

Measure	***U-Value (W/m²K)***
Standing seam liner sheet 50mm PIR Insulation (λ=0.022) over rail 50mm insulation within rail (λ=0.037) Air gap/thermally broken brackets and spacers VCL Profiled metal liner sheet Purlin	0.29
Standing seam liner sheet 100mm PIR Insulation over rail (λ=0.022) 50mm insulation within rail (λ=0.037) Air gap/thermally broken brackets and spacers VCL Profiled metal liner sheet Purlin	0.18
Standing seam liner sheet 150mm PIR Insulation over rail (λ=0.022) 50mm insulation within rail (λ=0.037) Air gap/thermally broken brackets and spacers VCL Profiled metal liner sheet Purlin	0.14

9.3 Existing Buildings – Analysis of Packages

In addition to the elemental analysis, existing building measures were assessed on a package basis (i.e. with more than one measure implemented at a time).

Table 9.4 (a-j) provides the specifications for each improvement package for each of the five building categories. Each package comprises a combination of ‘fabric’, ‘services’, ‘heating’ and ‘PV’ options. For each reference buildings, around 140 different packages were evaluated (7 or 8 ‘fabric’ options, 3 ‘services’ options, 3 ‘heating’ options and 2 ‘PV’ options).

For fabric, there are initially a series of packages which assess the benefit of individually improving a fabric element from the baseline position (i.e. improvement to walls only, roof only or window only). Then a further series of packages are arranged around the elemental cost-optimal point for each individual building fabric measure identified in the first UK cost optimal report submitted in May 2013.

The cost optimal values are highlighted in bold. Where reasonable to do so, packages have been defined to include the cost optimal levels, as well as specifications both poorer and better than these levels (packages A to D).

Similarly, for services, three packages have been defined to include the cost optimal levels, as well as specifications typically both poorer and better than these levels (packages S1, S2, S3).

Table 9.4a: Measures included in analysis (Hospital, EE1)

Fabric (8 options)	***EE1***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.6	0.2	0.6	0.6	0.27	**0.2**	0.15
Roof U-value (W/m²K)	0.6	0.6	0.25	0.6	0.25	**0.25**	0.20
Window U-value (W/m²K)	4.8	4.8	4.8	1.4	1.8	**1.4**	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	55	60	**65**
AHU SFP	2.2	2.0	**1.8**

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**84% Gas boiler**	Gas CHP

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

Table 9.4b: Measures included in analysis (Hospital, EE2)

Fabric (8 options)	***EE2***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.45	0.2	0.45	0.45	0.27	**0.2**	0.15
Roof U-value (W/m²K)	0.6	0.6	0.25	0.6	0.25	**0.25**	0.20
Window U-value (W/m²K)	4.8	4.8	4.8	1.4	1.8	**1.4**	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	55	60	**65**
AHU SFP	2.2	2.0	**1.8**

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**84% Gas boiler**	Gas CHP

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

Table 9.4c: Measures included in analysis (Hotel, EE1)

Fabric (7 options)	***EE1***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.6	0.2	0.6	0.6	0.27	**0.2**	0.15
Roof U-value (W/m²K)	0.6	0.6	0.15	0.6	0.20	**0.15**	0.15
Window U-value (W/m²K)	3.3	3.3	3.3	1.4	1.8	**1.4**	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	**55**	60	65
Chiller Efficiency (SEER)	**3.9**	4.5	5.5
AHU SFP	**1.8**	1.8	1.8

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**Gas CHP**	84% Gas boiler

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

Table 9.4d: Measures included in analysis (Hotel, EE2)

Fabric (7 options)	***EE2***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.45	0.2	0.45	0.45	0.27	**0.2**	0.15
Roof U-value (W/m²K)	0.6	0.6	0.15	0.6	0.20	**0.15**	0.15
Window U-value (W/m²K)	3.3	3.3	3.3	1.4	1.8	**1.4**	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	**55**	60	65
Chiller Efficiency (SEER)	**3.9**	4.5	5.5
AHU SFP	**1.8**	1.8	1.8

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**Gas CHP**	84% Gas boiler

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

Table 9.4e: Measures included in analysis (Office, EE1)

Fabric (8 options)	***EE1***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***	***D***
Wall U-value (W/m²K)	0.6	0.2	0.6	0.6	0.27	**0.2**	0.15	0.11
Roof U-value (W/m²K)	0.6	0.6	0.25	0.6	0.25	**0.25**	0.20	0.15
Window U-value (W/m²K)	4.8	4.8	4.8	1.8	1.8	**1.8**	1.4	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	**55**	60	65

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**84% Gas boiler**	Gas CHP

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

Table 9.4f: Measures included in analysis (Office, EE2)

Fabric (8 options)	***EE2***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***	***D***
Wall U-value (W/m²K)	0.45	0.2	0.45	0.45	0.27	**0.2**	0.15	0.11
Roof U-value (W/m²K)	0.6	0.6	0.25	0.6	0.25	**0.25**	0.20	0.15
Window U-value (W/m²K)	4.8	4.8	4.8	1.8	1.8	**1.8**	1.4	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	**55**	60	65

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**84% Gas boiler**	Gas CHP

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

Table 9.4g: Measures included in analysis (Retail, EE1)

Fabric (8 options)	***EE1***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***	***D***
Wall U-value (W/m²K)	0.6	0.2	0.6	0.6	0.27	**0.2**	0.15	0.11
Roof U-value (W/m²K)	0.6	0.6	0.29	0.6	0.29	**0.29**	0.18	0.14
Window U-value (W/m²K)	3.3	3.3	3.3	1.8	1.8	**1.8**	1.4	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	60	**65**	**65**
Chiller Efficiency (SEER)	3.9	**3.9**	4.5
AHU SFP	2.0	**1.8**	**1.8**

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**84% Gas boiler**	Gas CHP

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

Table 9.4h: Measures included in analysis (Retail, EE2)

Fabric (8 options)	***EE2***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***	***D***
Wall U-value (W/m²K)	0.45	0.2	0.45	0.45	0.27	**0.2**	0.15	0.11
Roof U-value (W/m²K)	0.6	0.6	0.29	0.6	0.29	**0.29**	0.18	0.14
Window U-value (W/m²K)	3.3	3.3	3.3	1.8	1.8	**1.8**	1.4	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	60	**65**	**65**
Chiller Efficiency (SEER)	3.9	**3.9**	4.5
AHU SFP	2.0	**1.8**	**1.8**

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**84% Gas boiler**	Gas CHP

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

Table 9.4i: Measures included in analysis (School, EE1)

Fabric (7 options)	***EE1***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.6	0.30	0.6	0.6	**0.30**	0.14	0.10
Roof U-value (W/m²K)	0.6	0.6	0.25	0.6	**0.25**	0.20	0.15
Window U-value (W/m²K)	4.8	4.8	4.8	1.8	**1.8**	1.4	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	55	**60**	65

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**84% Gas boiler**	Gas CHP

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

Table 9.4j: Measures included in analysis (School, EE2)

Fabric (7 options)	***EE2***	***Wall Only***	***Roof Only***	***Window Only***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.45	0.30	0.45	0.45	**0.30**	0.14	0.10
Roof U-value (W/m²K)	0.6	0.6	0.25	0.6	**0.25**	0.20	0.15
Window U-value (W/m²K)	4.8	4.8	4.8	1.8	**1.8**	1.4	1.1

Services (3 options)	***S1***	***S2***	***S3***
Lighting (lm/W)	55	**60**	65

Heating (3 options)			
Heating Source	Gas (91%)+SHW	**84% Gas boiler**	Gas CHP

PV (2 options)		
PV Installation (percentage of foundation area)	0%	20%

10. Primary Energy Demand

10.1 New Buildings

10.1.1 Energy Performance Assessment

This section outlines the procedure for determining the primary energy for each package of measures. Each of the seven reference buildings was modelled using the Simplified Building Energy Model (SBEM)[42], the software that implements the National Calculation Methodology (NCM) for non domestic buildings. The NCM is the UK's response to the requirement of the EPBD to develop a methodology for calculating the energy performance of buildings.

To test each package of measures, the SBEM building model input files were updated accordingly and run through the SBEM calculation engine. The energy end uses (e.g. heating, cooling) were recorded directly from the SBEM output files. The end use energies were then summed for each energy carrier to find the delivered energy requirement. Any on-site generated energy was also determined at this stage. The primary energy factors were then applied to the delivered energy and on-site generated energy. The latter was subtracted from the former to give the net primary energy.

Annex 1 of the Cost Optimal Methodology states that "Member States shall use a calculation period of 30 years for residential and public buildings, and a calculation period of 20 years for commercial, non-residential buildings". For the purpose of this work, we have assumed a calculation period of 20 years for all of the buildings with the exception of 30 years for the secondary school and hospital.

10.1.2 Energy demand calculation

Table 10.1(a-g) summarises the results of the energy performance calculation for the most cost-optimal packages in each of the seven reference buildings. These tables include the energy breakdown by end use and the total energy requirement per fuel carrier. The primary energy factors used to calculate the total primary energy requirement and the primary energy reduction over the reference case are listed in Tables 8.3. The delivered energy per carrier has been incorporated into Table 10.1 as this is more helpful than producing separate tables.

[42] Simplified Building Energy Model (SBEM), BRE

Table 10.1a: Energy Demand Output Table – New Office (AC)

Package				***Energy Use***					***Fuel Use***			***Primary Energy***				
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction over Reference			
				kWh/m²					kWh/m²			kWh/m²	E	NI	W	S
B	GSHP+SHW	3	40%	2	7	14	1	15	1	38	4	82	29%	35%	16%	19%
B	GSHP	3	40%	2	7	14	3	15	3	38	4	83	28%	33%	14%	17%
B	Gas(86%)	3	40%	10	7	14	3	15	13	36	4	89	22%	28%	8%	11%
A	Gas(86%)	3	40%	13	8	15	3	15	15	38	4	98	15%	21%	-1%	2%
A	Gas(86%)	3	0%	13	8	15	3	15	15	38	0	108	6%	13%	-11%	-7%
A	Gas(86%)	2	40%	12	11	19	3	18	14	48	4	119	-3%	5%	-22%	-18%
A	Gas(86%)	2	0%	12	11	19	3	18	14	48	0	129	-12%	-3%	-33%	-28%
B	Gas(86%)	1	40%	10	12	26	3	28	12	66	4	160	-39%	-28%	-65%	-59%
B	Gas(86%)	1	0%	10	12	26	3	28	12	66	0	170	-48%	-36%	-75%	-69%
A	Gas(86%)	1	40%	12	14	29	3	28	15	71	4	175	-52%	-40%	-80%	-74%

Table 10.1b: Energy Demand Output Table – New Office (NV)

Package				***Energy Use***					***Fuel Use***			***Primary Energy***				
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction over Reference			
				kWh/m²					kWh/m²			kWh/m²	E	NI	W	S
C	GSHP+SHW	3	40%	2	0	3	1	12	0	19	14	11	83%	85%	77%	81%
C	GSHP	3	40%	2	0	3	3	12	0	20	14	14	78%	81%	71%	75%
A	GSHP	3	40%	5	0	3	3	12	0	23	14	21	68%	73%	58%	65%
A	GSHP	2	40%	5	0	3	3	15	0	25	14	26	61%	66%	47%	56%
A	Gas(86%)	3	40%	24	0	3	3	12	24	18	14	36	46%	53%	28%	39%
A	Gas(86%)	2	20%	23	0	3	3	15	23	20	7	57	14%	26%	-15%	3%
A	Gas(86%)	2	0%	23	0	3	3	15	23	20	0	73	-11%	4%	-48%	-25%
A	Gas(86%)	1	20%	20	0	3	3	28	20	34	7	86	-30%	-12%	-73%	-46%
B	Gas(86%)	1	0%	16	0	3	3	28	16	34	0	98	-48%	-28%	-98%	-66%
A	Gas(86%)	1	0%	20	0	3	3	28	20	34	0	102	-55%	-34%	-107%	-74%

Table 10.1c: Energy Demand Output Table – New Secondary School

Package				***Energy Use***					***Fuel Use***			***Primary Energy***				
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction over Reference			
				kWh/m²					kWh/m²			kWh/m²	E	NI	W	S
C	GSHP+SHW	3	40%	2	0	1	54	9	54	13	21	41	66%	70%	62%	66%
C	GSHP	3	40%	2	0	1	58	9	58	13	21	46	62%	66%	57%	62%
C	Gas(86%)	3	40%	10	0	1	58	9	68	11	21	52	57%	61%	52%	57%
C	Gas(86%)	2	40%	9	0	1	58	11	67	12	21	56	54%	59%	48%	54%
B	Gas(86%)	3	40%	16	0	1	58	9	74	11	21	59	52%	56%	45%	51%
A	Gas(86%)	2	40%	19	0	1	58	11	78	12	21	67	45%	50%	38%	44%
A	Gas(86%)	1	40%	18	0	1	58	17	76	18	21	79	35%	42%	27%	35%
A	Gas(86%)	1	20%	18	0	1	58	17	76	18	11	104	15%	23%	4%	14%
A	Gas(86%)	2	0%	19	0	1	58	11	78	12	0	117	4%	13%	-9%	3%
A	Gas(86%)	1	0%	18	0	1	58	17	76	18	0	128	-5%	5%	-19%	-6%

Table 10.1d: Energy Demand Output Table – New Hospital

Package				***Energy Use***					***Fuel Use***			***Primary Energy***				
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction over Reference			
				kWh/m²					kWh/m²			kWh/m²	E	NI	W	S
C	GSHP+SHW	3	40%	15	8	21	50	19	50	63	8	188	21%	28%	14%	16%
B	GSHP+SHW	3	40%	16	7	21	50	19	50	63	8	189	20%	28%	14%	16%
B	GSHP	3	40%	16	7	21	52	19	52	63	8	190	20%	27%	13%	15%
A	GSHP	3	40%	17	8	21	52	19	52	65	8	195	18%	25%	11%	13%
A	Gas CHP	3	40%	125	8	21	52	19	176	48	43	212	11%	19%	3%	6%
A	Gas(86%)	3	40%	79	8	21	52	19	131	48	8	244	-3%	6%	-12%	-9%
A	Gas(86%)	3	20%	79	8	21	52	19	131	48	4	253	-7%	3%	-16%	-12%
A	Gas(86%)	2	40%	78	9	24	52	22	129	55	8	258	-9%	1%	-18%	-15%
A	Gas(86%)	1	40%	78	10	26	52	30	129	66	8	284	-20%	-9%	-30%	-26%
A	Gas(86%)	1	0%	78	10	26	52	30	129	66	0	302	-27%	-16%	-38%	-34%

Table 10.1e: Energy Demand Output Table – New Hotel

Package				***Energy Use***					***Fuel Use***			***Primary Energy***				
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction over Reference			
				kWh/m²					kWh/m²			kWh/m²	E	NI	W	S
C	GSHP+SHW	3	40%	8	7	29	159	19	159	63	4	319	19%	31%	18%	20%
B	GSHP+SHW	3	40%	12	5	29	159	19	159	65	4	324	18%	30%	16%	19%
B	Gas(91%)+SHW	3	40%	54	5	29	159	19	213	53	4	356	10%	23%	8%	11%
B	Gas(91%)+SHW	2	40%	52	6	36	159	21	212	63	4	377	4%	18%	2%	6%
B	Gas(86%)	2	40%	55	6	36	171	21	226	63	4	393	0%	15%	-2%	2%
A	Gas(86%)	2	40%	65	8	39	171	21	235	69	4	418	-6%	9%	-8%	-5%
A	Gas(86%)	2	0%	65	8	39	171	21	235	69	0	428	-8%	7%	-11%	-7%
B	Gas(86%)	1	40%	64	7	57	171	31	235	95	4	479	-21%	-4%	-24%	-20%
B	Gas(86%)	1	0%	64	7	57	171	31	235	95	0	489	-24%	-6%	-27%	-22%
A	Gas(86%)	1	0%	74	10	64	171	31	244	105	0	523	-32%	-14%	-35%	-31%

Table 10.1f: Energy Demand Output Table – New Distribution Warehouse

Package				***Energy Use***					***Fuel Use***			***Primary Energy***				
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction over Reference			
				kWh/m²					kWh/m²			kWh/m²	E	NI	W	S
C	GSHP+SHW	3	40%	9	1	2	8	11	8	23	41	-34	130%	126%	132%	125%
C	GSHP	3	40%	9	1	2	16	11	16	23	41	-25	122%	119%	124%	119%
B	GSHP	2	40%	12	0	2	16	14	16	28	41	-13	112%	110%	113%	110%
A	GSHP	2	40%	16	1	2	16	14	16	33	41	-2	102%	102%	102%	102%
B	Gas(86%)	2	40%	54	0	2	16	14	69	16	41	19	83%	85%	82%	86%
A	Gas(86%)	2	40%	73	1	2	16	14	88	17	41	42	63%	68%	60%	69%
B	Gas(86%)	2	20%	54	0	2	16	14	69	16	21	68	40%	48%	35%	49%
A	Gas(86%)	2	20%	73	1	2	16	14	88	17	21	91	19%	30%	13%	32%
A	Gas(86%)	2	0%	73	1	2	16	14	88	17	0	139	-24%	-7%	-34%	-4%
A	Gas(86%)	1	0%	63	1	2	16	39	79	42	0	188	-67%	-45%	-81%	-40%

Table 10.1g: Energy Demand Output Table – New Retail Warehouse

Package				***Energy Use***					***Fuel Use***			***Primary Energy***				
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction over Reference			
				kWh/m²					kWh/m²			kWh/m²	E	NI	WI	S
C	GSHP+SHW	3	40%	6	11	16	1	29	1	61	41	48	74%	75%	71%	72%
C	GSHP	3	40%	6	11	16	2	29	2	61	41	49	73%	75%	71%	72%
B	GSHP	3	40%	8	10	16	2	29	2	63	41	53	71%	73%	69%	70%
B	Gas(86%)	3	40%	35	10	16	2	29	37	55	41	75	60%	62%	56%	57%
A	Gas(86%)	3	40%	46	10	17	2	29	48	55	41	87	53%	55%	48%	50%
A	Gas(86%)	2	40%	45	12	20	2	31	46	63	41	105	43%	46%	38%	40%
A	Gas(86%)	2	20%	45	12	20	2	31	46	63	21	154	17%	21%	8%	12%
A	Gas(86%)	2	0%	45	12	20	2	31	46	63	0	202	-10%	-4%	-21%	-16%
A	Gas(86%)	1	40%	41	23	31	2	63	43	117	41	227	-23%	-17%	-35%	-30%
A	Gas(86%)	1	20%	41	23	31	2	63	43	117	21	276	-49%	-42%	-64%	-58%

10.2 Existing Buildings

10.2.1 Energy Performance Assessment

The same process was followed as for new non domestic buildings, outlined in Section 10.1.1.

10.2.2 Energy demand calculation – Elemental Analysis

Table 10.2 (a-j) summarises the results of the energy performance calculation for each of the five reference buildings. These tables include the energy breakdown by end use and the total energy requirement per fuel carrier. The primary energy factors used to calculate the total primary energy requirement and the primary energy reduction over the reference case are listed in Tables 8.3. The delivered energy per carrier has been incorporated into Table 10.2 as this is more helpful than producing separate tables.

10.2.3 Energy demand calculation – Analysis of Packages

Table 10.3 (a-j) summarises the results of the energy performance calculation for the most cost-optimal packages for the five reference buildings. These tables include the energy breakdown by end use and the total energy requirement per fuel carrier. The primary energy factors used to calculate the total primary energy requirement are listed in Table 8.3.

Table 10.2a: Energy Demand Output Table – Existing Office Building (NV) (EE1)

Measure	**Value**	**Energy Use**					**Fuel Use**			**Primary Energy**	
		Heat	*Cool*	*Aux*	*DHW*	*Light*	*Gas*	*Grid Elec.*	*Gen. Elec.*	*Total*	*Reduction*
		kWh/m²					*kWh/m²*			*kWh/m²*	*%*
Floor U-value	0.1	41	0	1	114	4	41	118	0	326	1%
Floor U-value	0.15	41	0	1	114	4	41	118	0	326	0%
Floor U-value	0.2	42	0	1	114	4	42	118	0	327	0%
Floor U-value	0.25	43	0	1	114	4	43	118	0	328	0%
Wall U-Value	0.11	39	0	1	114	4	39	118	0	324	1%
Wall U-Value	0.15	40	0	1	114	4	40	118	0	324	1%
Wall U-Value	0.15	40	0	1	114	4	40	118	0	324	1%
Wall U-Value	0.21	40	0	1	114	4	40	118	0	325	1%
Wall U-Value	0.21	41	0	1	114	4	41	118	0	326	1%
Wall U-Value	0.27	42	0	1	114	4	42	118	0	327	0%
Wall U-Value	0.36	43	0	1	114	4	43	118	0	329	0%
Wall U-Value	0.47	45	0	1	114	4	45	118	0	331	-1%
Roof U-value	0.15	42	0	1	114	4	42	118	0	327	0%
Roof U-value	0.2	43	0	1	114	4	43	118	0	328	0%
Roof U-value	0.25	43	0	1	114	4	43	118	0	329	0%
Heating Source	Gas CHP	57	0	1	114	4	57	118	16	306	6%
Heating Source	Gas + SHW	37	0	1	114	2	37	116	0	317	2%
Heating Source	Gas	39	0	1	114	4	39	118	0	324	0%
Window U-value	0.9	29	0	1	114	4	29	118	0	313	1%
Window U-value	1.1	30	0	1	114	4	30	118	0	314	1%
Window U-value	1.4	31	0	1	114	4	31	118	0	315	1%
Window U-value	1.8	33	0	1	114	4	33	118	0	317	0%
Lighting Efficacy	65	95	0	1	26	4	95	31	0	181	2%
Lighting Efficacy	60	93	0	1	28	4	93	33	0	184	0%
Lighting Efficacy	55	91	0	1	31	4	91	36	0	187	-2%

Table 10.2b: Energy Demand Output Table – Existing Office Building (NV) (EE2)

Measure	***Value***	***Energy Use***					***Fuel Use***			***Primary Energy***	
		Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction
		kWh/m²					kWh/m²			kWh/m²	%
Floor U-value	0.1	46	0	1	68	3	46	72	0	223	1%
Floor U-value	0.15	47	0	1	68	3	47	72	0	224	1%
Floor U-value	0.2	48	0	1	68	3	48	72	0	224	0%
Floor U-value	0.25	49	0	1	68	3	49	72	0	225	0%
Wall U-Value	0.11	45	0	1	68	3	45	72	0	221	3%
Wall U-Value	0.15	46	0	1	68	3	46	72	0	222	3%
Wall U-Value	0.15	46	0	1	68	3	46	72	0	222	3%
Wall U-Value	0.21	47	0	1	68	3	47	72	0	223	2%
Wall U-Value	0.21	47	0	1	68	3	47	72	0	224	2%
Wall U-Value	0.27	48	0	1	68	3	48	72	0	225	2%
Wall U-Value	0.36	50	0	1	68	3	50	72	0	227	1%
Wall U-Value	0.47	53	0	1	68	3	53	72	0	230	-1%
Roof U-value	0.15	46	0	1	68	3	46	72	0	222	2%
Roof U-value	0.2	46	0	1	68	3	46	72	0	223	1%
Roof U-value	0.25	47	0	1	68	3	47	72	0	224	1%
Heating Source	Gas CHP	63	0	1	68	3	63	72	18	199	10%
Heating Source	Gas + SHW	40	0	1	68	1	40	71	0	212	4%
Heating Source	Gas	45	0	1	68	3	45	72	0	221	1%
Window U-value	0.9	31	0	1	68	3	31	72	0	205	4%
Window U-value	1.1	32	0	1	68	3	32	72	0	206	3%
Window U-value	1.4	33	0	1	68	3	33	72	0	208	2%
Window U-value	1.8	35	0	1	68	3	35	72	0	210	1%
Lighting Efficacy	65	79	0	1	26	3	79	30	0	160	4%
Lighting Efficacy	60	77	0	1	28	3	77	32	0	163	2%
Lighting Efficacy	55	75	0	1	31	3	75	35	0	167	0%

Table 10.2c: Energy Demand Output Table – Existing Secondary School (EE1)

Measure	***Value***	***Energy Use***					***Fuel Use***			***Primary Energy***	
		Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction
		kWh/m²					kWh/m²			kWh/m²	%
Floor U-value	0.1	48	0	1	33	118	165	35	0	268	1%
Floor U-value	0.15	49	0	1	33	118	166	35	0	270	1%
Floor U-value	0.2	50	0	1	33	118	167	35	0	271	0%
Floor U-value	0.25	51	0	1	33	118	168	35	0	272	0%
Wall U-Value	0.1	51	0	1	33	118	169	35	0	272	2%
Wall U-Value	0.14	52	0	1	33	118	169	35	0	273	2%
Wall U-Value	0.16	52	0	1	33	118	170	35	0	273	2%
Wall U-Value	0.19	52	0	1	33	118	170	35	0	274	2%
Wall U-Value	0.21	53	0	1	33	118	170	35	0	274	2%
Wall U-Value	0.3	54	0	1	33	118	171	35	0	275	1%
Wall U-Value	0.39	55	0	1	33	118	173	35	0	277	1%
Roof U-value	0.15	55	0	1	33	118	173	35	0	277	0%
Roof U-value	0.2	56	0	1	33	118	173	35	0	277	0%
Roof U-value	0.25	56	0	1	33	118	174	35	0	278	0%
Heating Source	Gas CHP	68	0	1	33	118	186	35	19	246	8%
Heating Source	Gas + SHW	44	0	1	33	113	158	35	0	260	3%
Heating Source	Gas	47	0	1	33	118	165	35	0	268	0%
Window U-value	0.9	41	0	1	33	118	158	35	0	260	2%
Window U-value	1.1	41	0	1	33	118	159	35	0	261	1%
Window U-value	1.4	43	0	1	33	118	160	35	0	263	1%
Window U-value	1.8	44	0	1	33	118	162	35	0	265	0%
Lighting Efficacy	65	68	0	1	15	118	186	17	0	249	1%
Lighting Efficacy	60	67	0	1	17	118	185	18	0	251	0%
Lighting Efficacy	55	66	0	1	18	118	184	20	0	254	-1%

Table 10.2d: Energy Demand Output Table – Existing Secondary School (EE2)

Measure	***Value***	***Energy Use***					***Fuel Use***			***Primary Energy***	
		Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction
		kWh/m²					kWh/m²			kWh/m²	%
Floor U-value	0.1	42	0	1	28	88	130	30	0	217	2%
Floor U-value	0.15	43	0	1	28	88	131	30	0	218	1%
Floor U-value	0.2	44	0	1	28	88	132	30	0	219	1%
Floor U-value	0.25	45	0	1	28	88	133	30	0	221	0%
Wall U-Value	0.1	44	0	1	28	88	132	30	0	220	4%
Wall U-Value	0.14	45	0	1	28	88	133	30	0	220	4%
Wall U-Value	0.16	45	0	1	28	88	133	30	0	221	4%
Wall U-Value	0.19	45	0	1	28	88	134	30	0	221	4%
Wall U-Value	0.21	46	0	1	28	88	134	30	0	222	4%
Wall U-Value	0.3	47	0	1	28	88	135	30	0	223	3%
Wall U-Value	0.39	48	0	1	28	88	136	30	0	224	3%
Roof U-value	0.15	46	0	1	28	88	135	30	0	222	2%
Roof U-value	0.2	47	0	1	28	88	135	30	0	223	1%
Roof U-value	0.25	47	0	1	28	88	135	30	0	223	1%
Heating Source	Gas CHP	58	0	1	28	88	146	30	16	197	10%
Heating Source	Gas + SHW	38	0	1	28	84	121	30	0	207	5%
Heating Source	Gas	42	0	1	28	88	130	30	0	218	1%
Window U-value	0.9	32	0	1	28	88	120	30	0	206	4%
Window U-value	1.1	32	0	1	28	88	121	30	0	207	3%
Window U-value	1.4	34	0	1	28	88	122	30	0	208	2%
Window U-value	1.8	35	0	1	28	88	124	30	0	210	2%
Lighting Efficacy	65	56	0	1	15	88	144	17	0	202	3%
Lighting Efficacy	60	55	0	1	17	88	143	18	0	204	2%
Lighting Efficacy	55	54	0	1	18	88	143	20	0	207	1%

Table 10.2e: Energy Demand Output Table – Existing Hospital (EE1)

Measure	***Value***	***Energy Use***					***Fuel Use***			***Primary Energy***	
		Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction
		kWh/m²					kWh/m²			kWh/m²	%
Floor U-value	0.1	53	46	26	87	105	158	159	0	554	0%
Floor U-value	0.15	54	46	26	87	105	158	159	0	554	0%
Floor U-value	0.2	54	46	26	87	105	159	159	0	555	0%
Floor U-value	0.25	54	46	26	87	105	159	159	0	555	0%
Wall U-Value	0.11	48	47	26	87	105	153	160	0	550	0%
Wall U-Value	0.15	49	46	26	87	105	153	160	0	551	0%
Wall U-Value	0.15	49	46	26	87	105	153	160	0	551	0%
Wall U-Value	0.21	50	46	26	87	105	154	160	0	551	0%
Wall U-Value	0.21	50	46	26	87	105	155	160	0	551	0%
Wall U-Value	0.27	51	46	26	87	105	156	159	0	552	0%
Wall U-Value	0.36	53	46	26	87	105	157	159	0	554	0%
Wall U-Value	0.47	55	46	26	87	105	160	159	0	556	-1%
Roof U-value	0.15	56	45	26	87	105	160	159	0	555	0%
Roof U-value	0.2	56	45	26	87	105	160	159	0	556	0%
Roof U-value	0.25	56	45	26	87	105	161	159	0	556	0%
Heating Source	Gas CHP	76	45	26	87	105	180	158	21	527	4%
Heating Source	Gas + SHW	44	45	26	87	103	147	158	0	541	1%
Heating Source	Gas	47	45	26	87	105	152	158	0	545	0%
Window U-value	1.4	39	51	26	87	105	144	164	0	550	0%
Window U-value	1.8	41	50	26	87	105	146	163	0	550	0%
Window U-value	1.1	38	52	26	87	105	142	165	0	550	0%
Window U-value	0.9	37	52	26	87	105	141	166	0	551	0%
AHU SFP	1.8	58	45	26	87	105	162	158	0	558	0%
AHU SFP	2	58	45	26	87	105	162	158	0	558	0%
AHU SFP	2.2	58	45	26	87	105	162	158	0	558	0%
Lighting Efficacy	65	78	20	26	28	105	182	74	0	380	2%
Lighting Efficacy	60	77	21	26	30	105	181	77	0	386	0%
Lighting Efficacy	55	76	22	26	33	105	180	81	0	394	-2%

Table 10.2f: Energy Demand Output Table – Existing Hospital (EE2)

Measure	***Value***	***Energy Use***					***Fuel Use***			***Primary Energy***	
		Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction
		kWh/m²					kWh/m²			kWh/m²	%
Floor U-value	0.1	51	36	19	70	105	155	125	0	470	0%
Floor U-value	0.15	51	35	19	70	105	156	125	0	470	0%
Floor U-value	0.2	51	35	19	70	105	156	125	0	470	0%
Floor U-value	0.25	52	35	19	70	105	156	125	0	471	0%
Wall U-Value	0.11	47	36	19	70	105	151	125	0	466	1%
Wall U-Value	0.15	48	36	19	70	105	152	125	0	467	1%
Wall U-Value	0.15	48	36	19	70	105	152	125	0	467	1%
Wall U-Value	0.21	49	36	19	70	105	153	125	0	468	1%
Wall U-Value	0.21	49	36	19	70	105	153	125	0	468	1%
Wall U-Value	0.27	50	35	19	70	105	155	125	0	469	0%
Wall U-Value	0.36	52	35	19	70	105	156	124	0	470	0%
Wall U-Value	0.47	54	35	19	70	105	159	124	0	472	0%
Roof U-value	0.15	52	35	19	70	105	156	124	0	470	0%
Roof U-value	0.2	52	35	19	70	105	156	124	0	470	0%
Roof U-value	0.25	52	35	19	70	105	157	124	0	470	0%
Heating Source	Gas CHP	70	35	19	70	105	175	124	20	444	4%
Heating Source	Gas + SHW	41	35	19	70	103	144	124	0	456	1%
Heating Source	Gas	45	35	19	70	105	149	124	0	462	0%
Window U-value	1.4	35	40	19	70	105	139	129	0	463	0%
Window U-value	1.1	34	41	19	70	105	138	130	0	463	0%
Window U-value	1.8	37	39	19	70	105	141	129	0	463	0%
Window U-value	0.9	33	41	19	70	105	137	131	0	463	0%
AHU SFP	1.8	54	35	19	70	105	158	124	0	472	0%
AHU SFP	2	54	35	19	70	105	158	124	0	472	0%
AHU SFP	2.2	54	35	19	70	105	158	124	0	472	0%
Lighting Efficacy	65	68	19	19	28	105	173	66	0	350	2%
Lighting Efficacy	60	67	20	19	30	105	172	69	0	356	0%
Lighting Efficacy	55	66	20	19	33	105	171	72	0	363	-1%

Table 10.2g: Energy Demand Output Table – Existing Hotel (EE1)

Measure	***Value***	***Energy Use***					***Fuel Use***			***Primary Energy***	
		Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction
		kWh/m²					kWh/m²			kWh/m²	%
Floor U-value	0.1	143	18	74	47	239	382	139	0	760	1%
Floor U-value	0.15	144	18	75	47	239	383	139	0	761	0%
Floor U-value	0.2	145	18	75	47	239	384	140	0	763	0%
Floor U-value	0.25	146	18	75	47	239	385	140	0	764	0%
Wall U-Value	0.11	132	19	74	47	239	371	139	0	747	1%
Wall U-Value	0.15	134	19	74	47	239	373	139	0	750	1%
Wall U-Value	0.15	134	19	74	47	239	373	139	0	750	1%
Wall U-Value	0.21	136	19	74	47	239	375	140	0	752	1%
Wall U-Value	0.21	136	19	74	47	239	375	140	0	753	1%
Wall U-Value	0.27	139	19	74	47	239	378	140	0	756	0%
Wall U-Value	0.36	143	19	75	47	239	382	140	0	762	0%
Wall U-Value	0.47	148	19	75	47	239	387	140	0	768	-1%
Roof U-value	0.15	141	18	73	47	239	380	138	0	754	0%
Roof U-value	0.2	143	18	74	47	239	382	138	0	757	0%
Roof U-value	0.25	144	18	74	47	239	383	138	0	759	0%
Heating Source	Gas CHP	195	18	75	47	239	434	141	55	691	7%
Heating Source	Gas + SHW	119	18	75	47	227	346	141	0	722	3%
Heating Source	Gas	125	18	75	47	239	364	141	0	743	0%
Window U-value	0.9	103	24	71	47	239	341	142	0	720	3%
Window U-value	1.1	107	23	72	47	239	346	141	0	724	2%
Window U-value	1.4	113	23	72	47	239	352	141	0	730	1%
Window U-value	1.8	121	22	73	47	239	360	141	0	739	0%
Chiller Efficiency	5.5	154	7	75	47	239	393	129	0	747	1%
Chiller Efficiency	4.5	154	8	75	47	239	393	130	0	751	0%
Chiller Efficiency	3.9	154	9	75	47	239	393	132	0	754	0%
AHU SFP	1.8	162	17	66	47	239	401	130	0	758	1%
AHU SFP	2	161	17	68	47	239	400	131	0	761	0%
AHU SFP	2.2	159	17	69	47	239	398	133	0	764	0%
Lighting Efficacy	65	167	15	75	29	239	406	120	0	741	0%
Lighting Efficacy	60	166	16	75	31	239	405	122	0	744	0%
Lighting Efficacy	55	164	16	75	33	239	403	124	0	748	-1%

Table 10.2h: Energy Demand Output Table – Existing Hotel (EE2)

Measure	***Value***	***Energy Use***					***Fuel Use***			***Primary Energy***	
		Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction
		kWh/m²					kWh/m²			kWh/m²	%
Floor U-value	0.1	123	14	66	32	210	333	112	0	639	1%
Floor U-value	0.15	124	14	66	32	210	334	112	0	641	0%
Floor U-value	0.2	125	14	66	32	210	335	112	0	642	0%
Floor U-value	0.25	126	14	66	32	210	336	112	0	644	0%
Wall U-Value	0.11	116	14	65	32	210	325	112	0	631	2%
Wall U-Value	0.15	117	14	65	32	210	327	112	0	633	2%
Wall U-Value	0.15	117	14	65	32	210	327	112	0	633	2%
Wall U-Value	0.21	119	14	66	32	210	329	112	0	636	2%
Wall U-Value	0.21	120	14	66	32	210	330	112	0	636	2%
Wall U-Value	0.27	122	14	66	32	210	332	112	0	640	1%
Wall U-Value	0.36	126	14	66	32	210	336	113	0	645	0%
Wall U-Value	0.47	131	14	67	32	210	341	113	0	651	-1%
Roof U-value	0.15	118	13	65	32	210	328	110	0	630	1%
Roof U-value	0.2	119	13	65	32	210	329	110	0	632	1%
Roof U-value	0.25	121	14	65	32	210	331	111	0	634	0%
Heating Source	Gas CHP	177	14	67	32	210	387	113	50	585	9%
Heating Source	Gas + SHW	111	14	67	32	198	310	113	0	616	4%
Heating Source	Gas	121	14	67	32	210	331	113	0	641	1%
Window U-value	0.9	82	19	62	32	210	292	113	0	596	4%
Window U-value	1.1	86	18	63	32	210	296	113	0	600	3%
Window U-value	1.4	92	18	63	32	210	301	113	0	606	2%
Window U-value	1.8	99	17	64	32	210	309	113	0	615	1%
Chiller Efficiency	5.5	130	6	67	32	210	340	105	0	630	2%
Chiller Efficiency	4.5	130	7	67	32	210	340	106	0	633	1%
Chiller Efficiency	3.9	130	8	67	32	210	340	107	0	635	1%
AHU SFP	1.8	132	14	64	32	210	342	109	0	644	2%
AHU SFP	2	131	14	65	32	210	341	111	0	647	1%
AHU SFP	2.2	130	14	67	32	210	340	113	0	650	1%
Lighting Efficacy	65	137	13	67	24	210	346	103	0	634	1%
Lighting Efficacy	60	136	13	67	25	210	345	104	0	636	1%
Lighting Efficacy	55	135	13	67	26	210	344	106	0	639	0%

Table 10.2i: Energy Demand Output Table – Existing Retail Warehouse (EE1)

Measure	***Value***	***Energy Use***					***Fuel Use***			***Primary Energy***	
		Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction
		kWh/m²					kWh/m²			kWh/m²	%
Floor U-value	0.1	64	40	51	41	2	67	132	0	387	0%
Floor U-value	0.15	65	40	51	41	2	67	132	0	387	0%
Floor U-value	0.2	66	39	51	41	2	68	132	0	388	0%
Floor U-value	0.25	66	39	51	41	2	69	131	0	388	0%
Wall U-Value	0.11	59	39	51	41	2	62	131	0	379	1%
Wall U-Value	0.15	60	39	51	41	2	62	131	0	380	1%
Wall U-Value	0.15	60	39	51	41	2	62	131	0	380	1%
Wall U-Value	0.21	61	39	51	41	2	63	131	0	381	1%
Wall U-Value	0.21	61	39	51	41	2	63	131	0	381	0%
Wall U-Value	0.27	62	39	51	41	2	65	131	0	382	0%
Wall U-Value	0.36	64	39	51	41	2	66	131	0	384	0%
Wall U-Value	0.47	66	39	51	41	2	68	131	0	386	-1%
Roof U-value	0.14	54	36	51	41	2	56	127	0	364	1%
Roof U-value	0.18	55	36	51	41	2	58	128	0	367	0%
Roof U-value	0.29	59	37	51	41	2	61	129	0	373	-2%
Heating Source	Gas CHP	88	39	51	41	2	90	131	25	352	6%
Heating Source	Gas + SHW	53	39	51	41	1	54	131	0	370	2%
Heating Source	Gas	56	39	51	41	2	58	131	0	375	0%
Window U-value	0.9	64	39	51	41	2	67	131	0	385	0%
Window U-value	1.1	65	39	51	41	2	67	131	0	385	0%
Window U-value	1.4	65	39	51	41	2	68	131	0	386	0%
Window U-value	1.8	66	39	51	41	2	68	131	0	386	0%
Chiller Efficiency	5.5	68	14	51	41	2	71	106	0	331	4%
Chiller Efficiency	4.5	68	17	51	41	2	71	109	0	338	2%
Chiller Efficiency	3.9	68	20	51	41	2	71	112	0	344	0%
AHU SFP	1.8	72	36	46	41	2	75	122	0	374	1%
AHU SFP	2	72	36	47	41	2	74	124	0	376	1%
AHU SFP	2.2	71	37	48	41	2	73	125	0	379	0%
Lighting Efficacy	65	72	35	51	32	2	75	118	0	363	1%
Lighting Efficacy	60	72	35	51	33	2	74	119	0	365	0%
Lighting Efficacy	55	72	35	51	34	2	74	120	0	367	-1%

Table 10.2j: Energy Demand Output Table – Existing Retail Warehouse (EE2)

Measure	***Value***	***Energy Use***					***Fuel Use***			***Primary Energy***	
		Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total	Reduction
		kWh/m²					kWh/m²			kWh/m²	%
Floor U-value	0.1	58	38	48	38	2	60	124	0	362	0%
Floor U-value	0.15	59	38	48	38	2	61	124	0	362	0%
Floor U-value	0.2	60	38	48	38	2	62	124	0	363	0%
Floor U-value	0.25	60	38	48	38	2	62	124	0	363	0%
Wall U-Value	0.11	55	38	48	38	2	57	123	0	356	1%
Wall U-Value	0.15	56	38	48	38	2	58	124	0	357	1%
Wall U-Value	0.15	56	38	48	38	2	58	124	0	357	1%
Wall U-Value	0.21	57	38	48	38	2	59	124	0	359	1%
Wall U-Value	0.21	57	37	48	38	2	59	124	0	359	1%
Wall U-Value	0.27	58	37	48	38	2	60	124	0	360	0%
Wall U-Value	0.36	60	37	48	38	2	62	124	0	362	0%
Wall U-Value	0.47	62	37	48	38	2	64	124	0	364	-1%
Roof U-value	0.14	47	35	45	38	2	49	118	0	333	1%
Roof U-value	0.18	48	35	45	38	2	50	118	0	336	0%
Roof U-value	0.29	52	36	46	38	2	54	120	0	344	-2%
Heating Source	Gas CHP	76	37	48	38	2	78	124	22	329	7%
Heating Source	Gas + SHW	48	37	48	38	1	49	124	0	347	2%
Heating Source	Gas	51	37	48	38	2	53	123	0	351	0%
Window U-value	0.9	58	38	48	38	2	60	124	0	360	1%
Window U-value	1.1	58	38	48	38	2	60	124	0	360	0%
Window U-value	1.4	59	38	48	38	2	61	124	0	361	0%
Window U-value	1.8	59	38	48	38	2	61	124	0	361	0%
Chiller Efficiency	5.5	62	14	48	38	2	64	100	0	308	4%
Chiller Efficiency	4.5	62	17	48	38	2	64	103	0	315	2%
Chiller Efficiency	3.9	62	19	48	38	2	64	105	0	321	0%
AHU SFP	1.8	63	36	46	38	2	65	121	0	359	2%
AHU SFP	2	62	37	47	38	2	64	122	0	361	1%
AHU SFP	2.2	62	37	48	38	2	64	124	0	364	0%
Lighting Efficacy	65	65	36	48	32	2	67	115	0	348	1%
Lighting Efficacy	60	64	36	48	33	2	66	116	0	350	0%
Lighting Efficacy	55	64	36	48	34	2	66	118	0	353	-1%

Table 10.3a: Energy Demand Output Table – Existing Hospital (EE1)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
A	3	Gas CHP	20%	66	24	26	97	28	163	78	22	315
Window Only	3	Gas CHP	20%	74	24	26	97	28	171	78	25	319
EE1	3	Gas CHP	20%	102	20	26	97	28	199	74	32	323
EE1	3	Gas CHP	0%	102	20	26	97	28	199	74	29	331
Window Only	3	Gas(86%)	20%	47	24	26	97	28	143	78	4	336
EE1	3	Gas(91%)+ SHW	20%	60	20	26	96	28	155	74	4	341
EE1	3	Gas(86%)	20%	65	20	26	97	28	161	74	4	347
EE1	3	Gas(86%)	0%	65	20	26	97	28	161	74	0	356
EE1	2	Gas(86%)	0%	64	21	26	97	30	160	77	0	362
EE1	1	Gas(86%)	0%	63	22	26	97	33	159	81	0	370

Table 10.3b: Energy Demand Output Table – Existing Hotel (EE1)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
C	3	Gas CHP	20%	109	7	58	239	29	348	94	33	537
A	3	Gas CHP	20%	136	6	60	239	29	374	95	40	551
Window Only	3	Gas CHP	20%	158	6	62	239	29	396	98	47	568
Roof Only	3	Gas CHP	20%	195	5	64	239	29	434	98	57	585
Roof Only	2	Gas CHP	20%	193	6	64	239	31	432	101	57	591
EE1	2	Gas CHP	20%	210	6	66	239	31	449	103	61	604
EE1	1	Gas CHP	20%	208	8	66	239	33	447	106	61	611
EE1	2	Gas(91%)+ SHW	20%	134	6	66	227	31	362	103	2	646
EE1	1	Gas(91%)+ SHW	20%	18	19	20	31	21	32	33	37	652
EE1	1	Gas(86%)	0%	144	8	66	239	33	380	106	0	679

Table 10.3c: Energy Demand Output Table – Existing Office (EE1)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
D	3	Gas CHP	20%	56	0	1	4	26	56	31	23	82
Window Only	3	Gas CHP	20%	86	0	1	4	26	86	31	31	96
Window Only	2	Gas CHP	20%	84	0	1	4	28	84	33	31	100
EE1	3	Gas CHP	20%	114	0	1	4	26	114	31	39	109
Window Only	3	Gas(86%)	20%	60	0	1	4	26	58	31	7	122
Window Only	1	Gas(86%)	20%	57	0	1	4	31	55	36	7	130
Window Only	3	Gas(86%)	0%	60	0	1	4	26	58	31	0	139
EE1	3	Gas(86%)	20%	79	0	1	4	26	78	31	7	144
EE1	1	Gas(86%)	20%	76	0	1	4	31	74	36	7	152
EE1	1	Gas(86%)	0%	76	0	1	4	31	74	36	0	168

Table 10.3d: Energy Demand Output Table – Existing Retail Warehouse (EE1)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
D	3	Gas CHP	20%	59	14	43	2	32	61	89	37	191
Roof Only	3	Gas CHP	20%	80	14	46	2	32	83	92	43	208
EE1	3	Gas CHP	20%	93	14	46	2	32	96	92	47	214
Window Only	3	Gas(86%)	20%	62	14	46	2	32	63	92	21	240
EE1	3	Gas(86%)	20%	64	14	46	2	32	65	92	21	242
EE1	1	Gas(86%)	20%	63	17	47	2	33	64	96	21	251
EE1	3	Gas CHP	0%	93	14	46	2	32	96	92	26	263
EE1	1	Gas CHP	0%	93	17	47	2	33	95	96	26	273
EE1	3	Gas(86%)	0%	64	14	46	2	32	65	92	0	291
EE1	1	Gas(86%)	0%	63	17	47	2	33	64	96	0	300

Table 10.3e: Energy Demand Output Table – Existing Secondary School (EE1)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
C	3	Gas CHP	20%	48	0	1	117	15	166	17	24	169
Window Only	3	Gas CHP	20%	63	0	1	117	15	181	17	28	176
Wall Only	3	Gas CHP	20%	76	0	1	117	15	193	17	32	182
EE1	3	Gas CHP	20%	81	0	1	117	15	198	17	33	184
Window Only	3	Gas(86%)	20%	44	0	1	117	15	161	17	11	196
Wall Only	3	Gas(86%)	20%	53	0	1	117	15	169	17	11	206
EE1	3	Gas(86%)	20%	57	0	1	117	15	173	17	11	210
Window Only	3	Gas(86%)	0%	44	0	1	117	15	161	17	0	221
EE1	3	Gas(86%)	0%	57	0	1	117	15	173	17	0	235
EE1	1	Gas(86%)	0%	55	0	1	117	18	171	20	0	240

Table 10.3f: Energy Demand Output Table – Existing Hospital (EE2)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
A	3	Gas CHP	20%	58	22	19	97	28	155	69	20	291
Window Only	3	Gas CHP	20%	62	23	19	97	28	159	70	21	294
EE2	3	Gas CHP	20%	89	19	19	97	28	186	66	29	297
EE2	2	Gas CHP	20%	88	20	19	97	30	185	69	29	304
Window Only	3	Gas(86%)	20%	39	23	19	97	28	136	70	4	309
EE2	3	Gas(91%)+ SHW	20%	52	19	19	96	28	148	66	4	313
EE2	3	Gas(86%)	20%	57	19	19	97	28	153	66	4	319
EE2	3	Gas(86%)	0%	57	19	19	97	28	153	66	0	328
EE2	2	Gas(86%)	0%	56	20	19	97	30	152	69	0	334
EE2	1	Gas(86%)	0%	55	20	19	97	33	151	72	0	341

Table 10.3g: Energy Demand Output Table – Existing Hotel (EE2)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
C	3	Gas CHP	20%	93	7	57	210	24	303	87	28	480
B	3	Gas CHP	20%	103	6	57	210	24	313	87	31	485
Window Only	3	Gas CHP	20%	133	6	60	210	24	343	90	40	505
Roof Only	3	Gas CHP	20%	170	5	61	210	24	380	90	50	522
Roof Only	1	Gas CHP	20%	167	7	61	210	26	377	94	49	531
EE2	1	Gas CHP	0%	183	7	64	210	26	393	97	52	550
Roof Only	2	Gas(91%)+ SHW	20%	108	6	61	198	25	306	92	2	558
EE2	2	Gas(91%)+ SHW	20%	118	6	64	198	25	317	94	2	575
EE2	1	Gas(91%)+ SHW	0%	117	7	64	198	26	316	97	0	585
EE2	1	Gas(86%)	0%	127	7	64	210	26	334	97	0	605

Table 10.3h: Energy Demand Output Table – Existing Office (EE2)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
D	3	Gas CHP	20%	42	0	1	3	26	42	30	19	74
A	3	Gas CHP	20%	54	0	1	3	26	54	30	22	80
Window Only	3	Gas CHP	20%	67	0	1	3	26	67	30	26	85
Wall Only	3	Gas CHP	20%	86	0	1	3	26	86	30	31	94
Window Only	3	Gas(86%)	20%	46	0	1	3	26	45	30	7	106
Wall Only	3	Gas(86%)	20%	60	0	1	3	26	59	30	7	121
EE2	3	Gas(86%)	20%	66	0	1	3	26	64	30	7	127
EE2	1	Gas(86%)	20%	62	0	1	3	31	61	35	7	135
EE2	3	Gas(86%)	0%	66	0	1	3	26	64	30	0	144
EE2	1	Gas(86%)	0%	62	0	1	3	31	61	35	0	151

Table 10.3i: Energy Demand Output Table – Existing Retail Warehouse (EE2)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
D	3	Gas CHP	20%	50	14	41	2	32	52	88	35	183
EE2	3	Gas CHP	20%	80	15	46	2	32	82	93	43	211
EE2	1	Gas CHP	20%	80	18	47	2	33	82	98	43	221
Window Only	3	Gas(86%)	20%	53	15	46	2	32	54	93	21	233
EE2	3	Gas(86%)	20%	55	15	46	2	32	56	93	21	235
EE2	1	Gas(86%)	20%	54	18	47	2	33	55	98	21	244
EE2	3	Gas CHP	0%	80	15	46	2	32	82	93	23	260
EE2	1	Gas CHP	0%	80	18	47	2	33	82	98	23	270
EE2	3	Gas(86%)	0%	55	15	46	2	32	56	93	0	284
EE2	1	Gas(86%)	0%	54	18	47	2	33	55	98	0	293

Table 10.3j: Energy Demand Output Table – Existing Secondary School (EE2)

Package				***Energy Use***						***Fuel Use***		***Primary Energy***
Fabric	Services	Heating	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Total
				kWh/m²			kWh/m²			kWh/m²		
C	3	Gas CHP	20%	36	0	1	88	15	124	17	21	131
Window Only	3	Gas CHP	20%	49	0	1	88	15	137	17	24	137
Wall Only	3	Gas CHP	20%	64	0	1	88	15	152	17	29	143
Window Only	3	Gas(86%)	20%	34	0	1	88	15	122	17	11	152
Wall Only	3	Gas(86%)	20%	45	0	1	88	15	132	17	11	163
EE2	3	Gas(86%)	20%	47	0	1	88	15	134	17	11	165
EE2	1	Gas(86%)	20%	45	0	1	88	18	132	20	11	171
Window Only	3	Gas(86%)	0%	34	0	1	88	15	122	17	0	177
EE2	3	Gas(86%)	0%	47	0	1	88	15	134	17	0	190
EE2	1	Gas(86%)	0%	45	0	1	88	18	132	20	0	195

11. Global Cost Calculation

11.1 Introduction

This section presents the analysis for new and existing non-domestic buildings. In each case, the cost data is initially presented followed by the results of the macro-economic and financial cost analysis.

In undertaking this work, various underpinning costs have been assumed. The costs are 2017 prices and where necessary, as indicated below, previous years data has been adjusted for inflation to 2017 prices using, for construction costs, the projections published by the Building Cost Information Service (BCIS)[43] and, for energy and greenhouse gas prices, the Office for National Statistics (ONS) Gross Domestic Product (GDP) deflator series[44] and projections from the Office of Budget Responsibility[45].

11.2 New Buildings

11.2.1 Capital Costs and Asset Lifetimes

Introduction

The capital cost data was sourced from a combination of recent tenders for relevant projects and first principles cost planning; drawing on published materials, costs and labour rates for relevant trades. This cost analysis has been compiled based upon the building types and specifications contained and have been priced as defined.

Unless specified, the rates for non-domestic buildings assume an average cost across the building types. The costs reflect current day pricing; uplift has been added to show corresponding prices at Q2 2017. Costs exclude preliminaries, overheads and profits (OH&P), contingency, fees and VAT.

The remainder of this section describes the cost data sourced and the 2016 and projected 2017 prices developed for use in the cost optimal modelling.

Building Fabric

Table 11.1 shows the cost data in 2016 and 2017 prices for the defined fabric specifications, differentiated by those applicable for naturally ventilated or air conditioned buildings where appropriate.

[43] Building Cost Information Service, Royal Institute of Chartered Surveyors
[44] Implied GDP deflator at market prices, Office for National Statistics
[45] Economic and fiscal outlook, Office of Budget Responsibility, March 2016

Table 11.1: Cost data for building fabric elements - new non domestic buildings

Element	Performance Rating	Unit	Cost (£ per unit)			
			2016		2017	
			Naturally Ventilated	Air Conditioned	Naturally Ventilated	Air Conditioned
External Walls	MASONRY CAVITY - 0.30 W/m^2 K	per m² of wall area	£134	£134	£138	£138
	LIGHTWEIGHT METAL FRAME - 0.30 W/m^2 K		£321	£321	£331	£331
	MASONRY CAVITY - 0.25 W/m^2 K		n/a	£134	n/a	£138
	LIGHTWEIGHT METAL FRAME - 0.25 W/m^2 K		£333	£333	£343	£343
	MASONRY CAVITY - 0.21 W/m^2 K		£139	n/a	£143	n/a
	LIGHTWEIGHT METAL FRAME - 0.21 W/m^2 K		£345	£345	£356	£356
	MASONRY CAVITY - 0.20 W/m^2 K		n/a	£139	n/a	£144
	LIGHTWEIGHT METAL FRAME - 0.20 W/m^2 K		n/a	£355	n/a	£366
	MASONRY CAVITY - 0.15 W/m^2 K		£154	n/a	£159	n/a
	LIGHTWEIGHT METAL FRAME - 0.15 W/m^2 K		£384	£384	£396	£396
Ground Floor	0.25 W/m^2 K	per m² of floor area	£174	£174	£179	£179
	0.20 W/m^2 K		£178	£178	£184	£184
	0.15 W/m^2 K		£183	£183	£189	£189
	0.10 W/m^2 K		£230	£230	£238	£238
Roof	SCHOOLS, OFFICES, HOSPITALS, HOTELS - flat roof: 0.25 W/m^2 K	per m² of roof area	£114	£114	£117	£117
	SCHOOLS, OFFICES, HOSPITALS, HOTELS - flat roof: 0.20 W/m^2 K		£122	£122	£126	£126
	SCHOOLS, OFFICES, HOSPITALS, HOTELS - flat roof: 0.15 W/m^2 K		£136	£136	£140	£140
	SCHOOLS, OFFICES, HOSPITALS, HOTELS - flat roof: 0.10 W/m^2 K		£162	£162	£167	£167
	HOTELS AND SCHOOLS - pitched roof, tiled, insulated ceiling: 0.25 W/m^2 K		£240	£240	£248	£248
	HOTELS AND SCHOOLS - pitched roof, tiled, insulated ceiling: 0.20 W/m^2 K		£240	£240	£248	£248
	HOTELS AND SCHOOLS - pitched roof, tiled, insulated ceiling: 0.15 W/m^2 K		£241	£241	£249	£249
	HOTELS AND SCHOOLS - pitched roof, tiled, insulated ceiling: 0.10 W/m^2 K		£245	£245	£253	£253
	WAREHOUSES - profiled metal, insulated ceiling: 0.25 W/m^2 K		£115	£115	£119	£119
	WAREHOUSES - profiled metal, insulated ceiling: 0.20 W/m^2 K		£117	£117	£121	£121
	WAREHOUSES - profiled metal, insulated ceiling: 0.15 W/m^2 K		£121	£121	£125	£125
	WAREHOUSES - profiled metal, insulated ceiling: 0.10 W/m^2 K *		£129	£129	£133	£133
Windows	TIMBER - 1.8 W/m^2 K	per m² of window area	£500	£500	£516	£516
	UPVC - 1.8 W/m^2 K		£303	£303	£313	£313
	TIMBER - 1.4 W/m^2 K		£558	£558	£576	£576
	UPVC - 1.4 W/m^2 K		£360	£360	£371	£371
	TIMBER - 1.1 W/m^2 K		£587	£587	£606	£606
	UPVC - 1.1 W/m^2 K		£397	£397	£410	£410
	TIMBER - 0.9 W/m^2 K		£670	£670	£692	£692
	UPVC - 0.9 W/m^2 K		£470	£470	£485	£485

* Note: the cost for U-value of 0.10 W/m2 K excludes any associated impact on the building storey heights resulting from the use of 180mm thick insulation

Table 11.1: Cost data for building fabric elements - new non domestic buildings (cont….)

Element	Performance Rating	Unit	Cost (£ per unit)			
			2016		2017	
			Naturally Ventilated	Air Conditioned	Naturally Ventilated	Air Conditioned
Air tightness	OFFICE: 3.0m³/hr/m²	per m² building GIA	£0.80	£2.00	£0.83	£2.06
	SCHOOL: 3.0m³/hr/m²		£1.35	£1.35	£1.39	£1.39
	HOSPITAL: 3.0m³/hr/m²		£1.24	£1.24	£1.28	£1.28
	HOTEL: 3.0m³/hr/m²		£1.25	£1.25	£1.29	£1.29
	DIST WAREHOUSE: 3.0m³/hr/m²		£1.22	£1.22	£1.26	£1.26
	RETAIL WAREHOUSE: 3.0m³/hr/m²		£1.22	£1.22	£1.26	£1.26
Thermal Bridging	OFFICE: improved	per m² building GIA	£0.63	£0.67	£0.65	£0.69
	SCHOOL: improved		£0.81	£0.81	£0.84	£0.84
	HOSPITAL: improved		£0.70	£0.70	£0.73	£0.73
	HOTEL: improved		£0.72	£0.72	£0.75	£0.75
	DIST WAREHOUSE: improved		£0.61	£0.61	£0.63	£0.63
	RETAIL WAREHOUSE: improved		£0.61	£0.61	£0.63	£0.63

Building services and renewable energy

Table 11.2 shows the sizing assumptions for the heating and cooling loads in the different non-domestic buildings.

Table 11.2: Heating and cooling load assumptions

Building Type	Heat Load (W/m²)	Building Size (m²)	Building Load (kW)	Unit Size (kW)	Cool Load (W/m²)	Building Load (kW)
Office (AC)	70	30,000	2100	700	120	3600
Office (NV)	70	4,500	315	100	-	-
Secondary School	100	11,100	1110	400	-	-
Hospital	80	18,500	1480	500	-	-
Hotel (AC)	90	15,200	1368	450	150	2280
Dist. Warehouse	80	4,900	392	130	-	-
Retail Warehouse (AC)	100	4,900	490	175	140	686

Table 11.3 shows the capital cost per kW capacity and annual maintenance costs per system for different heating systems including gas boilers, ground and air source heat pumps and combined heat and power.

Table 11.3: Capital and maintenance costs for heating systems - new non-domestic buildings (2017 prices)

Size (kWth)	*Capital (£/kW)*				*Maintenance (£)*			
	Gas Boiler	*GSHP*	*ASHP*	*Gas CHP*	*Gas Boiler*	*GSHP*	*ASHP*	*Gas CHP*
25	£93	£1,290	£655	£1,600	£170	£170	£179	£3,831
50	£93	£1,290	£655	£1,200	£284	£284	£298	£7,816
75	£77	£1,290	£645	£1,050	£426	£426	£447	£7,152
100	£77	£1,290	£645	£975	£568	£568	£596	£8,429
125	£77	£1,238	£645	£900	£710	£710	£745	£8,429
150	£62	£1,238	£645	£833	£851	£851	£894	£9,961
175	£62	£1,238	£645	£800	£993	£993	£1,043	£9,961
200	£62	£1,238	£645	£775	£1,135	£1,135	£1,192	£11,800
250	£62	£1,238	£645	£720	£1,419	£1,419	£1,490	£12,812
300	£62	£1,135	£645	£650	£1,533	£1,533	£1,609	£17,251
400	£52	£1,135	£619	£610	£2,043	£2,043	£2,146	£21,711
500	£52	£1,135	£619	£610	£2,497	£2,497	£2,622	£25,542

In assessing the costs per kW capacity shown in Table 11.3 it is important to remember that the capacity required will vary according to the system selected. For example, where a heat pump based system is selected the capacity required is typically lower due to its operating regime.

Table 11.4 shows the capital cost per system for different cooling and ventilation systems and performance levels. These systems are only applicable to building types with air conditioning and / or mechanical ventilation. Maintenance costs are assumed to be consistent irrespective of the efficiency of the cooling plant or ventilation systems and are therefore excluded from the analysis.

Table 11.4: Capital costs for cooling and ventilation systems new non-domestic buildings (2017 prices)

Building Type	***Cooling****			***Ventilation *****				***Heat exchanger effectiveness***		***Fan coils***	
	Chiller SEER			***Rate***	***AHU SFP***					***FCU SFP***	
	3.9	**4.5**	**5.5**	**(m^3/s)**	**2.2**	**2.0**	**1.8**	**45%**	**75%**	**0.6**	**0.2**
Office (AC)	£ 538,332	+ 5-10%	+ 20-25%	48	£ 312,077	+5%	+10-20%	£ 90,000	+15-20%	£ 712,080	+20%
Office (NV)	-	-	-	-		-	-	-	-	-	-
Secondary School	-	-	-	-	-	-	-	-	-	-	-
Hospital	-	-	-	46	£ 273,067	+5%	+10-20%	£ 75,000	+15-20%	-	-
Hotel (AC)	£ 340,943	+ 5-10%	+ 20-25%	24	£ 156,038	+5%	+10-20%	£ 45,000	+15-20%	£ 431,520	+20%
Dist. Warehouse	-	-	-	-	-	-	-	-	-	-	-
Retail Warehouse (AC)	£ 102,582	+ 5-10%	+ 20-25%	14	£ 91,022	+5%	+10-20%	£ 25,000	+15-20%	£ 117,237	+20%

Notes:
* Chiller costs based on use of two chillers each operating at 2/3 of capacity
**Ventilation costs based on 6 AHU for the office and hospital building and 3 and 2 AHUs respectively for the hotel and retail warehouse.

Table 11.5 shows the capital costs for lighting systems in each building.

Table 11.5: Capital costs for lighting systems new non-domestic buildings (2017 prices)

Building Type	***Capital cost (£/m^2)***	
Luminaire efficiency	***llm/cW***	***Total***
Office	52.9	£47
	61.5	£53
	72.6	£59
	95	£66
Hotel	50.6	£25
	63	£37
	82.8	£48
	95	£60
Warehouse	58.2	£57
	66.5	£65
	82	£74
	95	£85
School / Hospital	52.6	£70
	64.3	£76
	77.3	£82
	95	£94
Enhanced lighting controls	***Daylight***	***Occupancy***
Office (AC)	£7.7	£7.7
Office (NV)	£7.7	£7.7
Secondary School	£7.7	£7.7
Hospital	£7.7	£7.7
Hotel (AC)	£6.7	£6.7
Dist. Warehouse	£2.1	£2.6
Retail Warehouse (AC)	£2.1	£2.6

Table 11.6 shows the capital and maintenance costs for solar water heating systems with different collector areas.

Table 11.6: Capital and maintenance costs solar water heating systems new non-domestic buildings (2017 prices)

Size (m²)	***Total (£/m²)***	***Maintenance £/annum***
25	£929	£91
50	£929	£119
75	£929	£148
100	£929	£176
150	£929	£204
200	£929	£233
250	£929	£261
300	£929	£289
400	£929	£318
500	£929	£346
750	£929	£375

Table 11.7 shows the capital and maintenance costs for photovoltaic systems with different peak capacities. Costs have been developed from those published by the former Department of Energy and Climate Change (DECC) in August 2015[46].

Table 11.7: Capital and maintenance costs for non-domestic photovoltaic systems (2017 prices)

PV Size (kW(p))	*Capital cost*		*Annual maintenance cost*	
	£ per kWp	*Cost for system size (£)*	*£ per kWp*	*Cost for system size (£ pa)*
4	£1,409	£5,032	£33	£117
7	£1,211	£8,650	£15	£104
11	£1,050	£11,250	£9	£98
14	£1,050	£15,000	£9	£130
21	£1,050	£22,500	£9	£195
29	£1,050	£30,000	£9	£260
36	£1,050	£37,500	£9	£325
43	£1,050	£45,000	£9	£390
57	£985	£56,286	£9	£497
71	£985	£70,357	£9	£621
107	£985	£105,536	£9	£932
143	£985	£140,714	£9	£1,243
179	£900	£160,714	£8	£1,482
214	£900	£192,857	£8	£1,779
250	£900	£225,000	£8	£2,075
286*	£900	£257,143	£8	£2,371
Note * Cost taken is that for a 150-250kWp system as the next size banding ranges up to 5MWp.				

11.2.2 Projected cost reductions

The same projected cost reductions were applied as for domestic buildings (see Section 5.2.3).

11.2.3 Energy and carbon prices

For the purposes of this work, low, central and high energy prices have been used as shown in Table 11.8 (a-b), taken from the Interdepartmental Analyst Group (IAG) tables revised in September 2015[47] and adjusted to 2017 prices. The retail prices (Table 11.8a) are used for the financial analysis and the variable prices (Table 11.8b) are used for the macro-economic analysis.

[46] Small-scale generation cost update, Parson's Brinkerhoff, August 2015.
[47] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions

11.2.4 Cost of greenhouse gas emissions

The assumed costs of greenhouse gas emissions for the macroeconomic calculations are the same as used for the domestic calculations (see Section 5.2.5).

The carbon dioxide (CO_2) factors used in the calculations of the cost of greenhouse gas emissions have been taken from the Interdepartmental Analyst Group (IAG) tables - table 1 (commercial/public sector long-run marginal factors for electricity), and table 2a (gas).

11.2.5 Discount rates

A central real discount rate for the financial calculation of 6% has been used, with an additional sensitivity at 10%.

A central discount rate for the macroeconomics calculation of 3.5% has been used, as is also used for Government Impact Assessments in England, and a sensitivity of 3% has been used as required by the Commission.

Table 11.8a: Energy Costs - Retail

			2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Low	Electricity	p/kWh	10.3	10.1	10.8	11.8	11.6	12.4	12.4	13.2	13.9	13.7
Low	Gas	p/kWh	2.1	2.0	1.9	2.0	2.1	2.2	2.2	2.3	2.4	2.4
Central	Electricity	p/kWh	11.7	11.6	12.3	12.9	13.5	13.7	14.0	14.9	15.4	15.5
Central	Gas	p/kWh	2.8	2.8	2.8	2.9	3.0	3.1	3.3	3.4	3.5	3.5
High	Electricity	p/kWh	13.0	13.1	13.9	14.2	15.2	15.1	15.7	16.4	17.0	16.6
High	Gas	p/kWh	3.4	3.5	3.6	3.8	4.0	4.2	4.4	4.6	4.7	4.7

			2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Low	Electricity	p/kWh	14.2	14.1	14.2	14.3	14.3	14.3	14.3	14.3	14.3	14.3
Low	Gas	p/kWh	2.5	2.5	2.6	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Central	Electricity	p/kWh	15.7	15.2	15.1	15.2	15.2	15.2	15.2	15.2	15.2	15.2
Central	Gas	p/kWh	3.5	3.5	3.6	3.5	3.5	3.5	3.5	3.5	3.5	3.5
High	Electricity	p/kWh	17.0	16.3	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
High	Gas	p/kWh	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7

			2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Low	Electricity	p/kWh	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
Low	Gas	p/kWh	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Central	Electricity	p/kWh	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
Central	Gas	p/kWh	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
High	Electricity	p/kWh	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
High	Gas	p/kWh	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7

Table 11.8b: Energy Costs - Variable

			2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Low	Electricity	p/kWh	6.0	5.8	6.5	7.4	7.2	7.9	7.7	8.3	8.8	8.5
Low	Gas	p/kWh	1.3	1.2	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5
Central	Electricity	p/kWh	7.3	7.2	7.9	8.3	8.8	9.0	9.1	9.8	10.2	10.2
Central	Gas	p/kWh	1.8	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.5
High	Electricity	p/kWh	8.5	8.6	9.3	9.5	10.3	10.2	10.7	11.2	11.6	11.1
High	Gas	p/kWh	2.4	2.5	2.6	2.8	2.9	3.1	3.3	3.4	3.6	3.6

			2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Low	Electricity	p/kWh	9.0	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Low	Gas	p/kWh	1.6	1.6	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Central	Electricity	p/kWh	10.2	9.8	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
Central	Gas	p/kWh	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
High	Electricity	p/kWh	11.4	10.7	10.6	10.4	10.4	10.4	10.4	10.4	10.4	10.4
High	Gas	p/kWh	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

			2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Low	Electricity	p/kWh	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Low	Gas	p/kWh	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Central	Electricity	p/kWh	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
Central	Gas	p/kWh	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
High	Electricity	p/kWh	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
High	Gas	p/kWh	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

11.2.6 Results of the cost calculations

The following Tables summarise the results of the cost calculations for the most cost-optimal packages in each of the reference buildings. Table 11.9 relates to the macroeconomic calculations and Table 11.10 relates to the financial calculations.

- Table 11.9a / Table 11.10a: Central energy price, central discount factors
- Table 11.9b / Table 11.10b: Low energy price, central discount factors
- Table 11.9c / Table 11.10c: High energy price, central discount factors
- Table 11.9d / Table 11.10d: Central energy price, alternative discount factors
- Table 11.9e: Central energy price, central discount factor, alternative cost of carbon

It is important to note that the initial investment costs in these tables only reflect the delivery of the building elements associated with the defined packages and other construction costs involved in completing the property are excluded.

The sensitivity analysis shows that with lower energy prices there is a tendency for solutions with higher primary energy to become relatively more favourable. Similarly, with higher discount rates, it makes solutions with higher primary energy relatively more favourable due at least partly to the lower net present value energy prices.

Table 11.9a: Macroeconomic Costs (Central energy price, 3.5% discount factors, £/m²)

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Office (AC) – 20 year calc	B	GSHP+SHW	3	40%	82	394	5	47	2	-57	392
	B	GSHP	3	40%	83	385	5	48	2	-57	383
	B	Gas(86%)	3	40%	89	359	5	48	2	-57	358
	A	Gas(86%)	3	40%	98	342	5	53	3	-53	349
	A	Gas(86%)	3	0%	108*	336	5	57	3	-52	348
	A	Gas(86%)	2	40%	119	330	5	65	3	-53	350
	A	Gas(86%)	2	0%	129	324	5	69	3	-52	348
	B	Gas(86%)	1	40%	160	317	5	89	4	-57	358
	B	Gas(86%)	1	0%	170	311	5	93	4	-56	356
	A	Gas(86%)	1	40%	175	299	5	96	4	-53	352
Office (NV) – 20 year calc	C	GSHP+SHW	3	40%	11	437	9	11	0	-83	375
	C	GSHP	3	40%	14	406	9	13	0	-83	346
	A	GSHP	3	40%	21	354	9	17	0	-69	310
	A	GSHP	2	40%	26	348	9	19	1	-69	307
	A	Gas(86%)	3	40%	36	327	9	18	2	-69	286
	A	Gas(86%)	2	20%	57	312	8	28	2	-69	281
	A	Gas(86%)	2	0%	73	302	7	35	2	-68	278
	A	Gas(86%)	1	20%	86	289	8	45	3	-69	276
	B	Gas(86%)	1	0%	98	298	7	51	3	-73	285
	A	Gas(86%)	1	0%	102*	279	7	52	3	-68	273
Sec. School – 30 year calc	C	GSHP+SHW	3	40%	41	608	17	18	6	-79	570
	C	GSHP	3	40%	46	540	17	20	6	-72	512
	C	Gas(86%)	3	40%	52	483	17	21	8	-65	463
	C	Gas(86%)	2	40%	56	474	17	24	8	-66	455
	B	Gas(86%)	3	40%	59	454	17	24	8	-62	440
	A	Gas(86%)	2	40%	67	427	17	29	9	-61	420
	A	Gas(86%)	1	40%	79	394	17	38	9	-57	400
	A	Gas(86%)	1	20%	104	380	15	52	10	-56	400
	A	Gas(86%)	2	0%	117	396	13	56	10	-57	418
	A	Gas(86%)	1	0%	128*	363	13	65	10	-53	398
Hospital – 30 year calc	C	GSHP+SHW	3	40%	188	491	11	123	10	-62	573
	B	GSHP+SHW	3	40%	189	475	11	124	10	-61	559
	B	GSHP	3	40%	190	451	11	125	10	-59	538
	A	GSHP	3	40%	195	439	11	128	10	-57	530
	A	Gas CHP	3	40%	212	419	33	106	22	-55	523
	A	Gas(86%)	3	40%	244	396	11	133	18	-53	506
	A	Gas(86%)	3	20%	253	391	10	138	19	-52	506
	A	Gas(86%)	2	40%	258	383	11	144	19	-53	503
	A	Gas(86%)	1	40%	284	342	11	163	19	-48	487
	A	Gas(86%)	1	0%	302*	331	9	174	20	-47	487

Table 11.9a: Macroeconomic Costs (Central energy price, 3.5% discount factors, £/m²) cont..

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Hotel – 20 year calc	C	GSHP+SHW	3	40%	319	528	8	134	12	-91	592
	B	GSHP+SHW	3	40%	324	494	8	137	13	-85	567
	B	Gas(91%)+SHW	3	40%	356	462	8	139	15	-85	539
	B	Gas(91%)+SHW	2	40%	377	439	8	151	16	-85	529
	B	Gas(86%)	2	40%	393	430	8	156	17	-85	526
	A	Gas(86%)	2	40%	418	407	8	167	17	-80	520
	A	Gas(86%)	2	0%	428*	402	7	171	18	-79	519
	B	Gas(86%)	1	40%	479	399	8	202	19	-85	543
	B	Gas(86%)	1	0%	489	394	7	206	19	-85	542
	A	Gas(86%)	1	0%	523	371	7	223	20	-79	541
Whs (Dist.) – 20 year calc	C	GSHP+SHW	3	40%	-34	807	15	-8	0	-178	636
	C	GSHP	3	40%	-25	716	14	-5	0	-178	547
	B	GSHP	2	40%	-13	658	14	1	0	-167	507
	A	GSHP	2	40%	-2	632	14	8	1	-159	496
	B	Gas(86%)	2	40%	19	629	14	3	3	-167	483
	A	Gas(86%)	2	40%	42	603	14	11	4	-159	473
	B	Gas(86%)	2	20%	68	606	11	24	4	-165	480
	A	Gas(86%)	2	20%	91	580	11	31	5	-158	470
	A	Gas(86%)	2	0%	139*	553	7	52	6	-156	463
	A	Gas(86%)	1	0%	188	537	7	83	7	-156	478
Whs (Retail) – 20 year calc	C	GSHP+SHW	3	40%	48	873	18	41	1	-171	762
	C	GSHP	3	40%	49	782	17	41	1	-171	670
	B	GSHP	3	40%	53	756	17	43	1	-165	652
	B	Gas(86%)	3	40%	75	716	17	45	3	-165	616
	A	Gas(86%)	3	40%	87	696	17	49	4	-159	606
	A	Gas(86%)	2	40%	105	673	17	59	4	-159	594
	A	Gas(86%)	2	20%	154	650	14	80	5	-158	591
	A	Gas(86%)	2	0%	202*	622	10	101	6	-156	584
	A	Gas(86%)	1	40%	227	648	17	130	6	-159	642
	A	Gas(86%)	1	20%	276	625	14	151	7	-158	639

Table 11.9b: Macroeconomic Costs (Low energy price, 3.5% discount factors, £/m²)

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Office (AC) – 20 year calc	B	GSHP+SHW	3	40%	82	394	5	41	2	-57	386
	B	GSHP	3	40%	83	385	5	42	2	-57	376
	B	Gas(86%)	3	40%	89	359	5	41	2	-57	351
	A	Gas(86%)	3	40%	98	342	5	45	3	-53	341
	A	Gas(86%)	3	0%	108	336	5	48	3	-52	339
	A	Gas(86%)	2	40%	119	330	5	55	3	-53	340
	A	Gas(86%)	2	0%	129*	324	5	59	3	-52	338
	B	Gas(86%)	1	40%	160	317	5	76	4	-57	345
	B	Gas(86%)	1	0%	170	311	5	80	4	-56	344
	A	Gas(86%)	1	40%	175	299	5	83	4	-53	339
Office (NV) – 20 year calc	C	GSHP+SHW	3	40%	11	437	9	10	0	-83	374
	C	GSHP	3	40%	14	406	9	11	0	-83	344
	A	GSHP	3	40%	21	354	9	14	0	-69	308
	A	GSHP	2	40%	26	348	9	17	1	-69	305
	A	Gas(86%)	3	40%	36	327	9	13	2	-69	282
	A	Gas(86%)	2	20%	57	312	8	22	2	-69	276
	A	Gas(86%)	2	0%	73	302	7	28	2	-68	272
	A	Gas(86%)	1	20%	86	289	8	38	3	-69	269
	B	Gas(86%)	1	0%	98	298	7	43	3	-73	277
	A	Gas(86%)	1	0%	102*	279	7	44	3	-68	264
Sec. School – 30 year calc	C	GSHP+SHW	3	40%	41	608	17	11	6	-79	562
	C	GSHP	3	40%	46	540	17	12	6	-72	503
	C	Gas(86%)	3	40%	52	483	17	11	8	-65	454
	C	Gas(86%)	2	40%	56	474	17	14	8	-66	445
	B	Gas(86%)	3	40%	59	454	17	13	8	-62	429
	A	Gas(86%)	2	40%	67	427	17	17	9	-61	408
	A	Gas(86%)	1	40%	79	394	17	25	9	-57	388
	A	Gas(86%)	1	20%	104	380	15	38	10	-56	386
	A	Gas(86%)	2	0%	117	396	13	42	10	-57	403
	A	Gas(86%)	1	0%	128*	363	13	50	10	-53	382
Hospital – 30 year calc	C	GSHP+SHW	3	40%	188	491	11	103	10	-62	553
	B	GSHP+SHW	3	40%	189	475	11	104	10	-61	539
	B	GSHP	3	40%	190	451	11	104	10	-59	517
	A	GSHP	3	40%	195	439	11	107	10	-57	509
	B	Gas CHP	3	40%	206	431	33	71	21	-57	499
	A	Gas CHP	3	40%	212	419	33	72	22	-55	490
	A	Gas CHP	1	40%	252	365	33	100	23	-51	469
	A	Gas CHP	1	20%	261	360	32	105	23	-51	469
	A	Gas(86%)	1	40%	284	342	11	130	19	-48	454
	A	Gas(86%)	1	0%	302*	331	9	140	20	-47	453

Table 11.9b: Macroeconomic Costs (Low energy price, 3.5% discount factors, £/m² cont ….

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Hotel – 20 year calc	C	GSHP+SHW	3	40%	319	528	8	104	12	-91	562
	B	GSHP+SHW	3	40%	324	494	8	107	13	-85	537
	B	Gas(91%)+SHW	3	40%	356	462	8	104	15	-85	505
	B	Gas(91%)+SHW	2	40%	377	439	8	115	16	-85	493
	B	Gas(86%)	2	40%	393	430	8	118	17	-85	488
	A	Gas(86%)	2	40%	418	407	8	127	17	-80	480
	A	Gas(86%)	2	0%	428*	402	7	131	18	-79	478
	B	Gas(86%)	1	40%	479	399	8	158	19	-85	499
	B	Gas(86%)	1	0%	489	394	7	161	19	-85	497
	A	Gas(86%)	1	0%	523	371	7	175	20	-79	494
Whs (Dist.) – 20 year calc	C	GSHP+SHW	3	40%	-34	807	15	-7	0	-178	636
	C	GSHP	3	40%	-25	716	14	-6	0	-178	546
	B	GSHP	2	40%	-13	658	14	0	0	-167	506
	A	GSHP	2	40%	-2	632	14	6	1	-159	493
	B	Gas(86%)	2	40%	19	629	14	-3	3	-167	477
	A	Gas(86%)	2	40%	42	603	14	2	4	-159	464
	B	Gas(86%)	2	20%	68	606	11	16	4	-165	471
	A	Gas(86%)	2	20%	91	580	11	20	5	-158	459
	A	Gas(86%)	2	0%	139*	553	7	38	6	-156	449
	A	Gas(86%)	1	0%	188	537	7	66	7	-156	462
Whs (Retail) – 20 year calc	C	GSHP+SHW	3	40%	48	873	18	36	1	-171	757
	C	GSHP	3	40%	49	782	17	36	1	-171	665
	B	GSHP	3	40%	53	756	17	38	1	-165	647
	B	Gas(86%)	3	40%	75	716	17	36	3	-165	607
	A	Gas(86%)	3	40%	87	696	17	39	4	-159	596
	A	Gas(86%)	2	40%	105	673	17	48	4	-159	583
	A	Gas(86%)	2	20%	154	650	14	66	5	-158	577
	A	Gas(86%)	2	0%	202*	622	10	84	6	-156	567
	A	Gas(86%)	1	40%	227	648	17	110	6	-159	622
	A	Gas(86%)	1	20%	276	625	14	128	7	-158	617

Table 11.9c: Macroeconomic Costs (High energy price, 3.5% discount rate, £/m²)

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Office (AC) – 20 year calc	B	GSHP+SHW	3	40%	82	394	5	53	2	-57	397
	B	GSHP	3	40%	83	385	5	54	2	-57	389
	B	Gas(86%)	3	40%	89	359	5	55	2	-57	366
	A	Gas(86%)	3	40%	98	342	5	60	3	-53	357
	A	Gas(86%)	3	0%	108*	336	5	65	3	-52	356
	A	Gas(86%)	2	40%	119	330	5	74	3	-53	359
	A	Gas(86%)	2	0%	129	324	5	79	3	-52	358
	B	Gas(86%)	1	40%	160	317	5	100	4	-57	370
	B	Gas(86%)	1	0%	170	311	5	105	4	-56	369
	A	Gas(86%)	1	40%	175	299	5	109	4	-53	365
Office (NV) – 20 year calc	C	GSHP+SHW	3	40%	11	437	9	12	0	-83	377
	C	GSHP	3	40%	14	406	9	14	0	-83	347
	A	GSHP	3	40%	21	354	9	19	0	-69	312
	A	GSHP	2	40%	26	348	9	22	1	-69	310
	A	Gas(86%)	3	40%	36	327	9	22	2	-69	290
	A	Gas(86%)	2	20%	57	312	8	33	2	-69	287
	A	Gas(86%)	2	0%	73	302	7	41	2	-68	285
	A	Gas(86%)	1	20%	86	289	8	53	3	-69	283
	B	Gas(86%)	1	0%	98	298	7	58	3	-73	293
	A	Gas(86%)	1	0%	102*	279	7	60	3	-68	281
Sec. School – 30 year calc	C	GSHP+SHW	3	40%	41	608	17	28	6	-79	580
	C	GSHP	3	40%	46	540	17	31	6	-72	522
	C	Gas(86%)	3	40%	52	483	17	33	8	-65	475
	C	Gas(86%)	2	40%	56	474	17	36	8	-66	467
	B	Gas(86%)	3	40%	59	454	17	37	8	-62	453
	A	Gas(86%)	2	40%	67	427	17	42	9	-61	434
	A	Gas(86%)	1	40%	79*	394	17	52	9	-57	415
	A	Gas(86%)	1	20%	104	380	15	68	10	-56	417
	A	Gas(86%)	2	0%	117	396	13	73	10	-57	435
	A	Gas(86%)	1	0%	128	363	13	83	10	-53	416
Hospital – 30 year calc	C	GSHP+SHW	3	40%	188	491	11	144	10	-62	594
	B	GSHP+SHW	3	40%	189	475	11	145	10	-61	580
	B	GSHP	3	40%	190	451	11	146	10	-59	559
	A	GSHP	3	40%	195	439	11	150	10	-57	552
	A	GSHP	2	40%	210	426	11	162	10	-58	550
	A	GSHP	1	40%	236	385	11	183	11	-53	537
	A	Gas(86%)	3	20%	253	391	10	172	19	-52	539
	A	Gas(86%)	2	40%	258	383	11	178	19	-53	537
	A	Gas(86%)	1	40%	284*	342	11	200	19	-48	524
	A	Gas(86%)	1	0%	302	331	9	211	20	-47	524

Table 11.9c: Macroeconomic Costs (High energy price, 3.5% discount rate, £/m²) cont …

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Hotel – 20 year calc	C	GSHP+SHW	3	40%	319	528	8	166	12	-91	624
	B	GSHP+SHW	3	40%	324	494	8	169	13	-85	600
	B	Gas(91%)+SHW	3	40%	356	462	8	177	15	-85	577
	B	Gas(91%)+SHW	2	40%	377	439	8	191	16	-85	569
	B	Gas (86%)	2	40%	393	430	8	198	17	-85	567
	A	Gas (86%)	2	40%	418	407	8	211	17	-80	564
	A	Gas (86%)	2	0%	428*	402	7	216	18	-79	563
	B	Gas (86%)	1	40%	479	399	8	250	19	-85	591
	B	Gas (86%)	1	0%	489	394	7	255	19	-85	590
	A	Gas (86%)	1	0%	523	371	7	274	20	-79	593
Whs (Dist.) – 20 year calc	C	GSHP+SHW	3	40%	-34	807	15	-8	0	-178	636
	C	GSHP	3	40%	-25	716	14	-4	0	-178	548
	B	GSHP	2	40%	-13	658	14	3	0	-167	509
	A	GSHP	2	40%	-2	632	14	10	1	-159	498
	B	Gas(86%)	2	40%	19	629	14	11	3	-167	490
	A	Gas(86%)	2	40%	42	603	14	21	4	-159	483
	B	Gas(86%)	2	20%	68	606	11	34	4	-165	490
	A	Gas(86%)	2	20%	91	580	11	44	5	-158	483
	A	Gas(86%)	2	0%	139*	553	7	67	6	-156	478
	A	Gas(86%)	1	0%	188	537	7	101	7	-156	496
Whs (Retail) – 20 year calc	C	GSHP+SHW	3	40%	48	873	18	46	1	-171	767
	C	GSHP	3	40%	49	782	17	46	1	-171	675
	B	GSHP	3	40%	53	756	17	49	1	-165	658
	B	Gas(86%)	3	40%	75	716	17	54	3	-165	625
	A	Gas(86%)	3	40%	87	696	17	59	4	-159	616
	A	Gas(86%)	2	40%	105	673	17	71	4	-159	606
	A	Gas(86%)	2	20%	154	650	14	94	5	-158	605
	A	Gas(86%)	2	0%	202*	622	10	118	6	-156	601
	A	Gas(86%)	1	40%	227	648	17	150	6	-159	662
	A	Gas(86%)	1	20%	276	625	14	173	7	-158	662

Table 11.9d: Macroeconomic Costs (Central energy price, 3% discount rate, £/m²)

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Office (AC) – 20 year calc	B	GSHP+SHW	3	40%	82	394	6	50	2	-62	389
	B	GSHP	3	40%	83	385	5	50	2	-62	380
	B	Gas(86%)	3	40%	89	359	5	51	2	-62	355
	A	Gas(86%)	3	40%	98	342	5	55	3	-58	347
	A	Gas(86%)	3	0%	108*	336	5	59	3	-58	346
	A	Gas(86%)	2	40%	119	330	5	67	3	-58	348
	A	Gas(86%)	2	0%	129	324	5	72	3	-58	347
	B	Gas(86%)	1	40%	160	317	5	92	4	-62	356
	B	Gas(86%)	1	0%	170	311	5	97	4	-62	355
	A	Gas(86%)	1	40%	175	299	5	101	4	-58	352
Office (NV) – 20 year calc	C	GSHP+SHW	3	40%	11	437	10	12	0	-91	368
	C	GSHP	3	40%	14	406	9	13	0	-91	339
	A	GSHP	3	40%	21	354	9	17	0	-76	305
	A	GSHP	2	40%	26	348	9	20	1	-76	302
	A	Gas(86%)	3	40%	36	327	9	18	2	-76	280
	A	Gas(86%)	2	20%	57	312	8	29	2	-75	276
	A	Gas(86%)	2	0%	73	302	7	36	3	-75	273
	A	Gas(86%)	1	20%	86	289	8	47	3	-75	272
	B	Gas(86%)	1	0%	98	298	7	53	3	-80	281
	A	Gas(86%)	1	0%	102*	279	7	54	3	-75	269
Sec. School – 30 year calc	C	GSHP+SHW	3	40%	41	618	18	20	7	-91	571
	C	GSHP	3	40%	46	547	18	22	7	-82	512
	C	Gas(86%)	3	40%	52	489	18	22	8	-75	462
	C	Gas(86%)	2	40%	56	480	18	26	8	-76	455
	B	Gas(86%)	3	40%	59	459	18	25	9	-72	440
	A	Gas(86%)	2	40%	67	434	18	30	10	-71	420
	A	Gas(86%)	1	40%	79	399	18	40	10	-66	401
	A	Gas(86%)	1	20%	104	384	16	55	11	-64	402
	A	Gas(86%)	2	0%	117	401	14	60	11	-66	420
	A	Gas(86%)	1	0%	128*	367	14	70	11	-61	400
Hospital – 30 year calc	C	GSHP+SHW	3	40%	188	500	12	131	10	-72	582
	B	GSHP+SHW	3	40%	189	484	12	132	10	-71	567
	B	GSHP	3	40%	190	459	12	132	11	-68	546
	A	GSHP	3	40%	195	446	12	136	11	-66	539
	A	GSHP	2	40%	210	433	12	148	11	-67	537
	A	Gas(86%)	3	40%	244	402	12	142	20	-61	515
	A	Gas(86%)	3	20%	253	397	11	147	20	-60	515
	A	Gas(86%)	2	40%	258	389	12	153	20	-61	513
	A	Gas(86%)	1	40%	284	347	12	174	21	-56	498
	A	Gas(86%)	1	0%	302*	336	10	185	22	-54	498

Table 11.9d: Macroeconomic Costs (Central energy price, 3% discount rate, £/m²) cont …

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Hotel – 20 year calc	C	GSHP+SHW	3	40%	319	528	8	140	13	-100	590
	B	GSHP+SHW	3	40%	324	494	8	143	13	-93	566
	B	Gas(91%)+SHW	3	40%	356	462	8	145	16	-93	539
	B	Gas(91%)+SHW	2	40%	377	439	8	158	17	-93	529
	B	Gas(86%)	2	40%	393	430	8	163	18	-93	526
	A	Gas(86%)	2	40%	418	407	8	175	18	-87	521
	A	Gas(86%)	2	0%	428*	402	8	179	19	-87	520
	B	Gas(86%)	1	40%	479	399	8	211	20	-93	545
	B	Gas(86%)	1	0%	489	394	8	215	20	-93	544
	A	Gas(86%)	1	0%	523	371	8	233	21	-87	545
Whs (Dist.) – 20 year calc	C	GSHP+SHW	3	40%	-34	807	15	-8	0	-195	619
	C	GSHP	3	40%	-25	716	14	-5	0	-195	530
	B	GSHP	2	40%	-13	658	14	2	0	-183	492
	A	GSHP	2	40%	-2	632	14	8	1	-174	481
	B	Gas(86%)	2	40%	19	629	14	4	3	-183	468
	A	Gas(86%)	2	40%	42	603	14	11	4	-174	459
	B	Gas(86%)	2	20%	68	606	11	25	4	-181	466
	A	Gas(86%)	2	20%	91	580	11	33	5	-173	457
	A	Gas(86%)	2	0%	139*	553	8	55	7	-171	451
	A	Gas(86%)	1	0%	188	537	8	86	7	-171	468
Whs (Retail) – 20 year calc	C	GSHP+SHW	3	40%	48	873	18	43	1	-187	748
	C	GSHP	3	40%	49	782	17	43	1	-187	656
	B	GSHP	3	40%	53	756	17	45	1	-181	639
	B	Gas(86%)	3	40%	75	716	17	47	3	-181	603
	A	Gas(86%)	3	40%	87	696	17	51	4	-174	593
	A	Gas(86%)	2	40%	105	673	17	62	4	-174	582
	A	Gas(86%)	2	20%	154	650	14	84	5	-173	580
	A	Gas(86%)	2	0%	202*	622	11	105	6	-171	574
	A	Gas(86%)	1	40%	227	648	17	135	7	-174	633
	A	Gas(86%)	1	20%	276	625	14	157	8	-173	632

Table 11.9e: Macroeconomic Costs (Central energy price, 3.5% discount rate, Alternative Cost of Carbon, £/m²)

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Office (AC) – 20 year calc	B	GSHP+SHW	3	40%	82	394	5	47	4	-57	394
	B	GSHP	3	40%	83	385	5	48	4	-57	385
	B	Gas(86%)	3	40%	89	359	5	48	6	-57	362
	A	Gas(86%)	3	40%	98	342	5	53	7	-53	354
	A	Gas(86%)	3	0%	108*	336	5	57	7	-52	352
	A	Gas(86%)	2	40%	119	330	5	65	8	-53	354
	A	Gas(86%)	2	0%	129	324	5	69	8	-52	353
	B	Gas(86%)	1	40%	160	317	5	89	9	-57	363
	B	Gas(86%)	1	0%	170	311	5	93	9	-56	362
	A	Gas(86%)	1	40%	175	299	5	96	10	-53	358
Office (NV) – 20 year calc	C	GSHP+SHW	3	40%	11	437	9	11	0	-83	376
	C	GSHP	3	40%	14	406	9	13	1	-83	346
	A	GSHP	3	40%	21	354	9	17	1	-69	311
	A	GSHP	2	40%	26	348	9	19	1	-69	308
	A	Gas(86%)	3	40%	36	327	9	18	6	-69	290
	A	Gas(86%)	2	20%	57	312	8	28	6	-69	286
	A	Gas(86%)	2	0%	73	302	7	35	7	-68	283
	A	Gas(86%)	1	20%	86	289	8	45	7	-69	280
	B	Gas(86%)	1	0%	98	298	7	51	7	-73	289
	A	Gas(86%)	1	0%	102*	279	7	52	8	-68	278
Sec. School – 30 year calc	C	GSHP+SHW	3	40%	41	608	17	18	18	-79	582
	C	GSHP	3	40%	46	540	17	20	19	-72	524
	C	Gas(86%)	3	40%	52	483	17	21	22	-65	478
	C	Gas(86%)	2	40%	56	474	17	24	22	-66	470
	B	Gas(86%)	3	40%	59	454	17	24	24	-62	456
	A	Gas(86%)	2	40%	67	427	17	29	26	-61	437
	A	Gas(86%)	1	40%	79	394	17	38	26	-57	417
	A	Gas(86%)	1	20%	104	380	15	52	28	-56	418
	A	Gas(86%)	2	0%	117	396	13	56	29	-57	436
	A	Gas(86%)	1	0%	128*	363	13	65	29	-53	417
Hospital – 30 year calc	C	GSHP+SHW	3	40%	188	491	11	123	25	-62	589
	B	GSHP+SHW	3	40%	189	475	11	124	25	-61	574
	B	GSHP	3	40%	190	451	11	125	26	-59	553
	A	GSHP	3	40%	195	439	11	128	26	-57	546
	A	GSHP	2	40%	210	426	11	139	27	-58	544
	A	GSHP	1	40%	236	385	11	158	28	-53	529
	A	GSHP	1	20%	245	380	10	163	29	-52	530
	A	GSHP	1	0%	253	374	9	169	29	-52	529
	A	Gas(86%)	1	40%	284	342	11	163	53	-48	521
	A	Gas(86%)	1	0%	302*	331	9	174	54	-47	521

Table 11.9e: Macroeconomic Costs (Central energy price, 3.5% discount rate, Alternative Cost of Carbon, £/m²) cont…

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Hotel – 20 year calc	C	GSHP+SHW	3	40%	319	528	8	134	41	-91	620
	B	GSHP+SHW	3	40%	324	494	8	137	41	-85	596
	B	Gas(91%)+SHW	3	40%	356	462	8	139	52	-85	576
	B	Gas(91%)+SHW	2	40%	377	439	8	151	52	-85	566
	B	Gas(86%)	2	40%	393	430	8	156	55	-85	564
	A	Gas(86%)	2	40%	418	407	8	167	58	-80	561
	A	Gas(86%)	2	0%	428*	402	7	171	58	-79	559
	B	Gas(86%)	1	40%	479	399	8	202	61	-85	585
	B	Gas(86%)	1	0%	489	394	7	206	61	-85	584
	A	Gas(86%)	1	0%	523	371	7	223	64	-79	586
Whs (Dist.) – 20 year calc	C	GSHP+SHW	3	40%	-34	807	15	-8	0	-178	636
	C	GSHP	3	40%	-25	716	14	-5	2	-178	548
	B	GSHP	2	40%	-13	658	14	1	2	-167	509
	A	GSHP	2	40%	-2	632	14	8	3	-159	498
	B	Gas(86%)	2	40%	19	629	14	3	13	-167	492
	A	Gas(86%)	2	40%	42	603	14	11	17	-159	485
	B	Gas(86%)	2	20%	68	606	11	24	15	-165	491
	A	Gas(86%)	2	20%	91	580	11	31	19	-158	484
	A	Gas(86%)	2	0%	139*	553	7	52	21	-156	478
	A	Gas(86%)	1	0%	188	537	7	83	22	-156	493
Whs (Retail) – 20 year calc	C	GSHP+SHW	3	40%	48	873	18	41	2	-171	763
	C	GSHP	3	40%	49	782	17	41	2	-171	672
	B	GSHP	3	40%	53	756	17	43	3	-165	654
	B	Gas(86%)	3	40%	75	716	17	45	10	-165	623
	A	Gas(86%)	3	40%	87	696	17	49	12	-159	614
	A	Gas(86%)	2	40%	105	673	17	59	12	-159	602
	A	Gas(86%)	2	20%	154	650	14	80	15	-158	601
	A	Gas(86%)	2	0%	202*	622	10	101	17	-156	594
	A	Gas(86%)	1	40%	227	648	17	130	17	-159	653
	A	Gas(86%)	1	20%	276	625	14	151	19	-158	651

Table 11.10a: Financial Costs (Central energy price, 6% discount factors, £/m²)

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Office (AC) – 20 year calc	B	GSHP+SHW	3	40%	82	473	5	73	-	-43	508
	B	GSHP	3	40%	83	461	5	74	-	-43	497
	B	Gas(86%)	3	40%	89	431	5	74	-	-43	467
	A	Gas(86%)	3	40%	98	410	5	80	-	-40	455
	A	Gas(86%)	3	0%	108*	403	4	86	-	-40	454
	A	Gas(86%)	2	40%	119	396	5	99	-	-40	459
	A	Gas(86%)	2	0%	129	389	4	104	-	-40	458
	B	Gas(86%)	1	40%	160	380	5	135	-	-43	477
	B	Gas(86%)	1	0%	170	373	4	141	-	-43	476
	A	Gas(86%)	1	40%	175	359	5	147	-	-40	471
Office (NV) – 20 year calc	C	GSHP+SHW	3	40%	11	525	9	20	-	-63	491
	C	GSHP	3	40%	14	488	9	23	-	-63	456
	A	GSHP	3	40%	21	425	9	28	-	-53	409
	A	GSHP	2	40%	26	417	9	33	-	-53	406
	A	Gas(86%)	3	40%	36	392	9	29	-	-53	377
	A	Gas(86%)	2	20%	57	375	8	43	-	-52	373
	A	Gas(86%)	2	0%	73	363	7	52	-	-52	369
	A	Gas(86%)	1	20%	86	347	8	69	-	-52	371
	B	Gas(86%)	1	0%	98	358	7	77	-	-56	385
	A	Gas(86%)	1	0%	102*	335	7	79	-	-52	368
Sec. School – 30 year calc	C	GSHP+SHW	3	40%	41	686	16	29	-	-48	683
	C	GSHP	3	40%	46	614	15	31	-	-43	618
	C	Gas(86%)	3	40%	52	555	15	32	-	-39	562
	C	Gas(86%)	2	40%	56	541	15	36	-	-40	552
	B	Gas(86%)	3	40%	59	519	15	35	-	-37	532
	A	Gas(86%)	2	40%	67	486	15	42	-	-37	506
	A	Gas(86%)	1	40%	79	451	15	55	-	-34	486
	A	Gas(86%)	1	20%	104	435	13	72	-	-33	487
	A	Gas(86%)	2	0%	117	451	12	75	-	-35	504
	A	Gas(86%)	1	0%	128*	416	12	88	-	-32	484
Hospital – 30 year calc	C	GSHP+SHW	3	40%	188	552	10	112	-	-37	637
	B	GSHP+SHW	3	40%	189	533	10	113	-	-37	619
	B	GSHP	3	40%	190	507	10	113	-	-35	595
	A	GSHP	3	40%	195	492	10	117	-	-34	584
	A	Gas CHP	3	40%	212	471	30	98	-	-33	566
	A	Gas(86%)	3	40%	244	447	10	121	-	-32	546
	A	Gas CHP	1	40%	252	412	30	126	-	-31	537
	A	Gas(86%)	2	40%	258	430	10	131	-	-32	539
	A	Gas(86%)	1	40%	284	388	10	149	-	-29	517
	A	Gas(86%)	1	0%	302*	376	9	157	-	-28	513

Table 11.10a: Financial Costs (Central energy price, 6% discount factors, £/m²) cont…

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Hotel – 20 year calc	C	GSHP+SHW	3	40%	319	634	8	198	-	-70	771
	B	GSHP+SHW	3	40%	324	593	8	203	-	-65	739
	B	Gas(91%)+SHW	3	40%	356	555	8	203	-	-65	701
	B	Gas(91%)+SHW	2	40%	377	527	8	223	-	-65	693
	B	Gas(86%)	2	40%	393	516	8	229	-	-65	688
	A	Gas(86%)	2	40%	418	489	8	246	-	-61	682
	A	Gas(86%)	2	0%	428*	482	7	251	-	-61	680
	B	Gas(86%)	1	40%	479	479	8	299	-	-65	721
	B	Gas(86%)	1	0%	489	473	7	305	-	-65	720
	A	Gas(86%)	1	0%	523	445	7	329	-	-61	721
Whs (Dist.) – 20 year calc	C	GSHP+SHW	3	40%	-34	969	14	-3	-	-136	844
	C	GSHP	3	40%	-25	860	13	0	-	-136	737
	B	GSHP	2	40%	-13	790	13	10	-	-127	687
	A	Gas CHP	2	40%	4	749	33	-4	-	-121	657
	B	Gas(86%)	2	40%	19	755	13	11	-	-127	653
	A	Gas(86%)	2	40%	42	724	13	21	-	-121	638
	B	Gas(86%)	2	20%	68	728	11	39	-	-126	651
	A	Gas(86%)	2	20%	91	697	11	49	-	-120	636
	A	Gas(86%)	2	0%	139*	663	7	76	-	-119	628
	A	Gas(86%)	1	0%	188	645	7	123	-	-119	656
Whs (Retail) – 20 year calc	C	GSHP+SHW	3	40%	48	1047	17	71	-	-130	1006
	C	GSHP	3	40%	49	938	16	71	-	-130	896
	B	GSHP	3	40%	53	907	16	75	-	-126	872
	B	Gas(86%)	3	40%	75	860	16	76	-	-126	826
	A	Gas(86%)	3	40%	87	835	16	81	-	-121	811
	A	Gas(86%)	2	40%	105	807	16	97	-	-121	800
	A	Gas(86%)	2	20%	154	780	13	124	-	-120	798
	A	Gas(86%)	2	0%	202*	747	10	152	-	-119	790
	A	Gas(86%)	1	40%	227	778	16	205	-	-121	877
	A	Gas(86%)	1	20%	276	750	13	232	-	-120	875

Table 11.10b: Financial Costs (Low energy price, 6% discount factors, £/m²)

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Office (AC) – 20 year calc	B	GSHP+SHW	3	40%	82	473	5	66	-	-43	500
	B	GSHP	3	40%	83	461	5	66	-	-43	490
	B	Gas(86%)	3	40%	89	431	5	66	-	-43	459
	A	Gas(86%)	3	40%	98	410	5	71	-	-40	446
	A	Gas(86%)	3	0%	108*	403	4	76	-	-40	444
	A	Gas(86%)	2	40%	119	396	5	88	-	-40	448
	A	Gas(86%)	2	0%	129	389	4	93	-	-40	447
	B	Gas(86%)	1	40%	160	380	5	121	-	-43	463
	B	Gas(86%)	1	0%	170	373	4	126	-	-43	461
	A	Gas(86%)	1	40%	175	359	5	132	-	-40	456
Office (NV) – 20 year calc	C	GSHP+SHW	3	40%	11	525	9	18	-	-63	489
	C	GSHP	3	40%	14	488	9	20	-	-63	453
	A	GSHP	3	40%	21	425	9	25	-	-53	405
	A	GSHP	2	40%	26	417	9	29	-	-53	402
	A	Gas(86%)	3	40%	36	392	9	24	-	-53	372
	A	Gas(86%)	2	20%	57	375	8	36	-	-52	366
	A	Gas(86%)	2	0%	73	363	7	45	-	-52	362
	A	Gas(86%)	1	20%	86	347	8	61	-	-52	363
	B	Gas(86%)	1	0%	98	358	7	68	-	-56	377
	A	Gas(86%)	1	0%	102*	335	7	69	-	-52	359
Sec. School – 30 year calc	C	GSHP+SHW	3	40%	41	686	16	20	-	-48	674
	C	GSHP	3	40%	46	614	15	22	-	-43	608
	C	Gas(86%)	3	40%	52	555	15	21	-	-39	551
	C	Gas(86%)	2	40%	56	541	15	25	-	-40	541
	B	Gas(86%)	3	40%	59	519	15	24	-	-37	520
	A	Gas(86%)	2	40%	67	486	15	29	-	-37	493
	A	Gas(86%)	1	40%	79	451	15	41	-	-34	473
	A	Gas(86%)	1	20%	104	435	13	57	-	-33	472
	A	Gas(86%)	2	0%	117	451	12	61	-	-35	489
	A	Gas(86%)	1	0%	128*	416	12	73	-	-32	469
Hospital – 30 year calc	C	GSHP+SHW	3	40%	188	552	10	94	-	-37	618
	B	GSHP+SHW	3	40%	189	533	10	94	-	-37	600
	B	GSHP	3	40%	190	507	10	94	-	-35	576
	A	GSHP	3	40%	195	492	10	97	-	-34	565
	B	Gas CHP	3	40%	206	486	30	66	-	-34	548
	A	Gas CHP	3	40%	212	471	30	68	-	-33	535
	A	Gas(86%)	3	40%	244	447	10	93	-	-32	519
	A	Gas CHP	1	40%	252	412	30	93	-	-31	503
	A	Gas(86%)	1	40%	284	388	10	118	-	-29	486
	A	Gas(86%)	1	0%	302*	376	9	126	-	-28	482

Table 11.10b: Financial Costs (Low energy price, 6% discount factors, £/m²) cont …

Hotel – 20 year calc	C	GSHP+SHW	3	40%	319	634	8	165	-	-70	738
	B	GSHP+SHW	3	40%	324	593	8	170	-	-65	706
	B	Gas(91%)+SHW	3	40%	356	555	8	165	-	-65	663
	B	Gas(91%)+SHW	2	40%	377	527	8	183	-	-65	653
	B	Gas(86%)	2	40%	393	516	8	188	-	-65	647
	A	Gas(86%)	2	40%	418	489	8	202	-	-61	637
	A	Gas(86%)	2	0%	428*	482	7	207	-	-61	636
	B	Gas(86%)	1	40%	479	479	8	250	-	-65	672
	B	Gas(86%)	1	0%	489	473	7	255	-	-65	670
	A	Gas(86%)	1	0%	523	445	7	276	-	-61	668
Whs (Dist.) – 20 year calc	C	GSHP+SHW	3	40%	-34	969	14	-5	-	-136	842
	C	GSHP	3	40%	-25	860	13	-2	-	-136	735
	B	Gas CHP	3	40%	-14	798	33	-21	-	-127	684
	A	Gas CHP	2	40%	4	749	33	-15	-	-121	646
	B	Gas(86%)	2	40%	19	755	13	3	-	-127	644
	A	Gas(86%)	2	40%	42	724	13	10	-	-121	627
	B	Gas(86%)	2	20%	68	728	11	28	-	-126	640
	A	Gas(86%)	2	20%	91	697	11	36	-	-120	623
	A	Gas(86%)	2	0%	139*	663	7	61	-	-119	613
	A	Gas(86%)	1	0%	188	645	7	104	-	-119	637
Whs (Retail) – 20 year calc	C	GSHP+SHW	3	40%	48	1047	17	63	-	-130	998
	C	GSHP	3	40%	49	938	16	63	-	-130	888
	B	GSHP	3	40%	53	907	16	66	-	-126	864
	B	Gas(86%)	3	40%	75	860	16	64	-	-126	814
	A	Gas(86%)	3	40%	87	835	16	68	-	-121	798
	A	Gas(86%)	2	40%	105	807	16	83	-	-121	785
	A	Gas(86%)	2	20%	154	780	13	108	-	-120	781
	A	Gas(86%)	2	0%	202*	747	10	133	-	-119	771
	A	Gas(86%)	1	40%	227	778	16	180	-	-121	853
	A	Gas(86%)	1	20%	276	750	13	205	-	-120	849

Table 11.10c: Financial Costs (High energy price, 6% discount factors, £/m²)

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Office (AC) – 20 year calc	B	GSHP+SHW	3	40%	82	473	5	80	-	-43	515
	B	GSHP	3	40%	83	461	5	81	-	-43	504
	B	Gas(86%)	3	40%	89	431	5	82	-	-43	475
	A	Gas(86%)	3	40%	98	410	5	89	-	-40	464
	A	Gas(86%)	3	0%	108*	403	4	95	-	-40	463
	A	Gas(86%)	2	40%	119	396	5	109	-	-40	470
	A	Gas(86%)	2	0%	129	389	4	115	-	-40	469
	B	Gas(86%)	1	40%	160	380	5	149	-	-43	491
	B	Gas(86%)	1	0%	170	373	4	155	-	-43	490
	A	Gas(86%)	1	40%	175	359	5	162	-	-40	486
Office (NV) – 20 year calc	C	GSHP+SHW	3	40%	11	525	9	22	-	-63	493
	C	GSHP	3	40%	14	488	9	25	-	-63	458
	A	GSHP	3	40%	21	425	9	31	-	-53	412
	A	GSHP	2	40%	26	417	9	36	-	-53	409
	A	Gas(86%)	3	40%	36	392	9	35	-	-53	383
	A	Gas(86%)	2	20%	57	375	8	49	-	-52	379
	A	Gas(86%)	2	0%	73*	363	7	59	-	-52	377
	A	Gas(86%)	1	20%	86	347	8	78	-	-52	380
	B	Gas(86%)	1	0%	98	358	7	85	-	-56	394
	A	Gas(86%)	1	0%	102	335	7	88	-	-52	377
Sec. School – 30 year calc	C	GSHP+SHW	3	40%	41	686	16	39	-	-48	693
	C	GSHP	3	40%	46	614	15	43	-	-43	629
	C	Gas(86%)	3	40%	52	555	15	44	-	-39	575
	C	Gas(86%)	2	40%	56	541	15	49	-	-40	565
	B	Gas(86%)	3	40%	59	519	15	49	-	-37	545
	A	Gas(86%)	2	40%	67	486	15	57	-	-37	521
	A	Gas(86%)	1	40%	79*	451	15	70	-	-34	502
	A	Gas(86%)	1	20%	104	435	13	88	-	-33	504
	A	Gas(86%)	2	0%	117	451	12	92	-	-35	521
	A	Gas(86%)	1	0%	128	416	12	106	-	-32	502
Hospital – 30 year calc	C	GSHP+SHW	3	40%	188	552	10	132	-	-37	657
	B	GSHP+SHW	3	40%	189	533	10	132	-	-37	638
	B	GSHP	3	40%	190	507	10	133	-	-35	615
	A	GSHP	3	40%	195	492	10	137	-	-34	604
	A	GSHP	2	40%	210	476	10	148	-	-35	598
	A	GSHP	1	40%	236	433	10	168	-	-32	579
	A	Gas(86%)	3	20%	253	442	9	156	-	-31	576
	A	Gas(86%)	2	40%	258	430	10	162	-	-32	570
	A	Gas(86%)	1	40%	284	388	10	182	-	-29	551
	A	Gas(86%)	1	0%	302*	376	9	191	-	-28	547

Table 11.10c: Financial Costs (High energy price, 6% discount factors, £/m²) cont …

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Hotel – 20 year calc	C	GSHP+SHW	3	40%	319	634	8	234	-	-70	806
	B	GSHP+SHW	3	40%	324	593	8	239	-	-65	775
	B	Gas(91%)+SHW	3	40%	356	555	8	245	-	-65	743
	A	Gas(91%)+SHW	3	40%	376	527	8	260	-	-61	735
	B	Gas(86%)	2	40%	393	516	8	275	-	-65	734
	A	Gas(86%)	2	40%	418	489	8	294	-	-61	730
	A	Gas(86%)	2	0%	428*	482	7	300	-	-61	729
	B	Gas(86%)	1	40%	479	479	8	352	-	-65	774
	B	Gas(86%)	1	0%	489	473	7	358	-	-65	773
	A	Gas(86%)	1	0%	523	445	7	386	-	-61	778
Whs (Dist.) – 20 year calc	C	GSHP+SHW	3	40%	-34	969	14	-2	-	-136	846
	C	GSHP	3	40%	-25	860	13	3	-	-136	740
	B	GSHP	3	40%	-19	809	13	9	-	-127	704
	B	GSHP	2	40%	-13	790	13	14	-	-127	690
	A	GSHP	2	40%	-2	759	13	25	-	-121	676
	A	Gas(86%)	2	40%	42	724	13	34	-	-121	650
	B	Gas(86%)	2	20%	68	728	11	50	-	-126	662
	A	Gas(86%)	2	20%	91	697	11	63	-	-120	650
	A	Gas(86%)	2	0%	139*	663	7	92	-	-119	644
	A	Gas(86%)	1	0%	188	645	7	143	-	-119	676
Whs (Retail) – 20 year calc	C	GSHP+SHW	3	40%	48	1047	17	79	-	-130	1013
	C	GSHP	3	40%	49	938	16	79	-	-130	904
	B	GSHP	3	40%	53	907	16	83	-	-126	881
	B	Gas(86%)	3	40%	75	860	16	88	-	-126	838
	A	Gas(86%)	3	40%	87	835	16	94	-	-121	824
	A	Gas(86%)	2	40%	105	807	16	112	-	-121	815
	A	Gas(86%)	2	20%	154	780	13	142	-	-120	815
	A	Gas(86%)	2	0%	202*	747	10	171	-	-119	809
	A	Gas(86%)	1	40%	227	778	16	229	-	-121	902
	A	Gas(86%)	1	20%	276	750	13	258	-	-120	902

Table 11.10d: Financial Costs (Central energy price, 10% discount factors, £/m²)

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Office (AC) – 20 year calc	B	GSHP+SHW	3	40%	82	473	4	55	-	-21	510
	B	GSHP	3	40%	83	461	4	56	-	-21	500
	B	Gas(86%)	3	40%	89	431	4	56	-	-21	469
	A	Gas(86%)	3	40%	98	410	4	61	-	-20	455
	A	Gas(86%)	3	0%	108	403	3	65	-	-20	452
	A	Gas(86%)	2	40%	119	396	4	75	-	-20	454
	A	Gas(86%)	2	0%	129*	389	3	79	-	-20	451
	B	Gas(86%)	1	40%	160	380	4	102	-	-21	465
	B	Gas(86%)	1	0%	170	373	3	106	-	-21	462
	A	Gas(86%)	1	40%	175	359	4	111	-	-20	454
Office (NV) – 20 year calc	C	GSHP+SHW	3	40%	11	525	7	15	-	-31	516
	C	GSHP	3	40%	14	488	6	17	-	-31	480
	A	GSHP	3	40%	21	425	6	21	-	-26	426
	A	GSHP	2	40%	26	417	6	25	-	-26	422
	A	Gas(86%)	3	40%	36	392	6	22	-	-26	394
	A	Gas(86%)	2	20%	57	375	6	32	-	-26	387
	A	Gas(86%)	2	0%	73	363	5	39	-	-26	381
	A	Gas(86%)	1	20%	86	347	6	52	-	-26	379
	B	Gas(86%)	1	0%	98	358	5	58	-	-28	393
	A	Gas(86%)	1	0%	102*	335	5	59	-	-26	373
Sec. School – 30 year calc	C	GSHP+SHW	3	40%	41	649	11	20	-	-16	664
	C	GSHP	3	40%	46	586	10	22	-	-15	603
	C	Gas(86%)	3	40%	52	533	10	22	-	-13	552
	C	Gas(86%)	2	40%	56	519	10	25	-	-14	540
	B	Gas(86%)	3	40%	59	497	10	24	-	-13	519
	A	Gas(86%)	2	40%	67	464	10	29	-	-13	490
	A	Gas(86%)	1	40%	79	433	10	38	-	-12	469
	A	Gas(86%)	1	20%	104	418	9	50	-	-11	466
	A	Gas(86%)	2	0%	117	431	8	52	-	-12	480
	A	Gas(86%)	1	0%	128*	401	8	61	-	-11	459
Hospital – 30 year calc	C	GSHP+SHW	3	40%	188	520	7	78	-	-13	592
	B	GSHP+SHW	3	40%	189	501	7	78	-	-13	573
	B	GSHP	3	40%	190	478	7	79	-	-12	552
	A	GSHP	3	40%	195	463	7	81	-	-12	539
	A	Gas CHP	3	40%	212	444	21	68	-	-11	521
	A	Gas CHP	2	40%	226	427	21	75	-	-12	511
	A	Gas(86%)	3	40%	244	423	7	84	-	-11	503
	A	Gas CHP	1	40%	252	389	21	87	-	-10	487
	A	Gas(86%)	1	40%	284	369	7	103	-	-10	469
	A	Gas(86%)	1	0%	302*	357	6	109	-	-10	463

Table 11.10d: Financial Costs (Central energy price, 10% discount factors, £/m²) cont …

Building	Package				PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Hotel – 20 year calc	C	GSHP+SHW	3	40%	319	634	6	150	-	-34	756
	B	GSHP+SHW	3	40%	324	593	6	154	-	-32	721
	B	Gas(91%)+SHW	3	40%	356	555	6	154	-	-32	683
	A	Gas(91%)+SHW	3	40%	376	527	6	164	-	-30	667
	A	Gas(86%)	3	40%	393	516	6	169	-	-30	661
	A	Gas(91%)+SHW	2	40%	401	500	6	181	-	-30	656
	A	Gas(86%)	2	0%	428*	482	5	190	-	-30	648
	B	Gas(86%)	1	40%	479	479	6	226	-	-32	679
	B	Gas(86%)	1	0%	489	473	5	231	-	-32	677
	A	Gas(86%)	1	0%	523	445	5	249	-	-30	670
Whs (Dist.) – 20 year calc	C	GSHP+SHW	3	40%	-34	969	11	-3	-	-67	910
	C	GSHP	3	40%	-25	860	10	0	-	-67	803
	B	GSHP	3	40%	-19	809	10	4	-	-63	760
	B	GSHP	2	40%	-13	790	10	8	-	-63	745
	A	Gas CHP	2	40%	4	749	25	-3	-	-60	711
	A	Gas(86%)	2	40%	42	724	10	16	-	-60	690
	B	Gas(86%)	2	20%	68	728	8	29	-	-62	702
	A	Gas(86%)	2	20%	91	697	8	37	-	-59	682
	A	Gas(86%)	2	0%	139*	663	5	57	-	-59	667
	A	Gas(86%)	1	0%	188	645	5	93	-	-59	684
Whs (Retail) – 20 year calc	C	GSHP+SHW	3	40%	48	1047	13	54	-	-64	1050
	C	GSHP	3	40%	49	938	12	54	-	-64	940
	B	GSHP	3	40%	53	907	12	56	-	-62	913
	B	Gas(86%)	3	40%	75	860	12	57	-	-62	867
	A	Gas(86%)	3	40%	87	835	12	61	-	-60	848
	A	Gas(86%)	2	40%	105	807	12	73	-	-60	833
	A	Gas(86%)	2	20%	154	780	10	94	-	-59	825
	A	Gas(86%)	2	0%	202*	747	8	115	-	-59	810
	A	Gas(86%)	1	40%	227	778	12	155	-	-60	885
	A	Gas(86%)	1	20%	276	750	10	175	-	-59	876

11.3 Existing Buildings – Elemental Analysis

11.3.1 Capital Costs and Asset Lifetimes

Introduction

The capital cost data was sourced from a combination of recent tenders for relevant refurbishment projects and first principles cost planning drawing on published materials costs and labour rates for relevant trades. This cost analysis has been compiled based upon the building types and specifications contained and have been priced as defined.

Unless specified, the rates for non-domestic buildings assume an average cost across the building types. The costs reflect current day pricing; uplift has been added to show corresponding prices at Q2 2017. Costs exclude preliminaries, overheads and profits (OH&P), contingency, fees and VAT.

The remainder of this section describes the cost data sourced and the 2016 and projected 2017 prices developed for use in the cost optimal modelling.

Building Fabric

Table 11.11 shows the cost data in 2016 and 2017 prices for the defined fabric specifications, differentiated by those applicable for naturally ventilated or air conditioned buildings where appropriate.

Table 11.11: Cost data for building fabric elements - existing buildings

Element	*Performance Rating*	*Unit*	*Cost (£ per unit)*			
			2016		*2017*	
			Naturally Ventilated	*Air Conditioned*	*Naturally Ventilated*	*Air Conditioned*
External Walls	MASONRY CAVITY - 0.39 W/m³ K	per m² of wall area	£104	£104	£107	£107
	MASONRY CAVITY - 0.30 W/m³ K - ***No internal insulation***		£15	£15	£16	£16
	MASONRY CAVITY - 0.21 W/m³ K		£118	£118	£122	£122
	MASONRY CAVITY - 0.19 W/m³ K		£114	£114	£117	£117
	MASONRY CAVITY - 0.16 W/m³ K		£168	£168	£174	£174
	MASONRY CAVITY - 0.14 W/m³ K		£198	£198	£205	£205
	MASONRY CAVITY - 0.10 W/m³ K		£176	£176	£181	£181
	LIGHTWEIGHT METAL FRAME - 0.47 W/m³ K		£273	£273	£282	£282
	LIGHTWEIGHT METAL FRAME - 0.36 W/m³ K		£294	£294	£303	£303
	LIGHTWEIGHT METAL FRAME - 0.27 W/m³ K		£318	£318	£328	£328
	LIGHTWEIGHT METAL FRAME - 0.25 W/m³ K		£346	£346	£357	£357
	LIGHTWEIGHT METAL FRAME - 0.21 W/m³ K		£360	£360	£372	£372
	LIGHTWEIGHT METAL FRAME - 0.15 W/m³ K		£375	£375	£387	£387
	LIGHTWEIGHT METAL FRAME - 0.11 W/m³ K		£405	£405	£418	£418
Ground Floor	0.25 W/m³ K	per m² of floor area	£139	£139	£143	£143
	0.20 W/m³ K		£143	£143	£148	£148
	0.15 W/m³ K		£148	£148	£153	£153
	0.10 W/m³ K		£195	£195	£201	£201
Roof	SCHOOLS, OFFICES, HOSPITALS, HOTELS - flat roof: 0.25 W/m³ K	per m² of roof area	£142	£142	£146	£146
	SCHOOLS, OFFICES, HOSPITALS, HOTELS - flat roof: 0.20 W/m³ K		£196	£196	£202	£202
	SCHOOLS, OFFICES, HOSPITALS, HOTELS - flat roof: 0.15 W/m³ K		£210	£210	£217	£217
	WAREHOUSES - profiled metal, insulated ceiling: 0.29 W/m³ K		£189	£189	£195	£195
	WAREHOUSES - profiled metal, insulated ceiling: 0.18 W/m³ K		£192	£192	£198	£198
	WAREHOUSES - profiled metal, insulated ceiling: 0.14 W/m³ K		£195	£195	£202	£202

Table 11.11: Cost data for building fabric elements - existing buildings cont ..

Element	*Performance Rating*	*Unit*	*Cost (£ per unit)*			
			2016		*2017*	
			Naturally Ventilated	*Air Conditioned*	*Naturally Ventilated*	*Air Conditioned*
Windows	TIMBER - 1.8 W/m³ K	per m² of window area	£412	£412	£425	£425
	UPVC - 1.8 W/m³ K		£209	£209	£216	£216
	TIMBER - 1.4 W/m³ K		£499	£499	£515	£515
	UPVC - 1.4 W/m³ K		£292	£292	£302	£302
	TIMBER - 1.1 W/m³ K		£606	£606	£626	£626
	UPVC - 1.1 W/m³ K		£343	£343	£354	£354
	TIMBER - 0.9 W/m³ K		£718	£718	£741	£741
	UPVC - 0.9 W/m³ K		£396	£396	£409	£409

Building Services

Heating and cooling loads for each building type were taken as being the same as those for new buildings. The costs of installing new chillers, air handling units, gas boilers, gas CHP or lighting systems were considered for each relevant building together with the addition of a solar water heating system.

In each case consideration was given to the removal and disposal of existing plant.

Costs for photovoltaic installations are the same as those for new non-domestic buildings. The costs of installation on new and existing buildings were shown to be consistent in research for the former Department of Energy and Climate Change (DECC) in August 2015[48].

[48] Small-scale generation cost update, Parson's Brinkerhoff, August 2015

Table 11.12 shows the capital cost per kW capacity and annual maintenance costs per system for gas boilers and combined heat and power.

Table 11.12: Capital and maintenance costs for heating systems - existing buildings (2017 prices)

Size (kWth)	*Capital (£/kW)*		*Maintenance (£)*	
	Gas Boiler	*Gas CHP*	*Gas Boiler*	*Gas CHP*
25	£116	£2,050	£213	£4,789
50	£116	£1,540	£355	£9,770
75	£97	£1,350	£532	£8,940
100	£97	£1,250	£710	£10,536
125	£97	£1,150	£887	£10,536
150	£77	£1,070	£1,064	£12,452
175	£77	£1,030	£1,242	£12,452
200	£77	£990	£1,419	£14,751
250	£77	£960	£1,774	£16,015
300	£77	£920	£1,916	£21,564
400	£65	£830	£2,554	£27,138
500	£65	£780	£3,122	£31,928

Table 11.13 shows the capital cost per system for different cooling and ventilation systems and performance levels. These systems are only applicable to building types with air conditioning and / or mechanical ventilation. Maintenance costs are assumed to be consistent irrespective of the efficiency of the cooling plant or ventilation systems and are therefore excluded from the analysis.

Table 11.14 shows the capital costs for lighting systems in each building.
Table 11.15 shows the capital and maintenance costs for solar water heating systems with different collector areas.

Table 11.13: Capital costs for cooling and ventilation systems - existing buildings (2017 prices)

Building Type	***Cooling****			***Ventilation *****			
	Chiller SEER			***Rate***	***AHUSFP***		
	3.9	***4.5***	***5.5***	***m³/s)***	***2.2***	***2.0***	***1.8***
Office (AC)	£ 694,449	+5-10%	+20-25%	48	£ 402,579	+5%	+10-20%
Office (NV)	-	-	-	-		-	-
Secondary School	-	-	-	-	-	-	-
Hospital	-	-	-	46	£ 352,257	+5%	+10-20%
Hotel (AC)	£ 439,818	+5-10%	+20-25%	24	£ 201,290	+5%	+10-20%
Dist. Warehouse	-	-	-	-	-	-	-
Retail Warehouse (AC)	£ 132,331	+5-10%	+20-25%	14	£ 117,419	+5%	+10-20%

Table 11.14: Capital costs for lighting systems - existing buildings (2017 prices)

Building Type	***Capital cost (£m2)***	
Luminaire efficiency	***llm/cW***	***Total***
Office	52.9	£57
	61.5	£64
	72.6	£71
	95	£79
Hotel	50.6	£30
	63	£45
	82.8	£58
	95	£72
Warehouse	58.2	£68
	66.5	£78
	82	£88
	95	£102
School / Hospital	52.6	£85
	64.3	£76
	77.3	£82
	95	£94
Enhanced lighting controls	***Daylight***	***Occupancy***
Office (AC)	£9.3	£9.3
Office (NV)	£9.3	£9.3
Secondary School	£9.3	£9.3
Hospital	£9.3	£9.3
Hotel (AC)	£8.0	£8.0
Dist. Warehouse	£3.1	£3.1
Retail Warehouse (AC)	£3.1	£3.1

Table 11.15: Capital and maintenance costs solar water heating systems - existing buildings (2017 prices)

Size (m²)	***Total (£/m²)***	***Maintenance £/annum***
25	£1,161	£114
50	£1,161	£149
75	£1,161	£184
100	£1,161	£220
150	£1,161	£255
200	£1,161	£291
250	£1,161	£326
300	£1,161	£362
400	£1,161	£397
500	£1,161	£433
750	£1,161	£468

11.3.2 Other cost information

The following information is the same as for new non-domestic buildings provided in Section 11.2.

- Projected cost reductions
- Energy prices
- Cost of Greenhouse gas emissions

In addition, the same discount rates were used as for new non-domestic buildings.

11.3.3 Results of the cost calculations

Due to the large number of permutations, we have not included all of the sensitivity results in the body of this report. Table 11.16 (a-j) details the results of the macroeconomic analysis using the central discount rate and energy cost.

The sensitivity analysis showed that lower energy prices improved the relative cost-effectiveness of less energy efficient products and higher energy prices improved the relative cost-effectiveness of more energy efficient products.

Higher discount rates devalued (and thus effectively lowered) the price of energy over the calculation period and thus tended to favour less energy efficient products.

Finally, as the alternative cost of carbon was overall higher than the central cost of carbon, analysis showed a similar tendency to increasing the energy prices.

Table 11.16a: Office (NV) (EE1): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	326	67	0	173	8	-23	225
Floor U-value	0.15	326	51	0	173	8	-18	214
Floor U-value	0.2	327	49	0	173	8	-17	214
Floor U-value	0.25	328	48	0	173	8	-17	213
Wall U-Value	0.11	324	94	0	172	8	-32	241
Wall U-Value	0.15	324	87	0	172	8	-30	237
Wall U-Value	0.15	324	87	0	172	8	-30	237
Wall U-Value	0.21	325	83	0	173	8	-29	235
Wall U-Value	0.21	326	83	0	173	8	-29	235
Wall U-Value	0.27	327	74	0	173	8	-25	229
Wall U-Value	0.36	329	68	0	174	8	-24	226
Wall U-Value	0.47	331	63	0	174	9	-22	224
Roof U-value	0.15	327	72	0	173	8	-25	229
Roof U-value	0.2	328	67	0	173	8	-23	226
Roof U-value	0.25	329	49	0	173	8	-17	214
Heating Source	Gas CHP	306	34	39	162	8	0	243
Heating Source	Gas + SHW	317	47	9	169	8	0	233
Heating Source	Gas	324	9	9	172	8	0	197
Window U-value	0.9	313	61	0	169	8	-11	227
Window U-value	1.1	314	53	0	169	8	-9	220
Window U-value	1.4	315	45	0	170	8	-8	215
Window U-value	1.8	317	32	0	170	8	-6	205
Lighting Efficacy	65	181	67	0	74	7	0	147
Lighting Efficacy	60	184	63	0	76	7	0	146
Lighting Efficacy	55	187	59	0	79	7	0	145

Table 11.16b: Office (NV) (EE2): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	223	67	0	112	6	-23	163
Floor U-value	0.15	224	51	0	113	6	-18	152
Floor U-value	0.2	224	49	0	113	6	-17	152
Floor U-value	0.25	225	48	0	113	6	-17	151
Wall U-Value	0.11	221	94	0	112	6	-32	179
Wall U-Value	0.15	222	87	0	112	6	-30	175
Wall U-Value	0.15	222	87	0	112	6	-30	175
Wall U-Value	0.21	223	83	0	113	6	-29	173
Wall U-Value	0.21	224	83	0	113	6	-29	173
Wall U-Value	0.27	225	74	0	113	6	-25	168
Wall U-Value	0.36	227	68	0	114	7	-24	165
Wall U-Value	0.47	230	63	0	115	7	-22	163
Roof U-value	0.15	222	72	0	112	6	-25	166
Roof U-value	0.2	223	67	0	112	6	-23	163
Roof U-value	0.25	224	49	0	113	6	-17	151
Heating Source	Gas CHP	199	34	39	100	6	0	179
Heating Source	Gas + SHW	212	47	9	108	6	0	171
Heating Source	Gas	221	9	9	112	6	0	135
Window U-value	0.9	205	61	0	107	5	-11	163
Window U-value	1.1	206	53	0	107	5	-9	157
Window U-value	1.4	208	45	0	108	6	-8	151
Window U-value	1.8	210	32	0	109	6	-6	141
Lighting Efficacy	65	160	67	0	67	6	0	140
Lighting Efficacy	60	163	63	0	69	6	0	138
Lighting Efficacy	55	167	59	0	72	6	0	137

Table 11.16c: Secondary School (EE1): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	268	101	0	135	22	-19	239
Floor U-value	0.15	270	76	0	135	22	-14	220
Floor U-value	0.2	271	74	0	135	22	-14	218
Floor U-value	0.25	272	72	0	136	23	-13	217
Wall U-Value	0.1	272	79	0	136	23	-15	223
Wall U-Value	0.14	273	89	0	136	23	-16	232
Wall U-Value	0.16	273	76	0	136	23	-14	221
Wall U-Value	0.19	274	51	0	137	23	-9	201
Wall U-Value	0.21	274	53	0	137	23	-10	203
Wall U-Value	0.3	275	7	0	137	23	-1	166
Wall U-Value	0.39	277	47	0	138	23	-9	199
Roof U-value	0.15	277	108	0	138	23	-20	249
Roof U-value	0.2	277	101	0	138	23	-19	244
Roof U-value	0.25	278	73	0	138	23	-13	221
Heating Source	Gas CHP	246	55	54	118	23	-7	244
Heating Source	Gas + SHW	260	93	17	131	21	-12	250
Heating Source	Gas	268	14	16	134	22	-2	184
Window U-value	0.9	260	42	0	131	21	0	195
Window U-value	1.1	261	36	0	132	21	0	190
Window U-value	1.4	263	31	0	132	22	0	185
Window U-value	1.8	265	22	0	133	22	0	177
Lighting Efficacy	65	249	114	0	112	23	-14	235
Lighting Efficacy	60	251	119	0	114	23	-15	242
Lighting Efficacy	55	254	124	0	116	23	-15	249

Table 11.16d: Secondary School (EE2): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	217	101	0	110	18	-19	210
Floor U-value	0.15	218	76	0	111	18	-14	191
Floor U-value	0.2	219	74	0	111	18	-14	190
Floor U-value	0.25	221	72	0	112	18	-13	188
Wall U-Value	0.1	220	79	0	111	18	-15	194
Wall U-Value	0.14	220	89	0	112	18	-16	203
Wall U-Value	0.16	221	76	0	112	18	-14	192
Wall U-Value	0.19	221	51	0	112	18	-9	172
Wall U-Value	0.21	222	53	0	112	18	-10	174
Wall U-Value	0.3	223	7	0	113	18	-1	136
Wall U-Value	0.39	224	47	0	113	18	-9	170
Roof U-value	0.15	222	108	0	112	18	-20	219
Roof U-value	0.2	223	101	0	113	18	-19	213
Roof U-value	0.25	223	73	0	113	18	-13	191
Heating Source	Gas CHP	197	55	54	96	19	-7	217
Heating Source	Gas + SHW	207	93	17	107	17	-12	221
Heating Source	Gas	218	14	16	111	18	-2	156
Window U-value	0.9	206	42	0	106	16	0	164
Window U-value	1.1	207	36	0	106	16	0	159
Window U-value	1.4	208	31	0	107	17	0	154
Window U-value	1.8	210	22	0	108	17	0	147
Lighting Efficacy	65	202	114	0	94	18	-14	212
Lighting Efficacy	60	204	119	0	95	18	-15	218
Lighting Efficacy	55	207	124	0	98	18	-15	225

Table 11.16e: Hospital (EE1): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	554	36	0	351	29	-7	409
Floor U-value	0.15	554	27	0	351	29	-5	402
Floor U-value	0.2	555	26	0	351	29	-5	401
Floor U-value	0.25	555	26	0	351	29	-5	401
Wall U-Value	0.11	550	136	0	350	29	-25	489
Wall U-Value	0.15	551	126	0	350	29	-23	481
Wall U-Value	0.15	551	126	0	350	29	-23	481
Wall U-Value	0.21	551	120	0	350	29	-22	477
Wall U-Value	0.21	551	120	0	350	29	-22	477
Wall U-Value	0.27	552	106	0	350	29	-20	466
Wall U-Value	0.36	554	98	0	350	29	-18	460
Wall U-Value	0.47	556	91	0	351	29	-17	455
Roof U-value	0.15	555	39	0	350	30	-7	412
Roof U-value	0.2	556	36	0	351	30	-7	410
Roof U-value	0.25	556	26	0	351	30	-5	402
Heating Source	Gas CHP	527	40	39	331	31	-5	435
Heating Source	Gas + SHW	541	38	12	345	28	-5	418
Heating Source	Gas	545	10	12	347	28	-1	396
Window U-value	1.4	550	28	0	353	28	0	409
Window U-value	1.8	550	20	0	353	28	0	400
Window U-value	1.1	550	33	0	354	28	0	414
Window U-value	0.9	551	38	0	355	28	0	420
AHU SFP	1.8	558	33	0	351	30	-4	410
AHU SFP	2	558	30	0	351	30	-4	407
AHU SFP	2.2	558	29	0	351	30	-4	406
Lighting Efficacy	65	380	114	0	211	27	-14	338
Lighting Efficacy	60	386	119	0	216	27	-15	347
Lighting Efficacy	55	394	124	0	222	27	-15	358

Table 11.16f: Hospital (EE2): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	470	36	0	289	27	-7	345
Floor U-value	0.15	470	27	0	289	27	-5	338
Floor U-value	0.2	470	26	0	289	27	-5	337
Floor U-value	0.25	471	26	0	289	27	-5	337
Wall U-Value	0.11	466	136	0	288	26	-25	425
Wall U-Value	0.15	467	126	0	288	26	-23	417
Wall U-Value	0.15	467	126	0	288	26	-23	417
Wall U-Value	0.21	468	120	0	288	27	-22	413
Wall U-Value	0.21	468	120	0	288	27	-22	413
Wall U-Value	0.27	469	106	0	288	27	-20	402
Wall U-Value	0.36	470	98	0	289	27	-18	396
Wall U-Value	0.47	472	91	0	289	27	-17	391
Roof U-value	0.15	470	39	0	288	27	-7	347
Roof U-value	0.2	470	36	0	288	27	-7	345
Roof U-value	0.25	470	26	0	288	27	-5	337
Heating Source	Gas CHP	444	40	39	270	28	-5	372
Heating Source	Gas + SHW	456	38	12	283	25	-5	354
Heating Source	Gas	462	10	12	285	26	-1	332
Window U-value	1.4	463	28	0	290	25	0	343
Window U-value	1.1	463	33	0	291	25	0	348
Window U-value	1.8	463	20	0	289	25	0	335
Window U-value	0.9	463	38	0	291	25	0	354
AHU SFP	1.8	472	33	0	289	27	-4	345
AHU SFP	2	472	30	0	289	27	-4	343
AHU SFP	2.2	472	29	0	289	27	-4	341
Lighting Efficacy	65	350	114	0	193	25	-14	317
Lighting Efficacy	60	356	119	0	197	25	-15	327
Lighting Efficacy	55	363	124	0	203	25	-15	337

Table 11.16g: Hotel (EE1): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	760	20	0	315	30	-7	358
Floor U-value	0.15	761	15	0	316	30	-5	356
Floor U-value	0.2	763	15	0	316	30	-5	356
Floor U-value	0.25	764	14	0	317	30	-5	356
Wall U-Value	0.11	747	201	0	312	29	-70	472
Wall U-Value	0.15	750	186	0	312	29	-64	463
Wall U-Value	0.15	750	186	0	312	29	-64	463
Wall U-Value	0.21	752	178	0	313	29	-62	459
Wall U-Value	0.21	753	178	0	313	30	-62	459
Wall U-Value	0.27	756	158	0	315	30	-55	447
Wall U-Value	0.36	762	146	0	316	30	-51	441
Wall U-Value	0.47	768	135	0	318	30	-47	437
Roof U-value	0.15	754	21	0	313	30	-7	356
Roof U-value	0.2	757	20	0	314	30	-7	356
Roof U-value	0.25	759	14	0	314	30	-5	354
Heating Source	Gas CHP	691	30	31	279	30	0	371
Heating Source	Gas + SHW	722	19	9	305	28	0	361
Heating Source	Gas	743	8	9	311	29	0	357
Window U-value	0.9	720	106	0	305	28	-18	420
Window U-value	1.1	724	92	0	306	28	-16	410
Window U-value	1.4	730	78	0	308	28	-14	401
Window U-value	1.8	739	56	0	310	29	-10	385
Chiller Efficiency	5.5	747	34	0	305	30	0	369
Chiller Efficiency	4.5	751	30	0	307	30	0	367
Chiller Efficiency	3.9	754	29	0	309	30	0	368
AHU SFP	1.8	758	15	0	309	31	0	354
AHU SFP	2	761	14	0	310	31	0	355
AHU SFP	2.2	764	13	0	312	31	0	356
Lighting Efficacy	65	741	47	0	297	30	0	374
Lighting Efficacy	60	744	41	0	299	30	0	371
Lighting Efficacy	55	748	35	0	302	30	0	368

Table 11.16h: Hotel (EE2): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	639	20	0	262	26	-7	300
Floor U-value	0.15	641	15	0	262	26	-5	298
Floor U-value	0.2	642	15	0	263	26	-5	298
Floor U-value	0.25	644	14	0	263	26	-5	298
Wall U-Value	0.11	631	201	0	259	25	-70	415
Wall U-Value	0.15	633	186	0	260	25	-64	407
Wall U-Value	0.15	633	186	0	260	25	-64	407
Wall U-Value	0.21	636	178	0	261	25	-62	403
Wall U-Value	0.21	636	178	0	261	25	-62	403
Wall U-Value	0.27	640	158	0	262	26	-55	391
Wall U-Value	0.36	645	146	0	264	26	-51	385
Wall U-Value	0.47	651	135	0	266	26	-47	381
Roof U-value	0.15	630	21	0	258	25	-7	297
Roof U-value	0.2	632	20	0	259	25	-7	297
Roof U-value	0.25	634	14	0	260	25	-5	294
Heating Source	Gas CHP	585	30	31	231	26	0	319
Heating Source	Gas + SHW	616	19	9	256	24	0	308
Heating Source	Gas	641	8	9	263	26	0	306
Window U-value	0.9	596	106	0	250	23	-18	361
Window U-value	1.1	600	92	0	251	23	-16	350
Window U-value	1.4	606	78	0	253	24	-14	341
Window U-value	1.8	615	56	0	255	24	-10	325
Chiller Efficiency	5.5	630	34	0	254	26	0	314
Chiller Efficiency	4.5	633	30	0	256	26	0	312
Chiller Efficiency	3.9	635	29	0	257	26	0	312
AHU SFP	1.8	644	15	0	262	26	0	303
AHU SFP	2	647	14	0	264	26	0	304
AHU SFP	2.2	650	13	0	266	26	0	305
Lighting Efficacy	65	634	47	0	255	26	0	328
Lighting Efficacy	60	636	41	0	256	26	0	323
Lighting Efficacy	55	639	35	0	258	26	0	319

Table 11.16i: Retail Warehouse (EE1): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	387	190	0	200	11	-66	334
Floor U-value	0.15	387	144	0	200	11	-50	304
Floor U-value	0.2	388	140	0	200	11	-48	301
Floor U-value	0.25	388	135	0	200	11	-47	298
Wall U-Value	0.11	379	181	0	197	10	-63	325
Wall U-Value	0.15	380	167	0	197	10	-58	316
Wall U-Value	0.15	380	167	0	197	10	-58	316
Wall U-Value	0.21	381	161	0	197	10	-56	312
Wall U-Value	0.21	381	161	0	197	10	-56	312
Wall U-Value	0.27	382	142	0	198	10	-49	301
Wall U-Value	0.36	384	131	0	198	10	-46	294
Wall U-Value	0.47	386	122	0	199	11	-42	289
Roof U-value	0.14	364	198	0	190	10	-69	328
Roof U-value	0.18	367	194	0	191	10	-67	327
Roof U-value	0.29	373	192	0	193	10	-66	328
Heating Source	Gas CHP	352	42	43	181	11	0	277
Heating Source	Gas + SHW	370	124	14	194	10	0	342
Heating Source	Gas	375	10	13	195	10	0	229
Window U-value	0.9	385	55	0	198	10	-10	254
Window U-value	1.1	385	48	0	198	10	-8	248
Window U-value	1.4	386	41	0	199	11	-7	243
Window U-value	1.8	386	29	0	199	11	-5	233
Chiller Efficiency	5.5	331	30	0	166	9	0	206
Chiller Efficiency	4.5	338	26	0	171	10	0	207
Chiller Efficiency	3.9	344	25	0	174	10	0	209
AHU SFP	1.8	374	26	0	190	11	0	226
AHU SFP	2	376	24	0	191	11	0	225
AHU SFP	2.2	379	23	0	193	11	0	226
Lighting Efficacy	65	363	76	0	183	10	0	270
Lighting Efficacy	60	365	70	0	184	10	0	265
Lighting Efficacy	55	367	65	0	186	10	0	261

Table 11.16j: Retail Warehouse (EE2): Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Package	Value	PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
				Maintenance	Energy			
Floor U-value	0.1	362	190	0	187	10	-66	321
Floor U-value	0.15	362	144	0	187	10	-50	291
Floor U-value	0.2	363	140	0	187	10	-48	288
Floor U-value	0.25	363	135	0	187	10	-47	285
Wall U-Value	0.11	356	181	0	185	10	-63	313
Wall U-Value	0.15	357	167	0	185	10	-58	304
Wall U-Value	0.15	357	167	0	185	10	-58	304
Wall U-Value	0.21	359	161	0	186	10	-56	300
Wall U-Value	0.21	359	161	0	186	10	-56	301
Wall U-Value	0.27	360	142	0	186	10	-49	289
Wall U-Value	0.36	362	131	0	187	10	-46	282
Wall U-Value	0.47	364	122	0	187	10	-42	277
Roof U-value	0.14	333	198	0	174	9	-69	312
Roof U-value	0.18	336	194	0	176	9	-67	311
Roof U-value	0.29	344	192	0	179	9	-66	313
Heating Source	Gas CHP	329	42	43	170	10	0	265
Heating Source	Gas + SHW	347	124	14	182	9	0	330
Heating Source	Gas	351	10	13	183	9	0	216
Window U-value	0.9	360	55	0	186	10	-10	241
Window U-value	1.1	360	48	0	186	10	-8	235
Window U-value	1.4	361	41	0	186	10	-7	230
Window U-value	1.8	361	29	0	187	10	-5	220
Chiller Efficiency	5.5	308	30	0	155	9	0	194
Chiller Efficiency	4.5	315	26	0	159	9	0	195
Chiller Efficiency	3.9	321	25	0	163	9	0	197
AHU SFP	1.8	359	26	0	184	10	0	220
AHU SFP	2	361	24	0	186	10	0	219
AHU SFP	2.2	364	23	0	187	10	0	220
Lighting Efficacy	65	348	76	0	177	10	0	263
Lighting Efficacy	60	350	70	0	179	10	0	259
Lighting Efficacy	55	353	65	0	180	10	0	255

11.4 Existing Buildings – Analysis of Packages

The underpinning costs and assumptions are consistent with that in Section 11.3.

The following tables summarise the results of the cost calculations for the most cost-optimal packages in each of the reference buildings. Table 11.17 relates to the macroeconomic calculations and Table 11.18 relate to the financial calculations.

- Table 11.17a / Table 11.18a: Central energy price, central discount factors
- Table 11.17b / Table 11.18b: Low energy price, central discount factors
- Table 11.17c / Table 11.18c: High energy price, central discount factors
- Table 11.17d / Table 11.18d: Central energy price, alternative discount factors
- Table 11.17e: Central energy price, central discount factor, alternative cost of carbon

The sensitivity analysis shows that with lower energy prices there is a tendency for solutions with higher primary energy to become relatively more favourable. Similarly, with higher discount rates, it makes solutions with higher primary energy relatively more favourable due at least partly to the lower net present value energy prices.

Table 11.17a: Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²)

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE1) – 30 year calc	A	3	Gas CHP	20%	315	345	40	180	23	-48	539
	Window Only	3	Gas CHP	20%	319	220	40	180	24	-24	440
	EE1	3	Gas CHP	20%	323	192	40	175	27	-24	410
	EE1	3	Gas CHP	0%	331	186	39	180	27	-23	409
	Window Only	3	Gas(86%)	20%	336	190	12	196	22	-20	401
	EE1	3	Gas(91%) +SHW	20%	341	194	13	194	23	-24	401
	EE1	3	Gas(86%)	20%	347	162	12	197	24	-20	376
	EE1	3	Gas(86%)	0%	356*	156	12	202	24	-19	375
	EE1	2	Gas(86%)	0%	362	162	12	207	24	-20	385
	EE1	1	Gas(86%)	0%	370	167	12	213	24	-20	395
Hotel (EE1) – 20 year calc	C	3	Gas CHP	20%	537	429	32	209	24	-88	606
	A	3	Gas CHP	20%	551	363	32	211	25	-71	560
	Window Only	3	Gas CHP	20%	568	208	32	216	26	-14	468
	Roof Only	3	Gas CHP	20%	585	151	32	218	28	-8	421
	Roof Only	2	Gas CHP	20%	591	141	32	222	28	-8	415
	EE1	2	Gas CHP	20%	604	120	32	225	29	0	406
	EE1	1	Gas CHP	20%	611	113	32	230	29	0	403
	EE1	2	Gas(91%) +SHW	20%	646	108	10	257	27	0	402
	EE1	1	Gas(91%) +SHW	20%	652	101	10	261	27	0	399
	EE1	1	Gas(86%)	0%	679*	87	9	270	28	0	394
Office (EE1) – 20 year calc	D	3	Gas CHP	20%	82	330	40	37	4	-67	343
	Window Only	3	Gas CHP	20%	96	143	40	38	5	-6	220
	Window Only	2	Gas CHP	20%	100	139	40	41	5	-6	219
	EE1	3	Gas CHP	20%	109	111	40	39	7	-1	196
	Window Only	3	Gas(86%)	20%	122	117	10	54	5	-6	180
	Window Only	1	Gas(86%)	20%	130	110	10	59	5	-6	177
	Window Only	3	Gas(86%)	0%	139	107	9	61	5	-6	177
	EE1	3	Gas(86%)	20%	144	85	10	60	6	-1	161
	EE1	1	Gas(86%)	20%	152	77	10	66	6	-1	158
	EE1	1	Gas(86%)	0%	168*	67	9	73	6	0	155
Retail Whs (EE1) – 20 year calc	D	3	Gas CHP	20%	191	625	46	101	6	-141	637
	Roof Only	3	Gas CHP	20%	208	390	46	106	7	-68	482
	EE1	3	Gas CHP	20%	214	198	46	107	8	-2	358
	Window Only	3	Gas(86%)	20%	240	195	16	123	7	-7	336
	EE1	3	Gas(86%)	20%	242	166	16	124	7	-2	313
	EE1	1	Gas(86%)	20%	251	158	16	129	8	-2	309
	EE1	3	Gas CHP	0%	263	171	43	129	9	0	351
	EE1	1	Gas CHP	0%	273	162	43	134	9	0	348
	EE1	3	Gas(86%)	0%	291	139	13	145	8	0	306
	EE1	1	Gas(86%)	0%	300*	130	13	151	9	0	302
Sec. Sch (EE1) – 30 year calc	C	3	Gas CHP	20%	169	410	56	71	19	-57	499
	Window Only	3	Gas CHP	20%	176	208	56	71	21	-23	334
	Wall Only	3	Gas CHP	20%	182	193	56	72	22	-24	319
	EE1	3	Gas CHP	20%	184	186	56	73	23	-23	315
	Window Only	3	Gas(86%)	20%	196	166	18	87	20	-17	273
	Wall Only	3	Gas(86%)	20%	206	150	18	91	21	-19	261
	EE1	3	Gas(86%)	20%	210	144	18	92	21	-17	258
	Window Only	3	Gas(86%)	0%	221	149	16	101	20	-15	271
	EE1	3	Gas(86%)	0%	235*	126	16	106	22	-15	256
	EE1	1	Gas(86%)	0%	240	137	16	111	22	-16	269

Table 11.17a: Macroeconomic Costs (Central energy price, 3.5% discount rate, £/m²) cont …

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE2) – 30 year calc	A	3	Gas CHP	20%	291	345	40	164	22	-48	522
	Window Only	3	Gas CHP	20%	294	220	40	165	22	-24	423
	EE2	3	Gas CHP	20%	297	192	40	160	25	-24	393
	EE2	2	Gas CHP	20%	304	195	40	165	25	-24	400
	Window Only	3	Gas(86%)	20%	309	190	12	178	21	-20	381
	EE2	3	Gas(91%) +SHW	20%	313	194	13	177	22	-24	382
	EE2	3	Gas(86%)	20%	319	162	12	179	22	-20	356
	EE2	3	Gas(86%)	0%	328*	156	12	184	23	-19	356
	EE2	2	Gas(86%)	0%	334	159	12	189	23	-19	363
	EE2	1	Gas(86%)	0%	341	163	12	194	23	-20	372
Hotel (EE2) – 20 year calc	C	3	Gas CHP	20%	480	429	32	189	21	-88	583
	B	3	Gas CHP	20%	485	408	32	190	22	-83	568
	Window Only	3	Gas CHP	20%	505	208	32	194	23	-14	443
	Roof Only	3	Gas CHP	20%	522	151	32	196	25	-8	396
	Roof Only	1	Gas CHP	20%	531	134	32	202	25	-8	385
	EE2	1	Gas CHP	0%	550	110	31	208	26	0	375
	Roof Only	2	Gas(91%) +SHW	20%	558	130	10	224	23	-8	379
	EE2	2	Gas(91%) +SHW	20%	575	108	10	231	24	0	373
	EE2	1	Gas(91%) +SHW	0%	585	98	9	236	24	0	368
	EE2	1	Gas(86%)	0%	605*	87	9	242	25	0	363
Office (EE2) – 20 year calc	D	3	Gas CHP	20%	74	330	40	35	3	-67	340
	A	3	Gas CHP	20%	80	265	40	36	4	-49	296
	Window Only	3	Gas CHP	20%	85	206	40	36	4	-28	258
	Wall Only	3	Gas CHP	20%	94	194	40	37	5	-29	247
	Window Only	3	Gas(86%)	20%	106	181	10	48	4	-28	215
	Wall Only	3	Gas(86%)	20%	121	168	10	53	5	-29	206
	EE2	3	Gas(86%)	20%	127	148	10	55	5	-22	196
	EE2	1	Gas(86%)	20%	135	140	10	60	5	-22	193
	EE2	3	Gas(86%)	0%	144	138	9	62	5	-22	192
	EE2	1	Gas(86%)	0%	151*	130	9	67	5	-22	190
Retail Whs (EE2) – 20 year calc	D	3	Gas CHP	20%	183	625	46	99	6	-141	634
	EE2	3	Gas CHP	20%	211	198	46	108	7	-2	358
	EE2	1	Gas CHP	20%	221	190	46	114	8	-2	356
	Window Only	3	Gas(86%)	20%	233	195	16	122	7	-7	334
	EE2	3	Gas(86%)	20%	235	166	16	123	7	-2	311
	EE2	1	Gas(86%)	20%	244	158	16	129	7	-2	308
	EE2	3	Gas CHP	0%	260	171	43	130	8	0	351
	EE2	1	Gas CHP	0%	270	162	43	136	9	0	349
	EE2	3	Gas(86%)	0%	284	139	13	144	8	0	304
	EE2	1	Gas(86%)	0%	293*	130	13	150	8	0	301
Sec. Sch (EE2) – 30 year calc	C	3	Gas CHP	20%	131	410	56	57	15	-57	480
	Window Only	3	Gas CHP	20%	137	208	56	58	16	-23	315
	Wall Only	3	Gas CHP	20%	143	193	56	58	18	-24	301
	Window Only	3	Gas(86%)	20%	152	166	18	69	15	-17	251
	Wall Only	3	Gas(86%)	20%	163	150	18	74	16	-19	240
	EE2	3	Gas(86%)	20%	165	144	18	75	17	-17	235
	EE2	1	Gas(86%)	20%	171	154	18	79	17	-19	249
	Window Only	3	Gas(86%)	0%	177	149	16	84	16	-15	249
	EE2	3	Gas(86%)	0%	190*	126	16	89	17	-15	233
	EE2	1	Gas(86%)	0%	195	137	16	93	17	-16	247

Table 11.17b: Macroeconomic Costs (Low energy price, 3.5% discount rate, £/m²)

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE1) – 30 year calc	A	3	Gas CHP	20%	315	345	40	140	23	-48	500
	Window Only	3	Gas CHP	20%	319	220	40	140	24	-24	400
	EE1	3	Gas CHP	20%	323	192	40	132	27	-24	367
	EE1	3	Gas CHP	0%	331	186	39	137	27	-23	366
	Window Only	3	Gas(86%)	20%	336	190	12	158	22	-20	363
	EE1	3	Gas(91%) +SHW	20%	341	194	13	155	23	-24	362
	EE1	3	Gas(86%)	20%	347	162	12	157	24	-20	336
	EE1	3	Gas(86%)	0%	356*	156	12	161	24	-19	335
	EE1	2	Gas(86%)	0%	362	162	12	166	24	-20	344
	EE1	1	Gas(86%)	0%	370	167	12	171	24	-20	354
Hotel (EE1) – 20 year calc	C	3	Gas CHP	20%	537	429	32	153	24	-88	550
	A	3	Gas CHP	20%	551	363	32	153	25	-71	501
	Window Only	3	Gas CHP	20%	568	208	32	155	26	-14	407
	Roof Only	3	Gas CHP	20%	585	151	32	153	28	-8	356
	Roof Only	2	Gas CHP	20%	591	141	32	156	28	-8	350
	EE1	2	Gas CHP	20%	604	120	32	158	29	0	338
	EE1	1	Gas CHP	20%	611	113	32	162	29	0	335
	EE1	2	Gas(91%) +SHW	20%	646	108	10	196	27	0	341
	EE1	1	Gas(91%) +SHW	20%	652	101	10	199	27	0	337
	EE1	1	Gas(86%)	0%	679*	87	9	205	28	0	330
Office (EE1) – 20 year calc	D	3	Gas CHP	20%	82	330	40	27	4	-67	332
	Window Only	3	Gas CHP	20%	96	143	40	25	5	-6	207
	Window Only	2	Gas CHP	20%	100	139	40	28	5	-6	206
	EE1	3	Gas CHP	20%	109	111	40	23	7	-1	180
	Window Only	3	Gas(86%)	20%	122	117	10	42	5	-6	168
	Window Only	1	Gas(86%)	20%	130	110	10	47	5	-6	165
	Window Only	3	Gas(86%)	0%	139	107	9	49	5	-6	164
	EE1	3	Gas(86%)	20%	144	85	10	46	6	-1	147
	EE1	1	Gas(86%)	20%	152	77	10	51	6	-1	144
	EE1	1	Gas(86%)	0%	168*	67	9	58	6	0	140
Retail Whs (EE1) – 20 year calc	D	3	Gas CHP	20%	191	625	46	82	6	-141	618
	Roof Only	3	Gas CHP	20%	208	390	46	84	7	-68	460
	EE1	3	Gas CHP	20%	214	198	46	84	8	-2	335
	Window Only	3	Gas(86%)	20%	240	195	16	102	7	-7	314
	EE1	3	Gas(86%)	20%	242	166	16	102	7	-2	291
	EE1	1	Gas(86%)	20%	251	158	16	107	8	-2	287
	EE1	3	Gas CHP	0%	263	171	43	103	9	0	326
	EE1	1	Gas CHP	0%	273	162	43	108	9	0	322
	EE1	3	Gas(86%)	0%	291	139	13	122	8	0	282
	EE1	1	Gas(86%)	0%	300*	130	13	127	9	0	278
Sec. Sch (EE1) – 30 year calc	C	3	Gas CHP	20%	169	410	56	43	19	-57	472
	Window Only	3	Gas CHP	20%	176	208	56	43	21	-23	305
	Wall Only	3	Gas CHP	20%	182	193	56	42	22	-24	289
	EE1	3	Gas CHP	20%	184	186	56	41	23	-23	284
	Window Only	3	Gas(86%)	20%	196	166	18	59	20	-17	245
	Wall Only	3	Gas(86%)	20%	206	150	18	62	21	-19	232
	EE1	3	Gas(86%)	20%	210	144	18	63	21	-17	228
	Window Only	3	Gas(86%)	0%	221	149	16	72	20	-15	242
	EE1	3	Gas(86%)	0%	235*	126	16	76	22	-15	225
	EE1	1	Gas(86%)	0%	240	137	16	80	22	-16	238

Table 11.17b: Macroeconomic Costs (Low energy price, 3.5% discount rate, £/m²) cont …

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE2) – 30 year calc	A	3	Gas CHP	20%	291	345	40	127	22	-48	486
	Window Only	3	Gas CHP	20%	294	220	40	128	22	-24	386
	EE2	3	Gas CHP	20%	297	192	40	120	25	-24	353
	EE2	2	Gas CHP	20%	304	195	40	125	25	-24	360
	Window Only	3	Gas(86%)	20%	309	190	12	143	21	-20	346
	EE2	3	Gas(91%) +SHW	20%	313	194	13	140	22	-24	345
	EE2	3	Gas(86%)	20%	319	162	12	142	22	-20	319
	EE2	3	Gas(86%)	0%	328*	156	12	146	23	-19	318
	EE2	2	Gas(86%)	0%	334	159	12	151	23	-19	325
	EE2	1	Gas(86%)	0%	341	163	12	156	23	-20	334
Hotel (EE2) – 20 year calc	C	3	Gas CHP	20%	480	429	32	139	21	-88	533
	B	3	Gas CHP	20%	485	408	32	139	22	-83	517
	Window Only	3	Gas CHP	20%	505	208	32	140	23	-14	389
	Roof Only	3	Gas CHP	20%	522	151	32	138	25	-8	338
	Roof Only	1	Gas CHP	20%	531	134	32	144	25	-8	327
	EE2	1	Gas CHP	0%	550	110	31	148	26	0	315
	Roof Only	2	Gas(91%) +SHW	20%	558	130	10	171	23	-8	326
	EE2	2	Gas(91%) +SHW	20%	575	108	10	176	24	0	318
	EE2	1	Gas(91%) +SHW	0%	585	98	9	181	24	0	313
	EE2	1	Gas(86%)	0%	605*	87	9	185	25	0	306
Office (EE2) – 20 year calc	D	3	Gas CHP	20%	74	330	40	26	3	-67	332
	A	3	Gas CHP	20%	80	265	40	26	4	-49	286
	Window Only	3	Gas CHP	20%	85	206	40	25	4	-28	247
	Wall Only	3	Gas CHP	20%	94	194	40	24	5	-29	233
	Window Only	3	Gas(86%)	20%	106	181	10	38	4	-28	205
	Wall Only	3	Gas(86%)	20%	121	168	10	41	5	-29	195
	EE2	3	Gas(86%)	20%	127	148	10	42	5	-22	183
	EE2	1	Gas(86%)	20%	135	140	10	47	5	-22	180
	EE2	3	Gas(86%)	0%	144	138	9	49	5	-22	179
	EE2	1	Gas(86%)	0%	151*	130	9	54	5	-22	177
Retail Whs (EE2) – 20 year calc	D	3	Gas CHP	20%	183	625	46	81	6	-141	616
	EE2	3	Gas CHP	20%	211	198	46	86	7	-2	336
	EE2	1	Gas CHP	20%	221	190	46	91	8	-2	333
	Window Only	3	Gas(86%)	20%	233	195	16	101	7	-7	313
	EE2	3	Gas(86%)	20%	235	166	16	102	7	-2	290
	EE2	1	Gas(86%)	20%	244	158	16	107	7	-2	286
	EE2	3	Gas CHP	0%	260	171	43	106	8	0	327
	EE2	1	Gas CHP	0%	270	162	43	111	9	0	324
	EE2	3	Gas(86%)	0%	284	139	13	121	8	0	281
	EE2	1	Gas(86%)	0%	293*	130	13	126	8	0	278
Sec. Sch (EE2) – 30 year calc	C	3	Gas CHP	20%	131	410	56	36	15	-57	459
	Window Only	3	Gas CHP	20%	137	208	56	35	16	-23	293
	Wall Only	3	Gas CHP	20%	143	193	56	34	18	-24	277
	Window Only	3	Gas(86%)	20%	152	166	18	48	15	-17	229
	Wall Only	3	Gas(86%)	20%	163	150	18	51	16	-19	217
	EE2	3	Gas(86%)	20%	165	144	18	51	17	-17	212
	EE2	1	Gas(86%)	20%	171	154	18	55	17	-19	226
	Window Only	3	Gas(86%)	0%	177	149	16	61	16	-15	226
	EE2	3	Gas(86%)	0%	190*	126	16	64	17	-15	209
	EE2	1	Gas(86%)	0%	195	137	16	68	17	-16	222

Table 11.17c: Macroeconomic Costs (High energy price, 3.5% discount rate, £/m²)

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE1) – 30 year calc	A	3	Gas CHP	20%	315	345	40	223	23	-48	582
	Window Only	3	Gas CHP	20%	319	220	40	225	24	-24	485
	EE1	3	Gas CHP	20%	323	192	40	224	27	-24	459
	EE1	3	Gas CHP	0%	331	186	39	229	27	-23	458
	Window Only	3	Gas(86%)	20%	336	190	12	237	22	-20	442
	EE1	3	Gas(91%) +SHW	20%	341	194	13	238	23	-24	444
	EE1	3	Gas(86%)	20%	347	162	12	241	24	-20	420
	EE1	3	Gas(86%)	0%	356*	156	12	246	24	-19	420
	EE1	2	Gas(86%)	0%	362	162	12	252	24	-20	430
	EE1	1	Gas(86%)	0%	370	167	12	258	24	-20	441
Hotel (EE1) – 20 year calc	C	3	Gas CHP	20%	537	429	32	271	24	-88	667
	A	3	Gas CHP	20%	551	363	32	276	25	-71	625
	Window Only	3	Gas CHP	20%	568	208	32	284	26	-14	536
	Roof Only	3	Gas CHP	20%	585	151	32	290	28	-8	493
	Roof Only	2	Gas CHP	20%	591	141	32	294	28	-8	487
	EE1	2	Gas CHP	20%	604	120	32	300	29	0	481
	EE1	1	Gas CHP	20%	611	113	32	305	29	0	478
	EE1	2	Gas(91%) +SHW	20%	646	108	10	325	27	0	470
	EE1	1	Gas(91%) +SHW	20%	652	101	10	329	27	0	467
	EE1	1	Gas(86%)	0%	679*	87	9	341	28	0	465
Office (EE1) – 20 year calc	D	3	Gas CHP	20%	82	330	40	48	4	-67	354
	Window Only	3	Gas CHP	20%	96	143	40	53	5	-6	235
	Window Only	2	Gas CHP	20%	100	139	40	56	5	-6	234
	EE1	3	Gas CHP	20%	109	111	40	57	7	-1	214
	Window Only	3	Gas(86%)	20%	122	117	10	67	5	-6	192
	Window Only	1	Gas(86%)	20%	130	110	10	72	5	-6	190
	Window Only	3	Gas(86%)	0%	139	107	9	74	5	-6	190
	EE1	3	Gas(86%)	20%	144	85	10	76	6	-1	176
	EE1	1	Gas(86%)	20%	152	77	10	81	6	-1	174
	EE1	1	Gas(86%)	0%	168*	67	9	89	6	0	171
Retail Whs (EE1) – 20 year calc	D	3	Gas CHP	20%	191	625	46	121	6	-141	657
	Roof Only	3	Gas CHP	20%	208	390	46	129	7	-68	505
	EE1	3	Gas CHP	20%	214	198	46	132	8	-2	383
	Window Only	3	Gas(86%)	20%	240	195	16	146	7	-7	358
	EE1	3	Gas(86%)	20%	242	166	16	147	7	-2	335
	EE1	1	Gas(86%)	20%	251	158	16	152	8	-2	332
	EE1	3	Gas CHP	0%	263	171	43	155	9	0	377
	EE1	1	Gas CHP	0%	273	162	43	161	9	0	375
	EE1	3	Gas(86%)	0%	291	139	13	170	8	0	330
	EE1	1	Gas(86%)	0%	300*	130	13	175	9	0	327
Sec. Sch (EE1) – 30 year calc	C	3	Gas CHP	20%	169	410	56	103	19	-57	531
	Window Only	3	Gas CHP	20%	176	208	56	106	21	-23	369
	Wall Only	3	Gas CHP	20%	182	193	56	109	22	-24	356
	EE1	3	Gas CHP	20%	184	186	56	110	23	-23	352
	Window Only	3	Gas(86%)	20%	196	166	18	119	20	-17	306
	Wall Only	3	Gas(86%)	20%	206	150	18	125	21	-19	295
	EE1	3	Gas(86%)	20%	210	144	18	127	21	-17	292
	Window Only	3	Gas(86%)	0%	221	149	16	134	20	-15	304
	EE1	3	Gas(86%)	0%	235*	126	16	142	22	-15	291
	EE1	1	Gas(86%)	0%	240	137	16	147	22	-16	305

Table 11.17c: Macroeconomic Costs (High energy price, 3.5% discount rate, £/m²) cont …

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE2) – 30 year calc	A	3	Gas CHP	20%	291	345	40	205	22	-48	563
	Window Only	3	Gas CHP	20%	294	220	40	206	22	-24	464
	EE2	3	Gas CHP	20%	297	192	40	205	25	-24	438
	EE2	2	Gas CHP	20%	304	195	40	210	25	-24	446
	Window Only	3	Gas(86%)	20%	309	190	12	216	21	-20	420
	EE2	3	Gas(91%) +SHW	20%	313	194	13	217	22	-24	422
	EE2	3	Gas(86%)	20%	319	162	12	220	22	-20	397
	EE2	3	Gas(86%)	0%	328*	156	12	225	23	-19	397
	EE2	2	Gas(86%)	0%	334	159	12	230	23	-19	405
	EE2	1	Gas(86%)	0%	341	163	12	237	23	-20	414
Hotel (EE2) – 20 year calc	C	3	Gas CHP	20%	480	429	32	243	21	-88	637
	B	3	Gas CHP	20%	485	408	32	245	22	-83	623
	Window Only	3	Gas CHP	20%	505	208	32	254	23	-14	503
	Roof Only	3	Gas CHP	20%	522	151	32	260	25	-8	460
	Roof Only	1	Gas CHP	20%	531	134	32	266	25	-8	449
	EE2	1	Gas CHP	0%	550	110	31	275	26	0	442
	Roof Only	2	Gas(91%) +SHW	20%	558	130	10	282	23	-8	437
	EE2	2	Gas(91%) +SHW	20%	575	108	10	291	24	0	432
	EE2	1	Gas(91%) +SHW	0%	585	98	9	296	24	0	428
	EE2	1	Gas(86%)	0%	605*	87	9	305	25	0	426
Office (EE2) – 20 year calc	D	3	Gas CHP	20%	74	330	40	44	3	-67	350
	A	3	Gas CHP	20%	80	265	40	46	4	-49	307
	Window Only	3	Gas CHP	20%	85	206	40	48	4	-28	271
	EE2	3	Gas CHP	20%	98	174	40	53	6	-22	250
	Window Only	3	Gas(86%)	20%	106	181	10	59	4	-28	225
	Wall Only	3	Gas(86%)	20%	121	168	10	66	5	-29	219
	EE2	3	Gas(86%)	20%	127	148	10	68	5	-22	209
	EE2	1	Gas(86%)	20%	135	140	10	74	5	-22	207
	EE2	3	Gas(86%)	0%	144	138	9	76	5	-22	206
	EE2	1	Gas(86%)	0%	151*	130	9	82	5	-22	204
Retail Whs (EE2) – 20 year calc	D	3	Gas CHP	20%	183	625	46	118	6	-141	653
	EE2	3	Gas CHP	20%	211	198	46	131	7	-2	382
	EE2	1	Gas CHP	20%	221	190	46	138	8	-2	380
	Window Only	3	Gas(86%)	20%	233	195	16	143	7	-7	355
	EE2	3	Gas(86%)	20%	235	166	16	144	7	-2	332
	EE2	1	Gas(86%)	20%	244	158	16	150	7	-2	330
	EE2	3	Gas CHP	0%	260	171	43	154	8	0	376
	EE2	1	Gas CHP	0%	270	162	43	161	9	0	374
	EE2	3	Gas(86%)	0%	284	139	13	167	8	0	327
	EE2	1	Gas(86%)	0%	293*	130	13	173	8	0	325
Sec. Sch (EE2) – 30 year calc	C	3	Gas CHP	20%	131	410	56	81	15	-57	505
	Window Only	3	Gas CHP	20%	137	208	56	84	16	-23	342
	Wall Only	3	Gas CHP	20%	143	193	56	88	18	-24	330
	Window Only	3	Gas(86%)	20%	152	166	18	95	15	-17	276
	Wall Only	3	Gas(86%)	20%	163	150	18	101	16	-19	267
	EE2	3	Gas(86%)	20%	165	144	18	102	17	-17	263
	EE2	1	Gas(86%)	20%	171	154	18	107	17	-19	277
	Window Only	3	Gas(86%)	0%	177	149	16	110	16	-15	275
	EE2	3	Gas(86%)	0%	190*	126	16	117	17	-15	262
	EE2	1	Gas(86%)	0%	195	137	16	122	17	-16	276

Table 11.17d: Macroeconomic Costs (Central energy price, 3% discount rate, £/m²)

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE1) – 30 year calc	A	3	Gas CHP	20%	315	351	42	191	25	-55	554
	Window Only	3	Gas CHP	20%	319	226	42	191	26	-27	459
	EE1	3	Gas CHP	20%	323	199	42	186	29	-27	429
	EE1	3	Gas CHP	0%	331	192	42	192	29	-26	429
	Window Only	3	Gas(86%)	20%	336	195	13	208	24	-23	418
	EE1	3	Gas(91%) +SHW	20%	341	201	14	207	25	-27	419
	EE1	3	Gas(86%)	20%	347	168	13	209	26	-23	394
	EE1	3	Gas(86%)	0%	356*	161	13	215	26	-22	393
	EE1	2	Gas(86%)	0%	362	167	13	220	26	-22	403
	EE1	1	Gas(86%)	0%	370	173	13	226	26	-23	414
Hotel (EE1) – 20 year calc	C	3	Gas CHP	20%	537	429	33	218	25	-96	609
	A	3	Gas CHP	20%	551	363	33	221	27	-78	566
	Window Only	3	Gas CHP	20%	568	208	33	226	28	-15	480
	Roof Only	3	Gas CHP	20%	585	151	33	227	30	-8	433
	Roof Only	2	Gas CHP	20%	591	141	33	231	30	-8	427
	EE1	2	Gas CHP	20%	604	120	33	236	31	0	419
	EE1	1	Gas CHP	20%	611	113	33	240	31	0	416
	EE1	2	Gas(91%) +SHW	20%	646	108	10	269	28	0	416
	EE1	1	Gas(91%) +SHW	20%	652	101	10	273	28	0	413
	EE1	1	Gas(86%)	0%	679*	87	10	282	30	0	408
Office (EE1) – 20 year calc	D	3	Gas CHP	20%	82	330	42	39	4	-74	340
	Window Only	3	Gas CHP	20%	96	143	42	40	5	-7	223
	Window Only	2	Gas CHP	20%	100	139	42	43	6	-7	222
	EE1	3	Gas CHP	20%	109	111	42	41	7	-1	200
	Window Only	3	Gas(86%)	20%	122	117	10	56	5	-7	182
	Window Only	1	Gas(86%)	20%	130	110	10	62	5	-7	180
	Window Only	3	Gas(86%)	0%	139	107	9	64	5	-6	180
	EE1	3	Gas(86%)	20%	144	85	10	63	6	-1	164
	EE1	1	Gas(86%)	20%	152	77	10	69	6	-1	162
	EE1	1	Gas(86%)	0%	168*	67	9	76	7	0	159
Retail Whs (EE1) – 20 year calc	D	3	Gas CHP	20%	191	625	48	106	7	-155	630
	Roof Only	3	Gas CHP	20%	208	390	48	111	8	-75	482
	EE1	3	Gas CHP	20%	214	198	48	112	8	-2	365
	Window Only	3	Gas(86%)	20%	240	195	17	129	8	-7	342
	EE1	3	Gas(86%)	20%	242	166	17	130	8	-2	319
	EE1	1	Gas(86%)	20%	251	158	17	135	8	-2	316
	EE1	3	Gas CHP	0%	263	171	45	134	10	0	359
	EE1	1	Gas CHP	0%	273	162	45	140	10	0	356
	EE1	3	Gas(86%)	0%	291	139	14	152	9	0	313
	EE1	1	Gas(86%)	0%	300*	130	14	157	9	0	310
Sec. Sch (EE1) – 30 year calc	C	3	Gas CHP	20%	169	416	60	75	21	-66	506
	Window Only	3	Gas CHP	20%	176	214	60	76	23	-26	347
	Wall Only	3	Gas CHP	20%	182	199	60	77	24	-28	332
	EE1	3	Gas CHP	20%	184	192	60	77	25	-26	328
	Window Only	3	Gas(86%)	20%	196	170	19	92	22	-20	284
	Wall Only	3	Gas(86%)	20%	206	155	19	96	23	-21	272
	EE1	3	Gas(86%)	20%	210	148	19	98	23	-20	269
	Window Only	3	Gas(86%)	0%	221	153	17	107	22	-17	282
	EE1	3	Gas(86%)	0%	235*	131	17	113	24	-17	267
	EE1	1	Gas(86%)	0%	240	142	17	118	24	-19	281

Table 11.17d: Macroeconomic Costs (Central energy price, 3% discount rate, £/m²) cont…

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE2) – 30 year calc	A	3	Gas CHP	20%	291	351	42	174	24	-55	536
	Window Only	3	Gas CHP	20%	294	226	42	175	24	-27	441
	EE2	3	Gas CHP	20%	297	199	42	170	27	-27	411
	EE2	2	Gas CHP	20%	304	201	42	175	27	-28	418
	Window Only	3	Gas(86%)	20%	309	195	13	189	22	-23	398
	EE2	3	Gas(91%) +SHW	20%	313	201	14	188	24	-27	399
	EE2	3	Gas(86%)	20%	319	168	13	190	24	-23	373
	EE2	3	Gas(86%)	0%	328*	161	13	195	25	-22	372
	EE2	2	Gas(86%)	0%	334	164	13	201	25	-22	380
	EE2	1	Gas(86%)	0%	341	168	13	207	25	-23	390
Hotel (EE2) – 20 year calc	C	3	Gas CHP	20%	480	429	33	197	22	-96	585
	B	3	Gas CHP	20%	485	408	33	198	23	-91	571
	Window Only	3	Gas CHP	20%	505	208	33	203	25	-15	453
	Roof Only	3	Gas CHP	20%	522	151	33	205	26	-8	407
	Roof Only	1	Gas CHP	20%	531	134	33	211	26	-8	396
	EE2	1	Gas CHP	0%	550	110	33	217	28	0	387
	Roof Only	2	Gas(91%) +SHW	20%	558	130	10	234	24	-8	390
	EE2	2	Gas(91%) +SHW	20%	575	108	10	241	25	0	385
	EE2	1	Gas(91%) +SHW	0%	585	98	10	246	25	0	380
	EE2	1	Gas(86%)	0%	605*	87	10	253	26	0	376
Office (EE2) – 20 year calc	D	3	Gas CHP	20%	74	330	42	37	3	-74	337
	A	3	Gas CHP	20%	80	265	42	37	4	-53	295
	Window Only	3	Gas CHP	20%	85	206	42	38	5	-31	259
	EE2	3	Gas CHP	20%	98	174	42	39	6	-25	236
	Window Only	3	Gas(86%)	20%	106	181	10	51	4	-31	215
	Wall Only	3	Gas(86%)	20%	121	168	10	55	5	-32	207
	EE2	3	Gas(86%)	20%	127	148	10	57	5	-25	197
	EE2	1	Gas(86%)	20%	135	140	10	63	5	-25	194
	EE2	3	Gas(86%)	0%	144	138	9	65	6	-24	194
	EE2	1	Gas(86%)	0%	151*	130	9	70	6	-24	192
Retail Whs (EE2) – 20 year calc	D	3	Gas CHP	20%	183	625	48	103	6	-155	627
	EE2	3	Gas CHP	20%	211	198	48	113	8	-2	366
	EE2	1	Gas CHP	20%	221	190	48	119	8	-2	363
	Window Only	3	Gas(86%)	20%	233	195	17	128	7	-7	340
	EE2	3	Gas(86%)	20%	235	166	17	128	7	-2	317
	EE2	1	Gas(86%)	20%	244	158	17	134	7	-2	315
	EE2	3	Gas CHP	0%	260	171	45	135	9	0	360
	EE2	1	Gas CHP	0%	270	162	45	142	9	0	357
	EE2	3	Gas(86%)	0%	284	139	14	150	8	0	311
	EE2	1	Gas(86%)	0%	293*	130	14	156	9	0	309
Sec. Sch (EE2) – 30 year calc	C	3	Gas CHP	20%	131	416	60	60	16	-66	486
	Window Only	3	Gas CHP	20%	137	214	60	61	18	-26	327
	Wall Only	3	Gas CHP	20%	143	199	60	62	19	-28	312
	Window Only	3	Gas(86%)	20%	152	170	19	74	16	-20	260
	Wall Only	3	Gas(86%)	20%	163	155	19	79	18	-21	249
	EE2	3	Gas(86%)	20%	165	148	19	79	18	-20	245
	EE2	1	Gas(86%)	20%	171	159	19	84	18	-21	259
	Window Only	3	Gas(86%)	0%	177	153	17	89	17	-17	259
	EE2	3	Gas(86%)	0%	190*	131	17	95	19	-17	244
	EE2	1	Gas(86%)	0%	195	142	17	99	19	-19	258

Table 11.17e: Macroeconomic Costs (Central energy price, 3.5% discount rate, alternative cost of carbon, £/m²)

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE1) – 30 year calc	A	3	Gas CHP	20%	315	345	40	180	64	-48	580
	Window Only	3	Gas CHP	20%	319	220	40	180	67	-24	483
	EE1	3	Gas CHP	20%	323	192	40	175	75	-24	458
	EE1	3	Gas CHP	0%	331	186	39	180	76	-23	458
	Window Only	3	Gas(86%)	20%	336	190	12	196	60	-20	439
	EE1	3	Gas(91%) +SHW	20%	341	194	13	194	64	-24	441
	EE1	3	Gas(86%)	20%	347	162	12	197	66	-20	417
	EE1	3	Gas(86%)	0%	356*	156	12	202	66	-19	417
	EE1	2	Gas(86%)	0%	362	162	12	207	66	-20	427
	EE1	1	Gas(86%)	0%	370	167	12	213	66	-20	438
Hotel (EE1) – 20 year calc	C	3	Gas CHP	20%	537	429	32	209	82	-88	664
	A	3	Gas CHP	20%	551	363	32	211	87	-71	622
	Window Only	3	Gas CHP	20%	568	208	32	216	92	-14	534
	Roof Only	3	Gas CHP	20%	585	151	32	218	99	-8	492
	Roof Only	2	Gas CHP	20%	591	141	32	222	99	-8	485
	EE1	2	Gas CHP	20%	604	120	32	225	102	0	479
	EE1	1	Gas CHP	20%	611	113	32	230	102	0	476
	EE1	2	Gas(91%) +SHW	20%	646	108	10	257	89	0	465
	EE1	1	Gas(91%) +SHW	20%	652	101	10	261	89	0	462
	EE1	1	Gas(86%)	0%	679*	87	9	270	94	0	460
Office (EE1) – 20 year calc	D	3	Gas CHP	20%	82	330	40	37	13	-67	352
	Window Only	3	Gas CHP	20%	96	143	40	38	19	-6	234
	Window Only	2	Gas CHP	20%	100	139	40	41	19	-6	232
	EE1	3	Gas CHP	20%	109	111	40	39	24	-1	213
	Window Only	3	Gas(86%)	20%	122	117	10	54	15	-6	190
	Window Only	1	Gas(86%)	20%	130	110	10	59	15	-6	188
	Window Only	3	Gas(86%)	0%	139	107	9	61	16	-6	188
	EE1	3	Gas(86%)	20%	144	85	10	60	19	-1	174
	EE1	1	Gas(86%)	20%	152	77	10	66	19	-1	171
	EE1	1	Gas(86%)	0%	168*	67	9	73	20	0	169
Retail Whs (EE1) – 20 year calc	D	3	Gas CHP	20%	191	625	46	101	19	-141	650
	Roof Only	3	Gas CHP	20%	208	390	46	106	23	-68	497
	EE1	3	Gas CHP	20%	214	198	46	107	26	-2	376
	Window Only	3	Gas(86%)	20%	240	195	16	123	21	-7	350
	EE1	3	Gas(86%)	20%	242	166	16	124	22	-2	327
	EE1	1	Gas(86%)	20%	251	158	16	129	22	-2	324
	EE1	3	Gas CHP	0%	263	171	43	129	28	0	370
	EE1	1	Gas CHP	0%	273	162	43	134	28	0	367
	EE1	3	Gas(86%)	0%	291	139	13	145	24	0	321
	EE1	1	Gas(86%)	0%	300*	130	13	151	24	0	318
Sec. Sch (EE1) – 30 year calc	C	3	Gas CHP	20%	169	410	56	71	57	-57	536
	Window Only	3	Gas CHP	20%	176	208	56	71	61	-23	374
	Wall Only	3	Gas CHP	20%	182	193	56	72	65	-24	363
	EE1	3	Gas CHP	20%	184	186	56	73	67	-23	359
	Window Only	3	Gas(86%)	20%	196	166	18	87	57	-17	310
	Wall Only	3	Gas(86%)	20%	206	150	18	91	60	-19	300
	EE1	3	Gas(86%)	20%	210	144	18	92	61	-17	298
	Window Only	3	Gas(86%)	0%	221	149	16	101	58	-15	309
	EE1	3	Gas(86%)	0%	235*	126	16	106	63	-15	296
	EE1	1	Gas(86%)	0%	240	137	16	111	63	-16	310

Table 11.17e: Macroeconomic Costs
(Central energy price, 3.5% discount rate, alternative cost of carbon, £/m²) cont …

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE2) – 30 year calc	A	3	Gas CHP	20%	291	345	40	164	61	-48	561
	Window Only	3	Gas CHP	20%	294	220	40	165	62	-24	463
	EE2	3	Gas CHP	20%	297	192	40	160	70	-24	438
	EE2	2	Gas CHP	20%	304	195	40	165	70	-24	445
	Window Only	3	Gas(86%)	20%	309	190	12	178	56	-20	417
	EE2	3	Gas(91%) +SHW	20%	313	194	13	177	60	-24	420
	EE2	3	Gas(86%)	20%	319	162	12	179	62	-20	396
	EE2	3	Gas(86%)	0%	328*	156	12	184	62	-19	395
	EE2	2	Gas(86%)	0%	334	159	12	189	62	-19	402
	EE2	1	Gas(86%)	0%	341	163	12	194	63	-20	412
Hotel (EE2) – 20 year calc	C	3	Gas CHP	20%	480	429	32	189	72	-88	634
	B	3	Gas CHP	20%	485	408	32	190	74	-83	620
	Window Only	3	Gas CHP	20%	505	208	32	194	80	-14	500
	Roof Only	3	Gas CHP	20%	522	151	32	196	87	-8	458
	Roof Only	1	Gas CHP	20%	531	134	32	202	87	-8	447
	EE2	1	Gas CHP	0%	550	110	31	208	90	0	439
	Roof Only	2	Gas(91%) +SHW	20%	558	130	10	224	76	-8	432
	EE2	2	Gas(91%) +SHW	20%	575	108	10	231	79	0	428
	EE2	1	Gas(91%) +SHW	0%	585	98	9	236	79	0	423
	EE2	1	Gas(86%)	0%	605*	87	9	242	83	0	421
Office (EE2) – 20 year calc	D	3	Gas CHP	20%	74	330	40	35	10	-67	347
	A	3	Gas CHP	20%	80	265	40	36	13	-49	305
	Window Only	3	Gas CHP	20%	85	206	40	36	15	-28	269
	A	3	Gas(86%)	20%	96	240	10	46	10	-49	257
	Window Only	3	Gas(86%)	20%	106	181	10	48	12	-28	223
	Wall Only	3	Gas(86%)	20%	121	168	10	53	15	-29	217
	EE2	3	Gas(86%)	20%	127	148	10	55	16	-22	207
	EE2	1	Gas(86%)	20%	135	140	10	60	16	-22	204
	EE2	3	Gas(86%)	0%	144	138	9	62	17	-22	204
	EE2	1	Gas(86%)	0%	151*	130	9	67	17	-22	201
Retail Whs (EE2) – 20 year calc	D	3	Gas CHP	20%	183	625	46	99	17	-141	645
	EE2	3	Gas CHP	20%	211	198	46	108	23	-2	374
	EE2	1	Gas CHP	20%	221	190	46	114	23	-2	372
	Window Only	3	Gas(86%)	20%	233	195	16	122	19	-7	347
	EE2	3	Gas(86%)	20%	235	166	16	123	20	-2	324
	EE2	1	Gas(86%)	20%	244	158	16	129	20	-2	321
	EE2	3	Gas CHP	0%	260	171	43	130	25	0	368
	EE2	1	Gas CHP	0%	270	162	43	136	26	0	366
	EE2	3	Gas(86%)	0%	284	139	13	144	22	0	318
	EE2	1	Gas(86%)	0%	293*	130	13	150	22	0	315
Sec. Sch (EE2) – 30 year calc	C	3	Gas CHP	20%	131	410	56	57	43	-57	508
	Window Only	3	Gas CHP	20%	137	208	56	58	47	-23	346
	Wall Only	3	Gas CHP	20%	143	193	56	58	51	-24	335
	Window Only	3	Gas(86%)	20%	152	166	18	69	43	-17	279
	Wall Only	3	Gas(86%)	20%	163	150	18	74	47	-19	271
	EE2	3	Gas(86%)	20%	165	144	18	75	48	-17	266
	EE2	1	Gas(86%)	20%	171	154	18	79	47	-19	280
	Window Only	3	Gas(86%)	0%	177	149	16	84	45	-15	278
	EE2	3	Gas(86%)	0%	190*	126	16	89	49	-15	265
	EE2	1	Gas(86%)	0%	195	137	16	93	49	-16	279

Table 11.18a: Financial Costs (Central energy price, 6% discount rate, £/m²)

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE1) – 30 year calc	A	3	Gas CHP	20%	315	385	36	251	-	-29	643
	Window Only	3	Gas CHP	20%	319	235	36	252	-	-14	509
	EE1	3	Gas CHP	20%	323	202	36	246	-	-14	470
	EE1	3	Gas CHP	0%	331	195	36	252	-	-14	469
	Window Only	3	Gas(86%)	20%	336	204	11	270	-	-12	473
	EE1	3	Gas(91%) +SHW	20%	341	204	12	267	-	-14	468
	EE1	3	Gas(86%)	20%	347	171	11	270	-	-12	440
	EE1	3	Gas(86%)	0%	356*	164	11	276	-	-11	440
	EE1	2	Gas(86%)	0%	362	170	11	283	-	-12	452
	EE1	1	Gas(86%)	0%	370	175	11	292	-	-12	465
Hotel (EE1) – 20 year calc	C	3	Gas CHP	20%	537	514	31	313	-	-67	791
	A	3	Gas CHP	20%	551	436	31	317	-	-54	729
	Window Only	3	Gas CHP	20%	568	249	31	325	-	-10	595
	Roof Only	3	Gas CHP	20%	585	181	31	328	-	-6	535
	Roof Only	2	Gas CHP	20%	591	169	31	334	-	-6	529
	EE1	2	Gas CHP	20%	604	144	31	341	-	0	515
	EE1	1	Gas CHP	20%	611	135	31	347	-	0	513
	EE1	2	Gas(91%) +SHW	20%	646	130	10	378	-	0	517
	EE1	1	Gas(91%) +SHW	20%	652	122	10	384	-	0	515
	EE1	1	Gas(86%)	0%	679*	104	9	396	-	0	509
Office (EE1) – 20 year calc	D	3	Gas CHP	20%	82	395	39	60	-	-51	443
	Window Only	3	Gas CHP	20%	96	172	39	63	-	-5	268
	Window Only	2	Gas CHP	20%	100	167	39	67	-	-5	268
	EE1	3	Gas CHP	20%	109	133	39	65	-	0	237
	Window Only	3	Gas(86%)	20%	122	141	10	82	-	-5	227
	Window Only	1	Gas(86%)	20%	130	131	10	90	-	-5	226
	Window Only	3	Gas(86%)	0%	139	129	8	91	-	-4	224
	EE1	3	Gas(86%)	20%	144	102	10	91	-	0	202
	EE1	1	Gas(86%)	20%	152	93	10	99	-	0	201
	EE1	1	Gas(86%)	0%	168*	81	8	108	-	0	197
Retail Whs (EE1) – 20 year calc	D	3	Gas CHP	20%	191	750	45	161	-	-108	848
	Roof Only	3	Gas CHP	20%	208	468	45	169	-	-52	631
	EE1	3	Gas CHP	20%	214	238	45	171	-	-1	453
	Window Only	3	Gas(86%)	20%	240	235	16	191	-	-5	436
	EE1	3	Gas(86%)	20%	242	200	16	192	-	-1	406
	EE1	1	Gas(86%)	20%	251	189	16	200	-	-1	404
	EE1	3	Gas CHP	0%	263	205	42	199	-	0	445
	EE1	1	Gas CHP	0%	273	194	42	207	-	0	443
	EE1	3	Gas(86%)	0%	291	167	13	219	-	0	398
	EE1	1	Gas(86%)	0%	300*	156	13	227	-	0	396
Sec. Sch (EE1) – 30 year calc	C	3	Gas CHP	20%	169	464	51	98	-	-34	579
	Window Only	3	Gas CHP	20%	176	222	51	100	-	-14	360
	Wall Only	3	Gas CHP	20%	182	204	51	101	-	-14	342
	EE1	3	Gas CHP	20%	184	196	51	102	-	-14	335
	Window Only	3	Gas(86%)	20%	196	178	16	117	-	-10	301
	Wall Only	3	Gas(86%)	20%	206	160	16	122	-	-11	287
	EE1	3	Gas(86%)	20%	210	152	16	124	-	-10	282
	Window Only	3	Gas(86%)	0%	221	159	15	134	-	-9	299
	EE1	3	Gas(86%)	0%	235*	133	15	141	-	-9	279
	EE1	1	Gas(86%)	0%	240	144	15	147	-	-10	296

Table 11.18a: Financial Costs (Central energy price, 6% discount rate, £/m²) cont …

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE2) – 30 year calc	A	3	Gas CHP	20%	291	385	36	229	-	-29	621
	Window Only	3	Gas CHP	20%	294	235	36	230	-	-14	487
	EE2	3	Gas CHP	20%	297	202	36	224	-	-14	448
	EE2	2	Gas CHP	20%	304	204	36	231	-	-14	457
	EE2	3	Gas CHP	0%	306	195	36	230	-	-14	447
	EE2	3	Gas(91%) +SHW	20%	313	204	12	243	-	-14	444
	EE2	3	Gas(86%)	20%	319	171	11	245	-	-12	415
	EE2	3	Gas(86%)	0%	328*	164	11	251	-	-11	414
	EE2	2	Gas(86%)	0%	334	167	11	258	-	-12	424
	EE2	1	Gas(86%)	0%	341	171	11	266	-	-12	436
Hotel (EE2) – 20 year calc	C	3	Gas CHP	20%	480	514	31	283	-	-67	761
	B	3	Gas CHP	20%	485	489	31	284	-	-63	741
	Window Only	3	Gas CHP	20%	505	249	31	292	-	-10	562
	Roof Only	3	Gas CHP	20%	522	181	31	296	-	-6	502
	Roof Only	1	Gas CHP	20%	531	161	31	305	-	-6	491
	EE2	1	Gas CHP	0%	550	132	31	314	-	0	477
	Roof Only	2	Gas(91%) +SHW	20%	558	156	10	330	-	-6	489
	EE2	2	Gas(91%) +SHW	20%	575	130	10	339	-	0	479
	EE2	1	Gas(91%) +SHW	0%	585	118	9	347	-	0	474
	EE2	1	Gas(86%)	0%	605*	104	9	355	-	0	469
Office (EE2) – 20 year calc	D	3	Gas CHP	20%	74	395	39	57	-	-51	440
	A	3	Gas CHP	20%	80	318	39	58	-	-37	378
	Window Only	3	Gas CHP	20%	85	247	39	59	-	-21	324
	EE2	3	Gas CHP	20%	98	209	39	62	-	-17	292
	Window Only	3	Gas(86%)	20%	106	217	10	74	-	-21	279
	Wall Only	3	Gas(86%)	20%	121	202	10	80	-	-22	269
	EE2	3	Gas(86%)	20%	127	178	10	83	-	-17	253
	EE2	1	Gas(86%)	20%	135	168	10	91	-	-17	252
	EE2	3	Gas(86%)	0%	144	166	8	92	-	-17	250
	EE2	1	Gas(86%)	0%	151*	156	8	100	-	-17	248
Retail Whs (EE2) – 20 year calc	D	3	Gas CHP	20%	183	750	45	157	-	-108	844
	EE2	3	Gas CHP	20%	211	238	45	172	-	-1	454
	EE2	1	Gas CHP	20%	221	228	45	181	-	-1	453
	Window Only	3	Gas(86%)	20%	233	235	16	189	-	-5	434
	EE2	3	Gas(86%)	20%	235	200	16	190	-	-1	404
	EE2	1	Gas(86%)	20%	244	189	16	199	-	-1	402
	EE2	3	Gas CHP	0%	260	205	42	200	-	0	446
	EE2	1	Gas CHP	0%	270	194	42	209	-	0	445
	EE2	3	Gas(86%)	0%	284	167	13	217	-	0	397
	EE2	1	Gas(86%)	0%	293*	156	13	226	-	0	395
Sec. Sch (EE2) – 30 year calc	C	3	Gas CHP	20%	131	464	51	80	-	-34	561
	Window Only	3	Gas CHP	20%	137	222	51	81	-	-14	341
	Wall Only	3	Gas CHP	20%	143	204	51	83	-	-14	324
	Window Only	3	Gas(86%)	20%	152	178	16	95	-	-10	279
	Wall Only	3	Gas(86%)	20%	163	160	16	100	-	-11	265
	EE2	3	Gas(86%)	20%	165	152	16	101	-	-10	259
	EE2	1	Gas(86%)	20%	171	163	16	108	-	-11	276
	Window Only	3	Gas(86%)	0%	177	159	15	111	-	-9	276
	EE2	3	Gas(86%)	0%	190*	133	15	118	-	-9	256
	EE2	1	Gas(86%)	0%	195	144	15	124	-	-10	273

Table 11.18b: Financial Costs (Low energy price, 6% discount rate, £/m²)

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE1) – 30 year calc	A	3	Gas CHP	20%	315	385	36	211	-	-29	603
	Window Only	3	Gas CHP	20%	319	235	36	211	-	-14	468
	EE1	3	Gas CHP	20%	323	202	36	202	-	-14	426
	EE1	3	Gas CHP	0%	331	195	36	208	-	-14	425
	Window Only	3	Gas(86%)	20%	336	204	11	231	-	-12	434
	EE1	3	Gas(91%) +SHW	20%	341	204	12	227	-	-14	428
	EE1	3	Gas(86%)	20%	347	171	11	229	-	-12	399
	EE1	3	Gas(86%)	0%	356*	164	11	235	-	-11	398
	EE1	2	Gas(86%)	0%	362	170	11	241	-	-12	410
	EE1	1	Gas(86%)	0%	370	175	11	249	-	-12	423
Hotel (EE1) – 20 year calc	C	3	Gas CHP	20%	537	514	31	252	-	-67	730
	A	3	Gas CHP	20%	551	436	31	253	-	-54	665
	Window Only	3	Gas CHP	20%	568	249	31	258	-	-10	528
	Roof Only	3	Gas CHP	20%	585	181	31	257	-	-6	464
	Roof Only	2	Gas CHP	20%	591	169	31	263	-	-6	457
	EE1	2	Gas CHP	20%	604	144	31	267	-	0	441
	EE1	1	Gas CHP	20%	611	135	31	273	-	0	439
	EE1	2	Gas(91%) +SHW	20%	646	130	10	310	-	0	450
	EE1	1	Gas(91%) +SHW	20%	652	122	10	316	-	0	447
	EE1	1	Gas(86%)	0%	679*	104	9	325	-	0	438
Office (EE1) – 20 year calc	D	3	Gas CHP	20%	82	395	39	48	-	-51	431
	Window Only	3	Gas CHP	20%	96	172	39	48	-	-5	254
	Window Only	2	Gas CHP	20%	100	167	39	52	-	-5	253
	EE1	3	Gas CHP	20%	109	133	39	48	-	0	219
	Window Only	3	Gas(86%)	20%	122	141	10	68	-	-5	214
	Window Only	1	Gas(86%)	20%	130	131	10	76	-	-5	213
	Window Only	3	Gas(86%)	0%	139	129	8	77	-	-4	210
	EE1	3	Gas(86%)	20%	144	102	10	75	-	0	186
	EE1	1	Gas(86%)	20%	152	93	10	83	-	0	185
	EE1	1	Gas(86%)	0%	168*	81	8	91	-	0	180
Retail Whs (EE1) – 20 year calc	D	3	Gas CHP	20%	191	750	45	139	-	-108	826
	Roof Only	3	Gas CHP	20%	208	468	45	145	-	-52	606
	EE	3	Gas CHP	20%	214	238	45	145	-	-1	427
	Window Only	3	Gas(86%)	20%	240	235	16	166	-	-5	412
	EE1	3	Gas(86%)	20%	242	200	16	167	-	-1	382
	EE1	1	Gas(86%)	20%	251	189	16	175	-	-1	378
	EE1	3	Gas CHP	0%	263	205	42	171	-	0	417
	EE1	1	Gas CHP	0%	273	194	42	178	-	0	414
	EE1	3	Gas(86%)	0%	291	167	13	192	-	0	372
	EE1	1	Gas(86%)	0%	300*	156	13	200	-	0	369
Sec. Sch (EE1) – 30 year calc	C	3	Gas CHP	20%	169	464	51	71	-	-34	552
	Window Only	3	Gas CHP	20%	176	222	51	71	-	-14	331
	Wall Only	3	Gas CHP	20%	182	204	51	71	-	-14	312
	EE1	3	Gas CHP	20%	184	196	51	71	-	-14	304
	Window Only	3	Gas(86%)	20%	196	178	16	89	-	-10	274
	Wall Only	3	Gas(86%)	20%	206	160	16	93	-	-11	258
	EE1	3	Gas(86%)	20%	210	152	16	94	-	-10	252
	Window Only	3	Gas(86%)	0%	221	159	15	105	-	-9	270
	EE1	3	Gas(86%)	0%	235*	133	15	110	-	-9	248
	EE1	1	Gas(86%)	0%	240	144	15	116	-	-10	265

Table 11.18b: Financial Costs (Low energy price, 6% discount rate, £/m²) cont ….

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE2) – 30 year calc	A	3	Gas CHP	20%	291	385	36	192	-	-29	584
	Window Only	3	Gas CHP	20%	294	235	36	193	-	-14	449
	EE2	3	Gas CHP	20%	297	202	36	184	-	-14	407
	EE2	2	Gas CHP	20%	304	204	36	190	-	-14	417
	EE2	3	Gas CHP	0%	306	195	36	189	-	-14	406
	EE2	3	Gas(91%) +SHW	20%	313	204	12	205	-	-14	406
	EE2	3	Gas(86%)	20%	319	171	11	207	-	-12	377
	EE2	3	Gas(86%)	0%	328*	164	11	213	-	-11	376
	EE2	2	Gas(86%)	0%	334	167	11	219	-	-12	385
	EE2	1	Gas(86%)	0%	341	171	11	227	-	-12	396
Hotel (EE2) – 20 year calc	C	3	Gas CHP	20%	480	514	31	229	-	-67	707
	B	3	Gas CHP	20%	485	489	31	229	-	-63	686
	Window Only	3	Gas CHP	20%	505	249	31	233	-	-10	503
	Roof Only	3	Gas CHP	20%	522	181	31	233	-	-6	439
	Roof Only	1	Gas CHP	20%	531	161	31	242	-	-6	428
	EE2	1	Gas CHP	0%	550	132	31	249	-	0	411
	Roof Only	2	Gas(91%) +SHW	20%	558	156	10	271	-	-6	431
	EE2	2	Gas(91%) +SHW	20%	575	130	10	279	-	0	419
	EE2	1	Gas(91%) +SHW	0%	585	118	9	286	-	0	413
	EE2	1	Gas(86%)	0%	605*	104	9	292	-	0	406
Office (EE2) – 20 year calc	D	3	Gas CHP	20%	74	395	39	47	-	-51	430
	A	3	Gas CHP	20%	80	318	39	47	-	-37	367
	Window Only	3	Gas CHP	20%	85	247	39	47	-	-21	312
	EE	3	Gas CHP	20%	98	209	39	47	-	-17	277
	Window Only	3	Gas(86%)	20%	106	217	10	63	-	-21	268
	Wall Only	3	Gas(86%)	20%	121	202	10	67	-	-22	256
	EE2	3	Gas(86%)	20%	127	178	10	69	-	-17	239
	EE2	1	Gas(86%)	20%	135	168	10	77	-	-17	238
	EE2	3	Gas(86%)	0%	144	166	8	78	-	-17	235
	EE2	1	Gas(86%)	0%	151*	156	8	85	-	-17	234
Retail Whs (EE2) – 20 year calc	D	3	Gas CHP	20%	183	750	45	137	-	-108	824
	EE2	3	Gas CHP	20%	211	238	45	148	-	-1	429
	EE2	1	Gas CHP	20%	221	228	45	156	-	-1	427
	Window Only	3	Gas(86%)	20%	233	235	16	166	-	-5	411
	EE2	3	Gas(86%)	20%	235	200	16	166	-	-1	381
	EE2	1	Gas(86%)	20%	244	189	16	174	-	-1	378
	EE2	3	Gas CHP	0%	260	205	42	173	-	0	419
	EE2	1	Gas CHP	0%	270	194	42	181	-	0	417
	EE2	3	Gas(86%)	0%	284	167	13	192	-	0	371
	EE2	1	Gas(86%)	0%	293*	156	13	200	-	0	368
Sec. Sch (EE2) – 30 year calc	C	3	Gas CHP	20%	131	464	51	59	-	-34	540
	Window Only	3	Gas CHP	20%	137	222	51	59	-	-14	319
	Wall Only	3	Gas CHP	20%	143	204	51	59	-	-14	299
	Window Only	3	Gas(86%)	20%	152	178	16	73	-	-10	257
	Wall Only	3	Gas(86%)	20%	163	160	16	77	-	-11	242
	EE2	3	Gas(86%)	20%	165	152	16	78	-	-10	236
	EE2	1	Gas(86%)	20%	171	163	16	84	-	-11	252
	Window Only	3	Gas(86%)	0%	177	159	15	89	-	-9	254
	EE2	3	Gas(86%)	0%	190*	133	15	94	-	-9	232
	EE2	1	Gas(86%)	0%	195	144	15	100	-	-10	248

Table 11.18c: Financial Costs (High energy price, 6% discount rate, £/m²)

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE1) – 30 year calc	A	3	Gas CHP	20%	315	385	36	296	-	-29	688
	Window Only	3	Gas CHP	20%	319	235	36	298	-	-14	555
	EE1	3	Gas CHP	20%	323	202	36	296	-	-14	519
	EE1	3	Gas CHP	0%	331	195	36	302	-	-14	519
	Window Only	3	Gas(86%)	20%	336	204	11	313	-	-12	516
	EE1	3	Gas(91%) +SHW	20%	341	204	12	312	-	-14	513
	EE1	3	Gas(86%)	20%	347	171	11	316	-	-12	486
	EE1	3	Gas(86%)	0%	356*	164	11	322	-	-11	485
	EE1	2	Gas(86%)	0%	362	170	11	329	-	-12	498
	EE1	1	Gas(86%)	0%	370	175	11	338	-	-12	512
Hotel (EE1) – 20 year calc	C	3	Gas CHP	20%	537	514	31	380	-	-67	858
	A	3	Gas CHP	20%	551	436	31	388	-	-54	800
	Window Only	3	Gas CHP	20%	568	249	31	399	-	-10	669
	Roof Only	3	Gas CHP	20%	585	181	31	407	-	-6	613
	Roof Only	2	Gas CHP	20%	591	169	31	413	-	-6	607
	EE1	2	Gas CHP	20%	604	144	31	422	-	0	596
	EE1	1	Gas CHP	20%	611	135	31	429	-	0	595
	EE1	2	Gas(91%) +SHW	20%	646	130	10	452	-	0	591
	EE1	1	Gas(91%) +SHW	20%	652	122	10	458	-	0	589
	EE1	1	Gas(86%)	0%	679*	104	9	473	-	0	586
Office (EE1) – 20 year calc	D	3	Gas CHP	20%	82	395	39	72	-	-51	455
	Window Only	3	Gas CHP	20%	96	172	39	78	-	-5	284
	Window Only	2	Gas CHP	20%	100	167	39	83	-	-5	284
	EE1	3	Gas CHP	20%	109	133	39	85	-	0	256
	Window Only	3	Gas(86%)	20%	122	141	10	96	-	-5	241
	Window Only	1	Gas(86%)	20%	130	131	10	104	-	-5	241
	Window Only	3	Gas(86%)	0%	139	129	8	105	-	-4	239
	EE1	3	Gas(86%)	20%	144	102	10	108	-	0	219
	EE1	1	Gas(86%)	20%	152	93	10	116	-	0	218
	EE1	1	Gas(86%)	0%	168*	81	8	126	-	0	215
Retail Whs (EE1) – 20 year calc	D	3	Gas CHP	20%	191	750	45	184	-	-108	871
	Roof Only	3	Gas CHP	20%	208	468	45	195	-	-52	656
	EE1	3	Gas CHP	20%	214	238	45	199	-	-1	480
	Window Only	3	Gas(86%)	20%	240	235	16	216	-	-5	461
	EE1	3	Gas(86%)	20%	242	200	16	217	-	-1	431
	EE1	1	Gas(86%)	20%	251	189	16	226	-	-1	429
	EE1	3	Gas CHP	0%	263	205	42	228	-	0	475
	EE1	1	Gas CHP	0%	273	194	42	237	-	0	473
	EE1	3	Gas(86%)	0%	291	167	13	246	-	0	425
	EE1	1	Gas(86%)	0%	300*	156	13	255	-	0	424
Sec. Sch (EE1) – 30 year calc	C	3	Gas CHP	20%	169	464	51	130	-	-34	611
	Window Only	3	Gas CHP	20%	176	222	51	134	-	-14	394
	Wall Only	3	Gas CHP	20%	182	204	51	137	-	-14	378
	EE1	3	Gas CHP	20%	184	196	51	139	-	-14	372
	Window Only	3	Gas(86%)	20%	196	178	16	149	-	-10	334
	Wall Only	3	Gas(86%)	20%	206	160	16	156	-	-11	321
	EE1	3	Gas(86%)	20%	210	152	16	159	-	-10	316
	Window Only	3	Gas(86%)	0%	221	159	15	167	-	-9	332
	EE1	3	Gas(86%)	0%	235*	133	15	177	-	-9	315
	EE1	1	Gas(86%)	0%	240	144	15	183	-	-10	332

Table 11.18c: Financial Costs (High energy price, 6% discount rate, £/m²) cont …

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE2) – 30 year calc	A	3	Gas CHP	20%	291	385	36	271	-	-29	663
	Window Only	3	Gas CHP	20%	294	235	36	273	-	-14	530
	EE2	3	Gas CHP	20%	297	202	36	270	-	-14	493
	EE2	2	Gas CHP	20%	304	204	36	277	-	-14	504
	EE2	3	Gas CHP	0%	306	195	36	276	-	-14	493
	EE2	3	Gas(91%) +SHW	20%	313	204	12	284	-	-14	485
	EE2	3	Gas(86%)	20%	319	171	11	287	-	-12	457
	EE2	3	Gas(86%)	0%	328*	164	11	294	-	-11	457
	EE2	2	Gas(86%)	0%	334	167	11	301	-	-12	467
	EE2	1	Gas(86%)	0%	341	171	11	310	-	-12	480
Hotel (EE2) – 20 year calc	C	3	Gas CHP	20%	480	514	31	342	-	-67	821
	B	3	Gas CHP	20%	485	489	31	345	-	-63	802
	Window Only	3	Gas CHP	20%	505	249	31	357	-	-10	627
	Roof Only	3	Gas CHP	20%	522	181	31	365	-	-6	572
	Roof Only	1	Gas CHP	20%	531	161	31	375	-	-6	561
	EE2	1	Gas CHP	0%	550	132	31	387	-	0	549
	Roof Only	2	Gas(91%) +SHW	20%	558	156	10	393	-	-6	552
	EE2	2	Gas(91%) +SHW	20%	575	130	10	405	-	0	544
	EE2	1	Gas(91%) +SHW	0%	585	118	9	413	-	0	540
	EE2	1	Gas(86%)	0%	605*	104	9	424	-	0	537
Office (EE2) – 20 year calc	D	3	Gas CHP	20%	74	395	39	67	-	-51	450
	A	3	Gas CHP	20%	80	318	39	69	-	-37	390
	Window Only	3	Gas CHP	20%	85	247	39	72	-	-21	337
	EE2	3	Gas CHP	20%	98	209	39	78	-	-17	309
	Window Only	3	Gas(86%)	20%	106	217	10	86	-	-21	291
	Wall Only	3	Gas(86%)	20%	121	202	10	94	-	-22	283
	EE2	3	Gas(86%)	20%	127	178	10	97	-	-17	268
	EE2	1	Gas(86%)	20%	135	168	10	106	-	-17	267
	EE2	3	Gas(86%)	0%	144	166	8	107	-	-17	265
	EE2	1	Gas(86%)	0%	151*	156	8	116	-	-17	264
Retail Whs (EE2) – 20 year calc	D	3	Gas CHP	20%	183	750	45	179	-	-108	865
	EE2	3	Gas CHP	20%	211	238	45	198	-	-1	480
	EE2	1	Gas CHP	20%	221	228	45	208	-	-1	479
	Window Only	3	Gas(86%)	20%	233	235	16	213	-	-5	458
	EE2	3	Gas(86%)	20%	235	200	16	214	-	-1	429
	EE2	1	Gas(86%)	20%	244	189	16	224	-	-1	427
	EE2	3	Gas CHP	0%	260	205	42	228	-	0	474
	EE2	1	Gas CHP	0%	270	194	42	237	-	0	473
	EE2	3	Gas(86%)	0%	284	167	13	243	-	0	423
	EE2	1	Gas(86%)	0%	293*	156	13	253	-	0	421
Sec. Sch (EE2) – 30 year calc	C	3	Gas CHP	20%	131	464	51	104	-	-34	585
	Window Only	3	Gas CHP	20%	137	222	51	108	-	-14	367
	Wall Only	3	Gas CHP	20%	143	204	51	112	-	-14	352
	Window Only	3	Gas(86%)	20%	152	178	16	120	-	-10	304
	Wall Only	3	Gas(86%)	20%	163	160	16	127	-	-11	292
	EE2	3	Gas(86%)	20%	165	152	16	129	-	-10	286
	EE2	1	Gas(86%)	20%	171	163	16	135	-	-11	303
	Window Only	3	Gas(86%)	0%	177	159	15	138	-	-9	302
	EE2	3	Gas(86%)	0%	190*	133	15	147	-	-9	285
	EE2	1	Gas(86%)	0%	195	144	15	153	-	-10	302

Table 11.18d: Financial Costs (Central energy price, 10% discount rate, £/m²)

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE1) – 30 year calc	A	3	Gas CHP	20%	315	360	25	175	-	-10	550
	Window Only	3	Gas CHP	20%	319	210	25	175	-	-5	406
	EE1	3	Gas CHP	20%	323	177	25	171	-	-5	368
	EE1	3	Gas CHP	0%	331	171	25	175	-	-5	366
	Window Only	3	Gas(86%)	20%	336	183	8	188	-	-4	375
	EE1	3	Gas(91%) +SHW	20%	341	179	8	186	-	-5	368
	EE1	3	Gas(86%)	20%	347	150	8	188	-	-4	342
	EE1	3	Gas(86%)	0%	356*	144	7	192	-	-4	339
	EE1	2	Gas(86%)	0%	362	149	7	197	-	-4	349
	EE1	1	Gas(86%)	0%	370	154	7	203	-	-4	360
Hotel (EE1) – 20 year calc	C	3	Gas CHP	20%	537	514	23	237	-	-33	741
	A	3	Gas CHP	20%	551	436	23	240	-	-27	672
	Window Only	3	Gas CHP	20%	568	249	23	246	-	-5	513
	Roof Only	3	Gas CHP	20%	585	181	23	248	-	-3	450
	Roof Only	2	Gas CHP	20%	591	169	23	253	-	-3	442
	EE1	2	Gas CHP	20%	604	144	23	258	-	0	424
	EE1	1	Gas CHP	20%	611	135	23	262	-	0	421
	EE1	2	Gas(91%) +SHW	20%	646	130	7	286	-	0	423
	EE1	1	Gas(91%) +SHW	20%	652	122	7	290	-	0	419
	EE1	1	Gas(86%)	0%	679*	104	7	299	-	0	411
Office (EE1) – 20 year calc	D	3	Gas CHP	20%	82	395	29	45	-	-25	444
	Window Only	3	Gas CHP	20%	96	172	29	47	-	-2	246
	Window Only	2	Gas CHP	20%	100	167	29	50	-	-2	244
	EE1	3	Gas CHP	20%	109	133	29	49	-	0	211
	Window Only	3	Gas(86%)	20%	122	141	7	62	-	-2	207
	Window Only	1	Gas(86%)	20%	130	131	7	68	-	-2	204
	Window Only	3	Gas(86%)	0%	139	129	6	69	-	-2	202
	EE1	3	Gas(86%)	20%	144	102	7	69	-	0	178
	EE1	1	Gas(86%)	20%	152	93	7	75	-	0	174
	EE1	1	Gas(86%)	0%	168*	81	6	82	-	0	169
Retail Whs (EE1) – 20 year calc	D	3	Gas CHP	20%	191	750	34	122	-	-53	852
	Roof Only	3	Gas CHP	20%	208	468	34	128	-	-26	604
	EE1	3	Gas CHP	20%	214	238	34	129	-	-1	401
	Window Only	3	Gas(86%)	20%	240	235	12	144	-	-3	388
	EE1	3	Gas(86%)	20%	242	200	12	145	-	-1	356
	EE1	1	Gas(86%)	20%	251	189	12	151	-	-1	351
	EE1	3	Gas CHP	0%	263	205	31	150	-	0	386
	EE1	1	Gas CHP	0%	273	194	31	157	-	0	382
	EE1	3	Gas(86%)	0%	291	167	10	166	-	0	342
	EE1	1	Gas(86%)	0%	300*	156	10	172	-	0	337
Sec. Sch (EE1) – 30 year calc	C	3	Gas CHP	20%	169	441	36	68	-	-12	533
	Window Only	3	Gas CHP	20%	176	199	36	69	-	-5	299
	Wall Only	3	Gas CHP	20%	182	180	36	70	-	-5	281
	EE1	3	Gas CHP	20%	184	172	36	71	-	-5	274
	Window Only	3	Gas(86%)	20%	196	161	11	81	-	-4	250
	Wall Only	3	Gas(86%)	20%	206	142	11	85	-	-4	235
	EE1	3	Gas(86%)	20%	210	134	11	86	-	-4	228
	Window Only	3	Gas(86%)	0%	221	143	10	93	-	-3	243
	EE1	3	Gas(86%)	0%	235*	117	10	98	-	-3	221
	EE1	1	Gas(86%)	0%	240	126	10	102	-	-3	235

Table 11.18d: Financial Costs (Central energy price, 10% discount rate, £/m²) cont ….

Building	Package				PE (KWh/m²)	Initial Invest. Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Services	Heating	PV			Maint.	Energy			
Hospital (EE2) – 30 year calc	A	3	Gas CHP	20%	291	360	25	159	-	-10	534
	Window Only	3	Gas CHP	20%	294	210	25	160	-	-5	391
	EE2	3	Gas CHP	20%	297	177	25	156	-	-5	353
	EE2	2	Gas CHP	20%	304	179	25	161	-	-5	360
	EE2	3	Gas CHP	0%	306	171	25	160	-	-5	351
	EE2	3	Gas(91%) +SHW	20%	313	179	8	169	-	-5	351
	EE2	3	Gas(86%)	20%	319	150	8	170	-	-4	324
	EE2	3	Gas(86%)	0%	328*	144	7	175	-	-4	322
	EE2	2	Gas(86%)	0%	334	146	7	179	-	-4	329
	EE2	1	Gas(86%)	0%	341	150	7	185	-	-4	338
Hotel (EE2) – 20 year calc	C	3	Gas CHP	20%	480	514	23	214	-	-33	719
	B	3	Gas CHP	20%	485	489	23	215	-	-31	696
	Window Only	3	Gas CHP	20%	505	249	23	221	-	-5	489
	Roof Only	3	Gas CHP	20%	522	181	23	224	-	-3	425
	Roof Only	1	Gas CHP	20%	531	161	23	231	-	-3	412
	EE2	1	Gas CHP	0%	550	132	23	238	-	0	392
	Roof Only	2	Gas(91%) +SHW	20%	558	156	7	249	-	-3	409
	EE2	2	Gas(91%) +SHW	20%	575	130	7	257	-	0	394
	EE2	1	Gas(91%) +SHW	0%	585	118	7	262	-	0	387
	EE2	1	Gas(86%)	0%	605*	104	7	269	-	0	380
Office (EE2) – 20 year calc	D	3	Gas CHP	20%	74	395	29	43	-	-25	442
	A	3	Gas CHP	20%	80	318	29	44	-	-18	373
	Window Only	3	Gas CHP	20%	85	247	29	45	-	-11	311
	EE2	3	Gas CHP	20%	98	209	29	47	-	-8	276
	Window Only	3	Gas(86%)	20%	106	217	7	56	-	-11	269
	Wall Only	3	Gas(86%)	20%	121	202	7	61	-	-11	259
	EE2	3	Gas(86%)	20%	127	178	7	63	-	-8	239
	EE2	1	Gas(86%)	20%	135	168	7	69	-	-8	236
	EE2	3	Gas(86%)	0%	144	166	6	70	-	-8	234
	EE2	1	Gas(86%)	0%	151*	156	6	76	-	-8	230
Retail Whs (EE2) – 20 year calc	D	3	Gas CHP	20%	183	750	34	119	-	-53	849
	EE2	3	Gas CHP	20%	211	238	34	130	-	-1	401
	EE2	1	Gas CHP	20%	221	228	34	137	-	-1	398
	Window Only	3	Gas(86%)	20%	233	235	12	143	-	-3	387
	EE2	3	Gas(86%)	20%	235	200	12	144	-	-1	355
	EE2	1	Gas(86%)	20%	244	189	12	150	-	-1	351
	EE2	3	Gas CHP	0%	260	205	31	151	-	0	387
	EE2	1	Gas CHP	0%	270	194	31	158	-	0	383
	EE2	3	Gas(86%)	0%	284	167	10	164	-	0	340
	EE2	1	Gas(86%)	0%	293*	156	10	171	-	0	336
Sec. Sch (EE2) – 30 year calc	C	3	Gas CHP	20%	131	441	36	55	-	-12	520
	Window Only	3	Gas CHP	20%	137	199	36	56	-	-5	286
	Wall Only	3	Gas CHP	20%	143	180	36	58	-	-5	269
	Window Only	3	Gas(86%)	20%	152	161	11	66	-	-4	234
	Wall Only	3	Gas(86%)	20%	163	142	11	70	-	-4	220
	EE2	3	Gas(86%)	20%	165	134	11	70	-	-4	213
	EE2	1	Gas(86%)	20%	171	144	11	75	-	-4	226
	Window Only	3	Gas(86%)	0%	177	143	10	78	-	-3	228
	EE2	3	Gas(86%)	0%	190*	117	10	82	-	-3	206
	EE2	1	Gas(86%)	0%	195	126	10	87	-	-3	220

12. Cost Optimal Level for Reference Buildings

12.1 New Buildings

The cost optimal level has been based on the macro-economic calculations. Macro-economic analysis is used by the Government for the purpose of evaluating different options for technical standards for Building Regulations. Furthermore, we have elected to use the discount rate of 3.5% to mirror that used by the Government policy analysis.

The macro-economic cost optimal curves for each of the reference buildings are shown in Figure 12.1 (a – g).

For comparison, current UK energy performance standards (weighted average) across England, Scotland, Wales and Northern Ireland) are shown.

Figure 12.1a: Results of the cost-optimal analysis (Office (AC), macroeconomic costs)

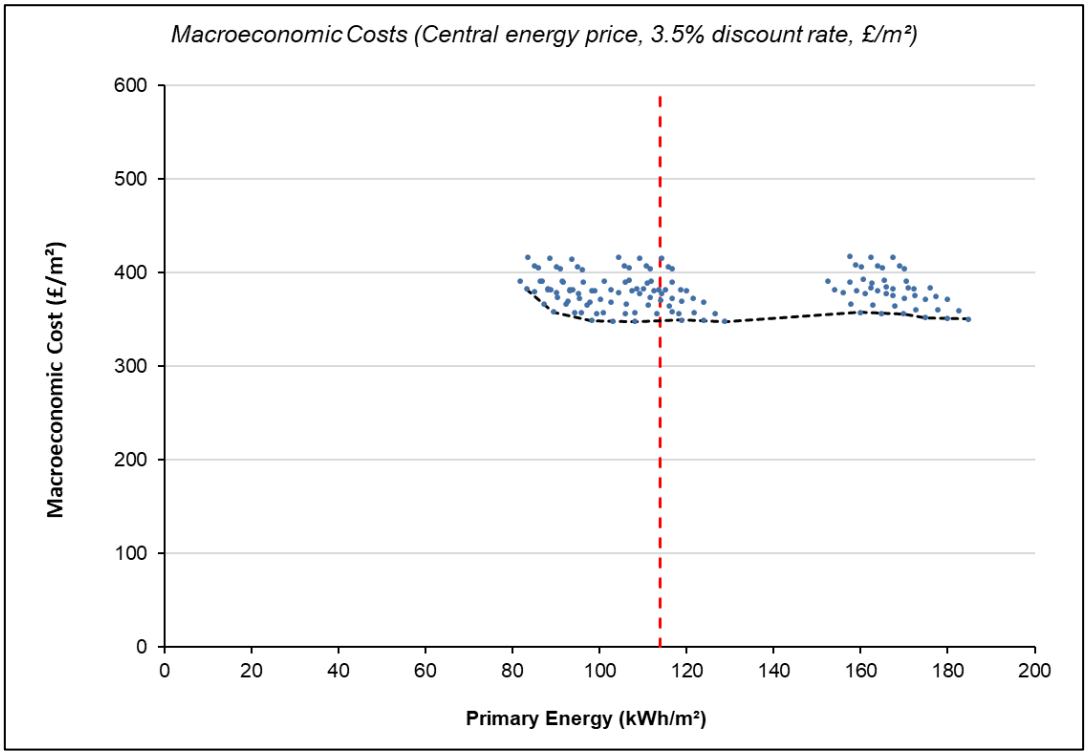


Figure 12.1b: Results of the cost-optimal analysis (Office (NV), macroeconomic costs)

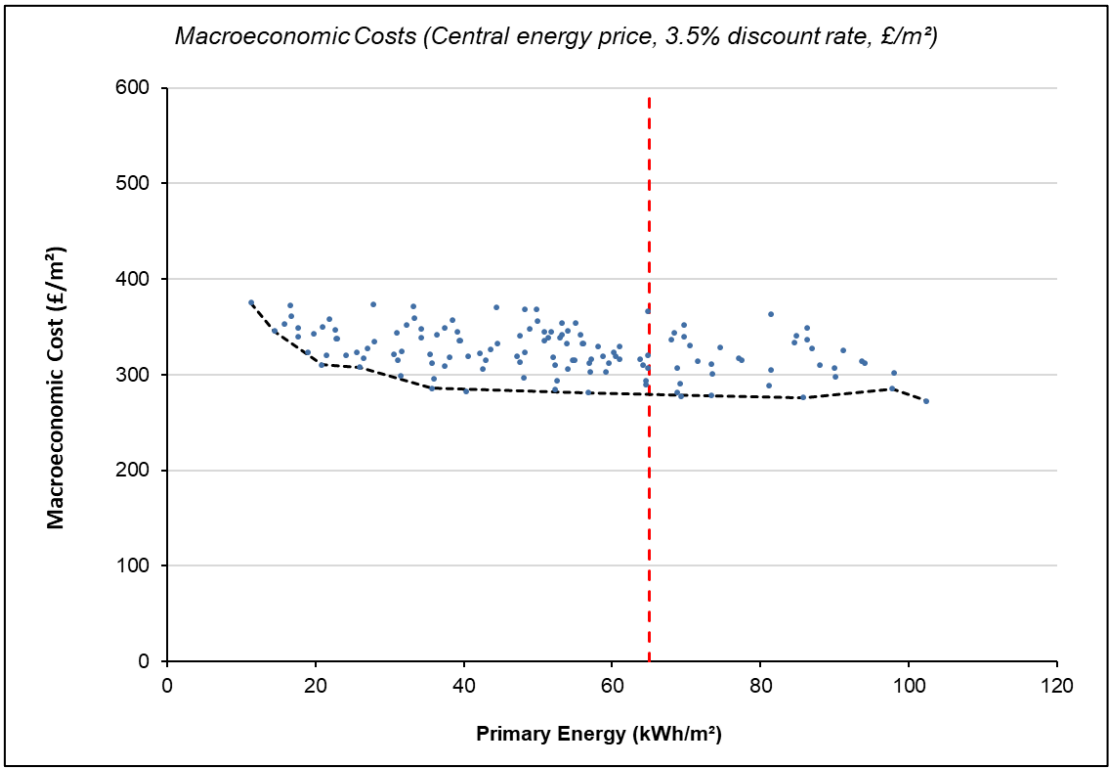


Figure 12.1c: Results of the cost-optimal analysis (Secondary School, macroeconomic costs)

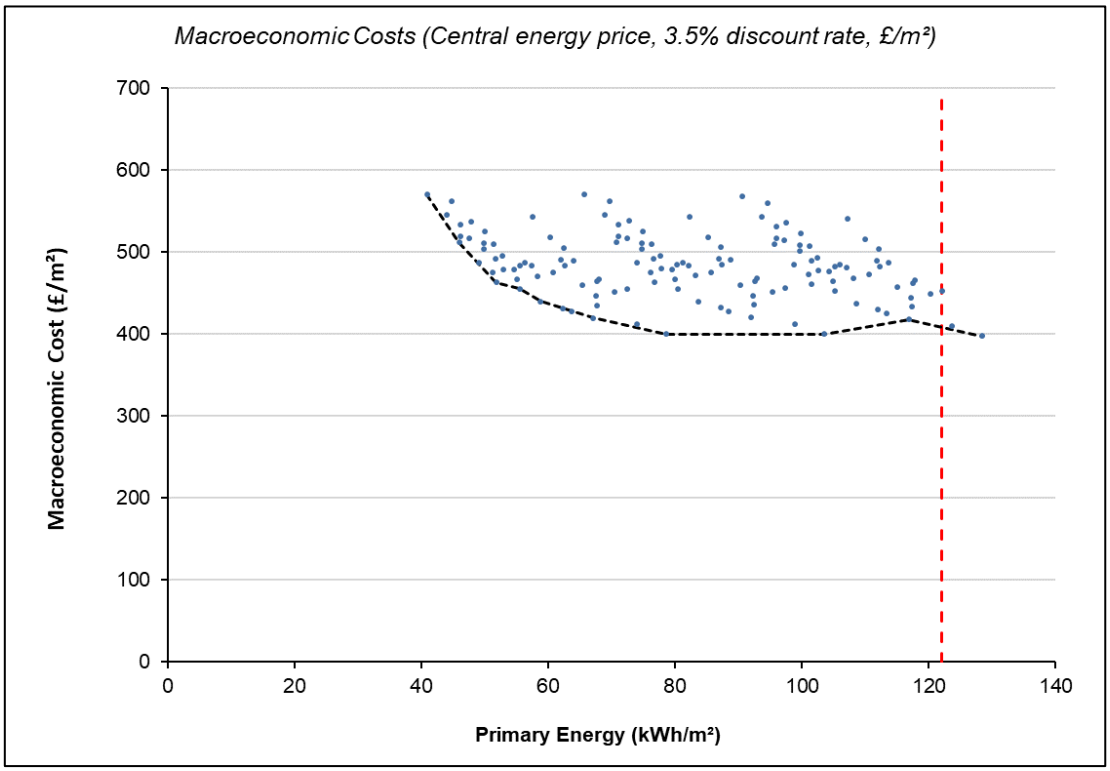


Figure 12.1d: Results of the cost-optimal analysis (Hospital, macroeconomic costs)

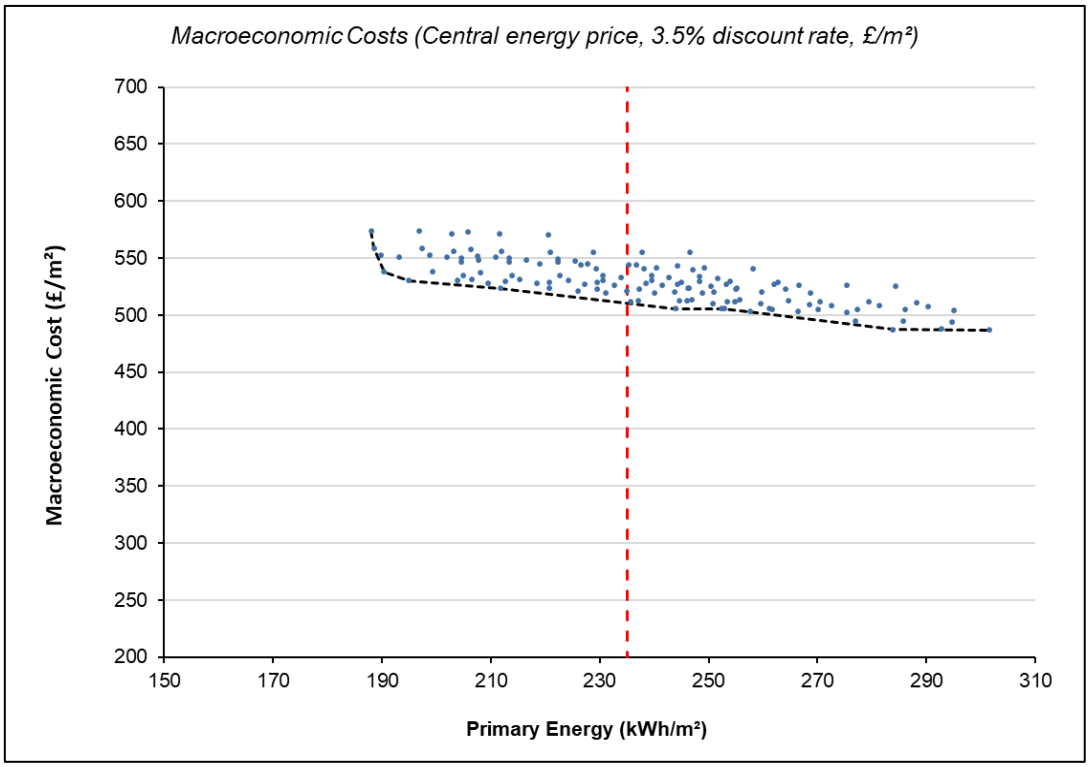


Figure 12.1e: Results of the cost-optimal analysis (Hotel, macroeconomic costs)

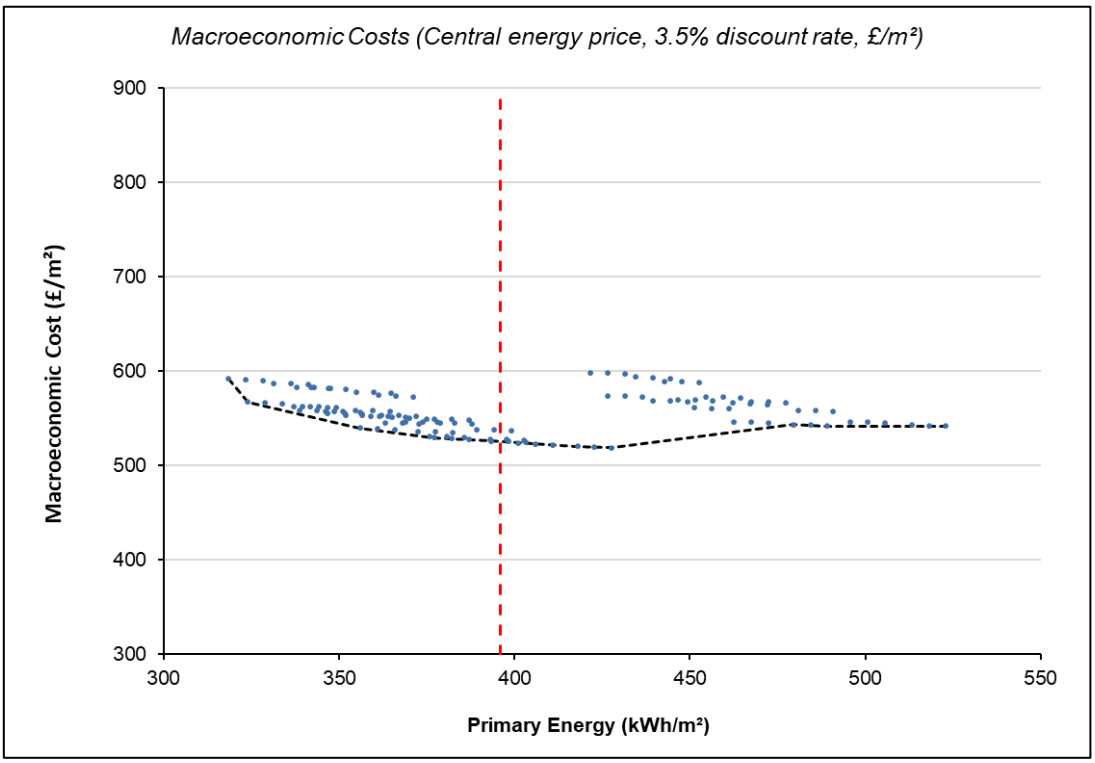


Figure 12.1f: Results of the cost-optimal analysis (Distribution Warehouse, macroeconomic costs)

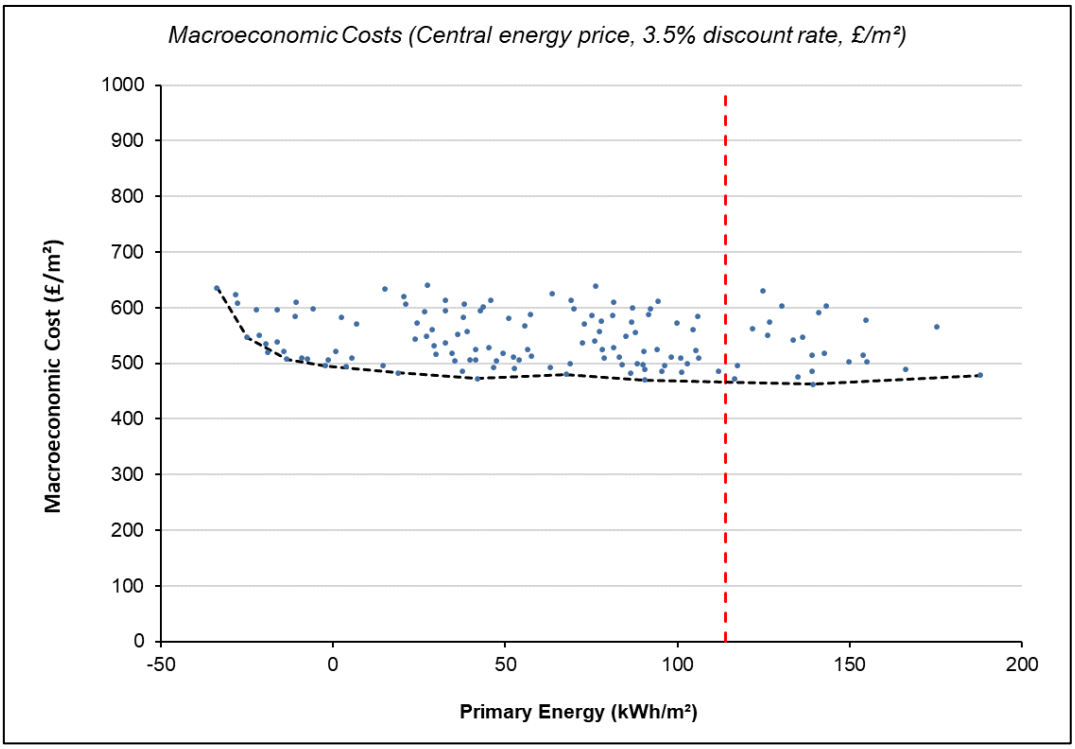
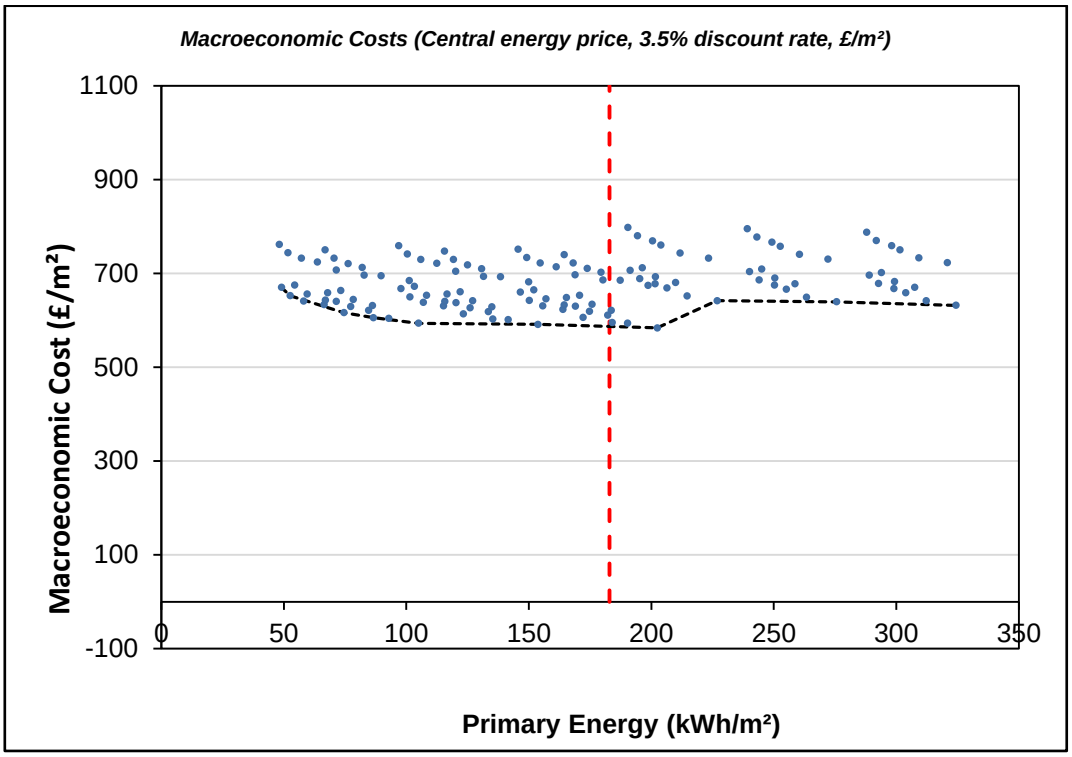


Figure 12.1g: Results of the cost-optimal analysis (Retail Warehouse, macroeconomic costs)



From these curves, the economic optimal energy performance level in primary energy (kWh/m^2/yr) is shown in Table 12.1. We have also included a range to cover the sensitivity cases investigated in Section 11. Furthermore, to allow for some sensitivity in the price of the fabric/services/renewables measures, we have included those primary energies within 5% of the lowest macro-economic cost.

Table 12.1: Economic Optimal Energy Performance Level in Primary Energy

Reference building	*Primary Energy (kWh/m^2/yr)*	*Sensitivity Range(kWh/m^2/yr)*
Office (AC)	108	89 – 175
Office (NV)	102	36 – 102
Secondary School	128	79 – 128
Hospital	302	244 – 302
Hotel (AC)	428	356 – 428
Dist. Warehouse	139	19 – 188
Retail Warehouse (AC)	202	87 – 202

12.2 Existing Buildings – Elemental Analysis

As for new buildings, gap analysis is based on the macro-economic calculations. Macro-economic analysis is used by the Government for the purpose of evaluating different options for technical standards for Building Regulations. Furthermore, we have elected to use the discount rate of 3.5% to mirror that used by the Government policy analysis.

The economic optimal value for each building element is shown in Table 12.2 (a – e) for the five building types respectively. Where there is a range recorded, it is because the cost associated across a range of building element values is the same (to the nearest integer).

We have also included a range to cover the sensitivity cases investigated in Section 11. We have not undertaken a sensitivity analysis on the price of the products as it is assumed that price uncertainties would similarly affect all products in any given comparison as the products are comparable. The only possible exception to this is the analysis the heating systems which includes comparison of different products. We note that there was no change in the optimum building element values under the sensitivity analysis.

Table 12.2a: Cost Optimal (Office)

Reference building	*Energy efficiency*	*Element*	*Primary Energy (kWh/m^2/yr)*	*Sensitivity Range(kWh/m^2/yr)*
Office (NV)	EE1	Wall	U=0.47W/m²K	-
Office (NV)	EE1	Roof	U=0.25W/m²K	-
Office (NV)	EE1	Heating	Gas boiler	-
Office (NV)	EE1	Floor	U=0.25W/m²K	-
Office (NV)	EE1	Window	U=1.8W/m²K	-
Office (NV)	EE1	Lighting	55 lm/W	-
Office (NV)	EE2	Wall	U=0.47W/m²K	-
Office (NV)	EE2	Roof	U=0.25W/m²K	-
Office (NV)	EE2	Heating	Gas boiler	-
Office (NV)	EE2	Floor	U=0.25W/m²K	-
Office (NV)	EE2	Window	U=1.8W/m²K	-
Office (NV)	EE2	Lighting	55 lm/W	-

Table 12.2b: Cost Optimal (School)

Reference building	*Energy efficiency*	*Element*	*Primary Energy (kWh/m²/yr)*	*Sensitivity Range(kWh/m²/yr)*
Secondary School	EE1	Wall	U=0.30W/m²K	-
Secondary School	EE1	Roof	U=0.25W/m²K	-
Secondary School	EE1	Heating	Gas boiler	-
Secondary School	EE1	Floor	U=0.25W/m²K	-
Secondary School	EE1	Window	U=1.8W/m²K	-
Secondary School	EE1	Lighting	65 lm/W	-
Secondary School	EE2	Wall	U=0.30W/m²K	-
Secondary School	EE2	Roof	U=0.25W/m²K	-
Secondary School	EE2	Heating	Gas boiler	-
Secondary School	EE2	Floor	U=0.25W/m²K	-
Secondary School	EE2	Window	U=1.8W/m²K	-
Secondary School	EE2	Lighting	65 lm/W	-

Table 12.2c: Cost Optimal (Hospital)

Reference building	*Energy efficiency*	*Element*	*Primary Energy (kWh/m²/yr)*	*Sensitivity Range(kWh/m²/yr)*
Hospital	EE1	Wall	U=0.47W/m²K	-
Hospital	EE1	Roof	U=0.25W/m²K	-
Hospital	EE1	Heating	Gas boiler	-
Hospital	EE1	Floor	U=0.25W/m²K	-
Hospital	EE1	Window	U=1.8W/m²K	-
Hospital	EE1	Lighting	65 lm/W	-
Hospital	EE1	AHU	2.2 W/l/s	-
Hospital	EE2	Wall	U=0.47W/m²K	-
Hospital	EE2	Roof	U=0.25W/m²K	-
Hospital	EE2	Heating	Gas boiler	-
Hospital	EE2	Floor	U=0.25W/m²K	-
Hospital	EE2	Window	U=1.8W/m²K	-
Hospital	EE2	Lighting	65 lm/W	-
Hospital	EE2	AHU	2.2 W/l/s	-

Table 12.2d: Cost Optimal (Hotel)

Reference building	*Energy efficiency*	*Element*	*Primary Energy (kWh/m²/yr)*	*Sensitivity Range(kWh/m²/yr)*
Hotel (AC)	EE1	Wall	U=0.47W/m²K	-
Hotel (AC)	EE1	Roof	U=0.25W/m²K	-
Hotel (AC)	EE1	Heating	Gas boiler	-
Hotel (AC)	EE1	Floor	U=0.15W/m²K	-
Hotel (AC)	EE1	Window	U=1.8W/m²K	-
Hotel (AC)	EE1	Lighting	55 lm/W	-
Hotel (AC)	EE1	Chiller	SEER = 4.5	-
Hotel (AC)	EE1	AHU	1.8 W/l/s	-
Hotel (AC)	EE2	Wall	U=0.47W/m²K	-
Hotel (AC)	EE2	Roof	U=0.25W/m²K	-
Hotel (AC)	EE2	Heating	Gas boiler	-
Hotel (AC)	EE2	Floor	U=0.15W/m²K	-
Hotel (AC)	EE2	Window	U=1.8W/m²K	-
Hotel (AC)	EE2	Lighting	55 lm/W	-
Hotel (AC)	EE2	Chiller	SEER = 4.5	-
Hotel (AC)	EE2	AHU	1.8 W/l/s	-

Table 12.2e: Cost Optimal (Retail warehouse)

Reference building	*Energy efficiency*	*Element*	*Primary Energy (kWh/m²/yr)*	*Sensitivity Range(kWh/m²/yr)*
Retail Warehouse (AC)	EE1	Wall	U=0.47W/m²K	-
Retail Warehouse (AC)	EE1	Roof	U=0.18W/m²K	-
Retail Warehouse (AC)	EE1	Heating	Gas boiler	-
Retail Warehouse (AC)	EE1	Floor	U=0.25W/m²K	-
Retail Warehouse (AC)	EE1	Window	U=1.8W/m²K	-
Retail Warehouse (AC)	EE1	Lighting	55 lm/W	-
Retail Warehouse (AC)	EE1	Chiller	SEER = 5.5	-
Retail Warehouse (AC)	EE1	AHU	2.0 W/l/s	-
Retail Warehouse (AC)	EE2	Wall	U=0.47W/m²K	-
Retail Warehouse (AC)	EE2	Roof	U=0.18W/m²K	-
Retail Warehouse (AC)	EE2	Heating	Gas boiler	-
Retail Warehouse (AC)	EE2	Floor	U=0.25W/m²K	-
Retail Warehouse (AC)	EE2	Window	U=1.8W/m²K	-
Retail Warehouse (AC)	EE2	Lighting	55 lm/W	-
Retail Warehouse (AC)	EE2	Chiller	SEER = 5.5	-
Retail Warehouse (AC)	EE2	AHU	2.0 W/l/s	-

12.3 Existing Buildings – Analysis of Packages

As for new buildings, the cost optimal comparison is undertaken using the macroeconomic cost calculations. Furthermore, we have elected to use the discount rate of 3.5% to mirror that used by the Government policy analysis.

The results of the cost-optimal analysis are presented in the charts at Figures 12.2 (a-j) below, and summarised in Table 12.3. The sensitivity highlighted alternative options either within 5% of the macroeconomic cost in the central case or the optimum solution in other of the sensitivity analyses. This is a similar approach to that discussed in more detail in the main report.

In summary, the results show the following:

- The cost optimal solutions show no improvement in the building fabric from the baseline case. Solutions with improvement to the wall or roof performance are included in the sensitivity analysis.
- The cost optimal solutions are based on a gas boiler with 86% efficiency. Solutions with 91% gas boiler plus solar hot water are included in the sensitivity analysis.
- There is a mix of level of other services in the cost optimal solutions, depending on the building type.
- The cost optimal solutions are based on no photovoltaic solar panels (PV). The sensitivity analysis includes options with 20% PV.

Table 12.3: Economic Optimal Energy Performance Level in Primary Energy

Reference building	*Optimal Solution*	*Sensitivity Range*
Hospital – EE1	EE1, gas boiler (86%), Level 3 other services, 0% PV (Primary Energy = 356 KWh/m²)	EE1, gas boiler (86%), Level 3 other services, 20% PV EE1, gas boiler (86%), Level 2 other services, 0% PV
Hospital – EE2	EE2, gas boiler (86%), Level 3 other services, 0% PV (Primary Energy = 328 KWh/m²)	EE2, gas boiler (86%), Level 3 other services, 20% PV EE2, gas boiler (86%), Level 2 other services, 0% PV EE2, gas boiler (86%), Level 1 other services, 0% PV
Hotel – EE1	EE1, gas boiler (86%), Level 1 other services, 0% PV (Primary Energy = 679 KWh/m²)	EE1, gas boiler (91%) + SHW, Level 1 other services, 20% PV Roof, gas boiler (91%) + SHW, Level 2 other services, 20% PV EE1, Gas CHP, Level 1 other services, 20% PV EE1, Gas CHP, Level 2 other services, 20% PV
Hotel – EE2	EE2, gas boiler (86%), Level 1 other services, 0% PV (Primary Energy = 605 KWh/m²)	EE2, gas boiler (86%) + SHW, Level 1 other services, 0% PV EE2, gas boiler (91%) + SHW, Level 2 other services, 20% PV Roof, gas boiler (91%) + SHW, Level 2 other services, 20% PV EE2, Gas CHP, Level 1 other services, 0% PV

Table 12.3: Economic Optimal Energy Performance Level in Primary Energy cont …

Reference building	***Optimal Solution***	***Sensitivity Range***
Office – EE1	EE1, gas boiler (86%), Level 1 other services, 0% PV (Primary Energy = 168 KWh/m²)	EE1, gas boiler (86%), Level 1 other services, 20% PV EE1, gas boiler (86%), Level 3 other services, 20% PV
Office - EE2	EE2, gas boiler (86%), Level 1 other services, 0% PV (Primary Energy = 151 KWh/m²)	EE2, gas boiler (86%), Level 3 other services, 20% PV EE2, gas boiler (86%), Level 1 other services, 20% PV EE2, gas boiler (86%), Level 3 other services, 20% PV
Retail Warehouse – EE1	EE1, gas boiler (86%), Level 1 other services, 0% PV (Primary Energy = 300 KWh/m²)	EE1, gas boiler (86%), Level 3 other services, 0% PV
Retail Warehouse – EE2	EE2, gas boiler (86%), Level 1 other services, 0% PV (Primary Energy = 293 KWh/m²)	EE2, gas boiler (86%), Level 3 other services, 0% PV
Secondary school – EE1	EE1, gas boiler (86%), Level 3 other services, 0% PV (Primary Energy = 235 KWh/m²)	Wall, gas boiler (86%), Level 3 other services, 20% PV EE1, gas boiler (86%), Level 3 other services, 20% PV
Secondary school – EE2	EE2, gas boiler (86%), Level 3 other services, 0% PV (Primary Energy = 190 KWh/m²)	Wall, gas boiler (86%), Level 3 other services, 20% PV EE2, gas boiler (86%), Level 3 other services, 20% PV

Figure 12.2a: Hospital – EE1

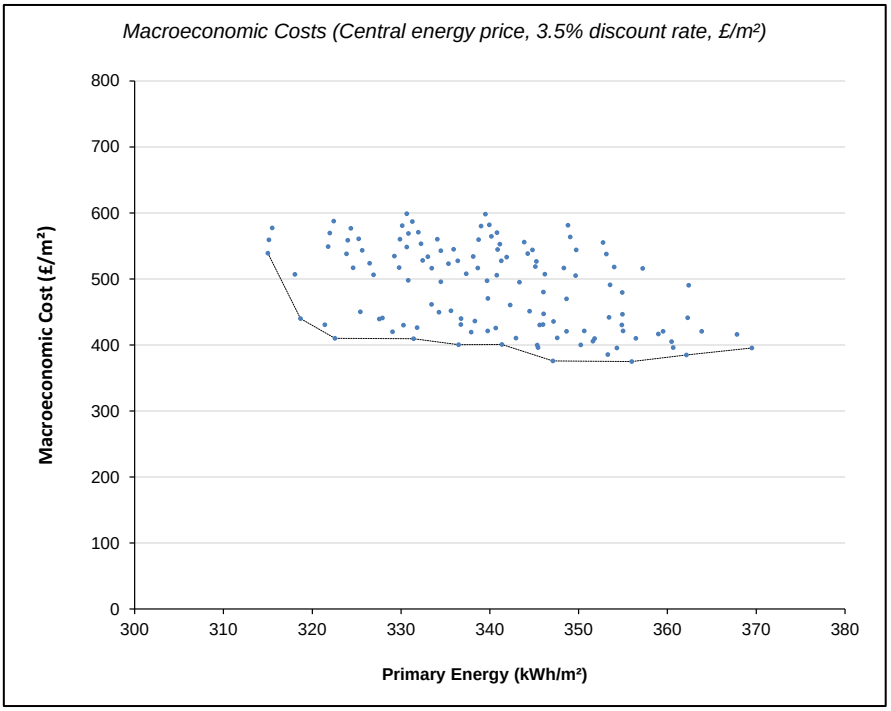


Figure 12.2b: Hotel – EE1

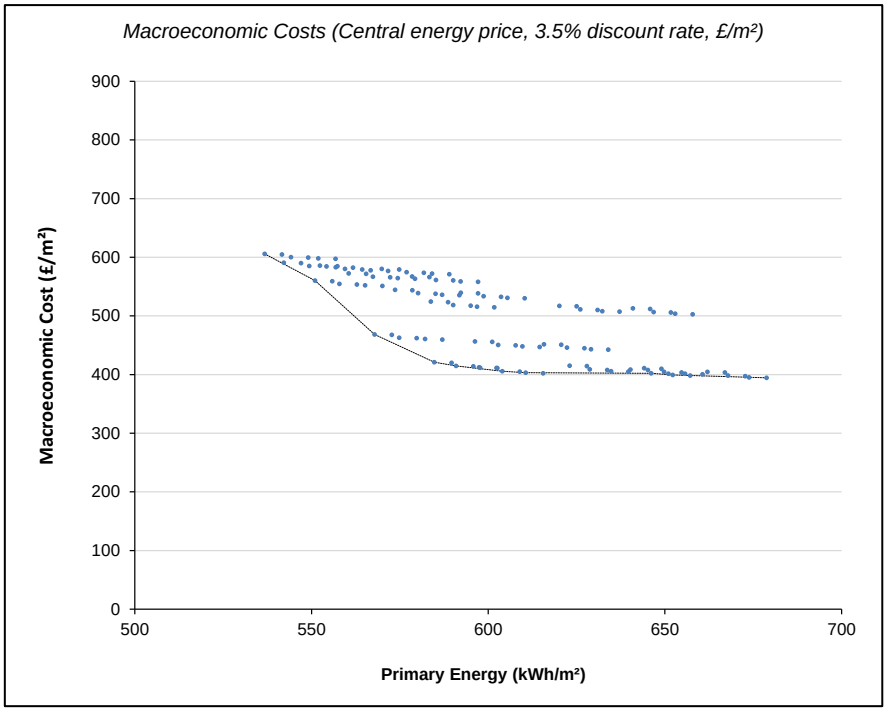


Figure 12.2c: Office – EE1

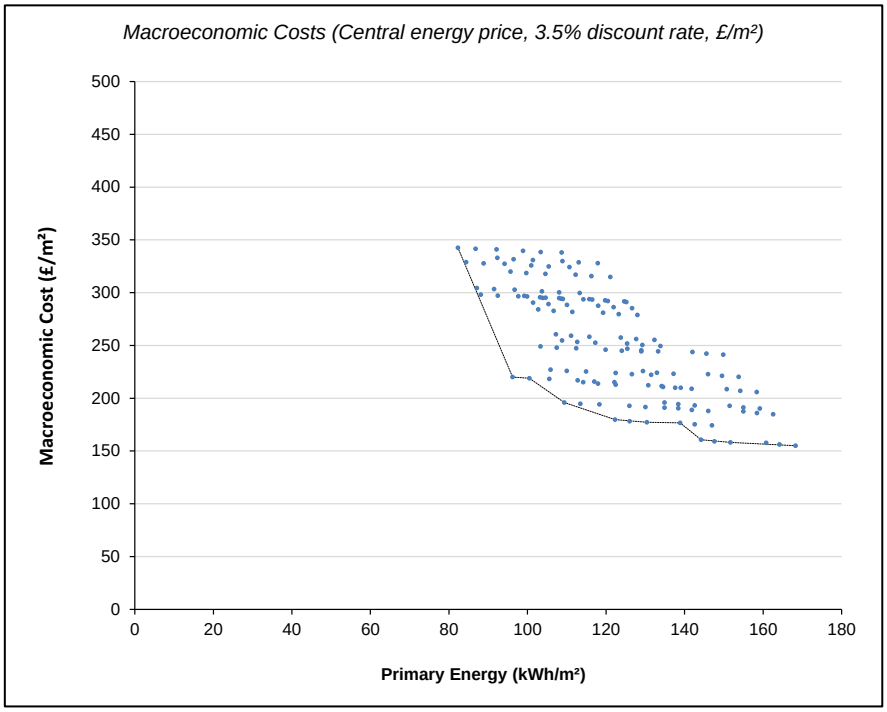


Figure 12.2d: Retail Warehouse – EE1

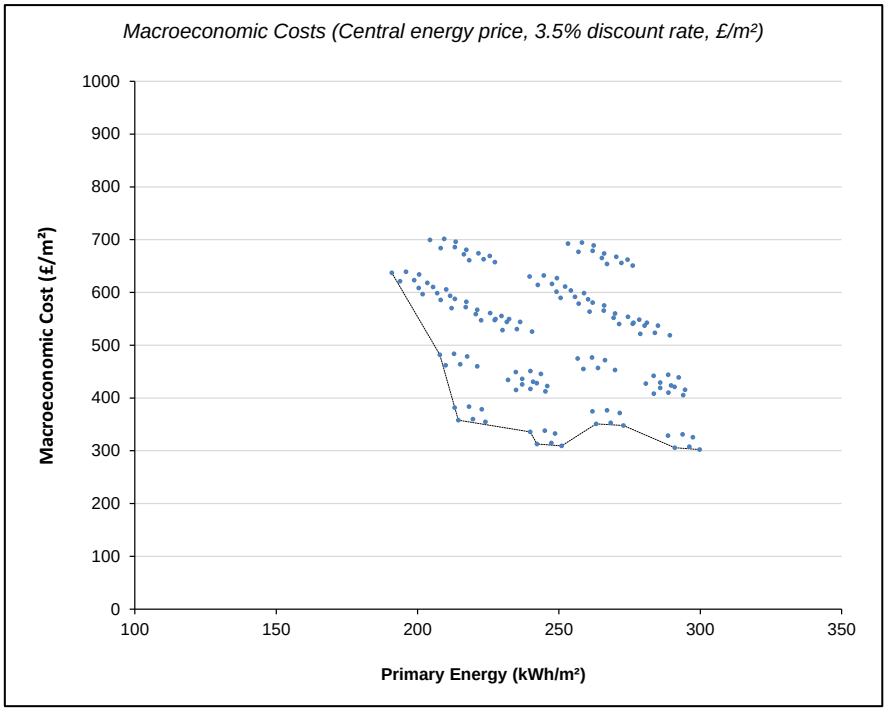


Figure 12.2e: Secondary School – EE1

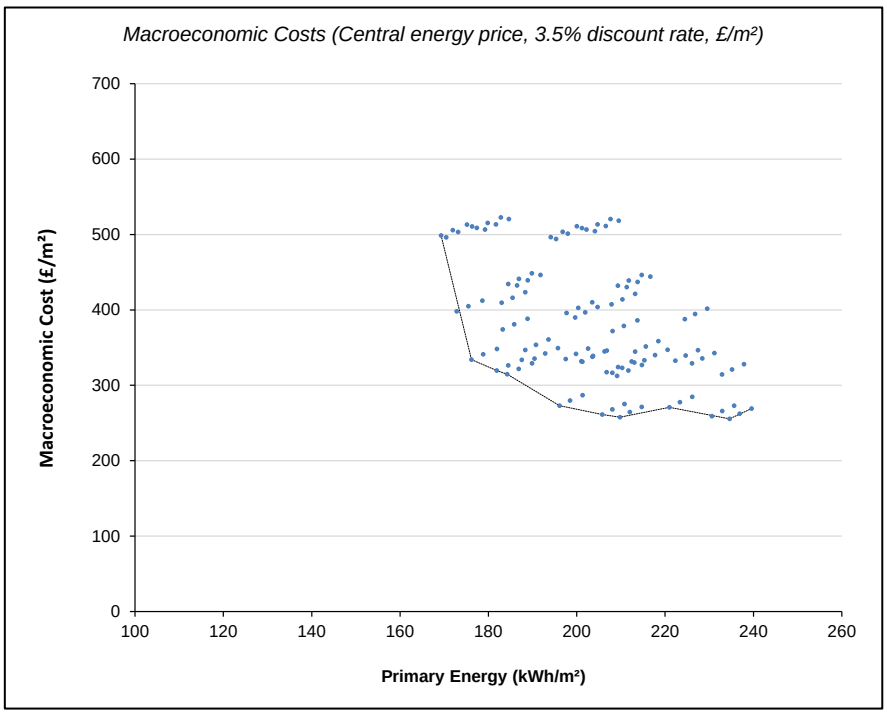


Figure 12.2f: Hospital – EE2

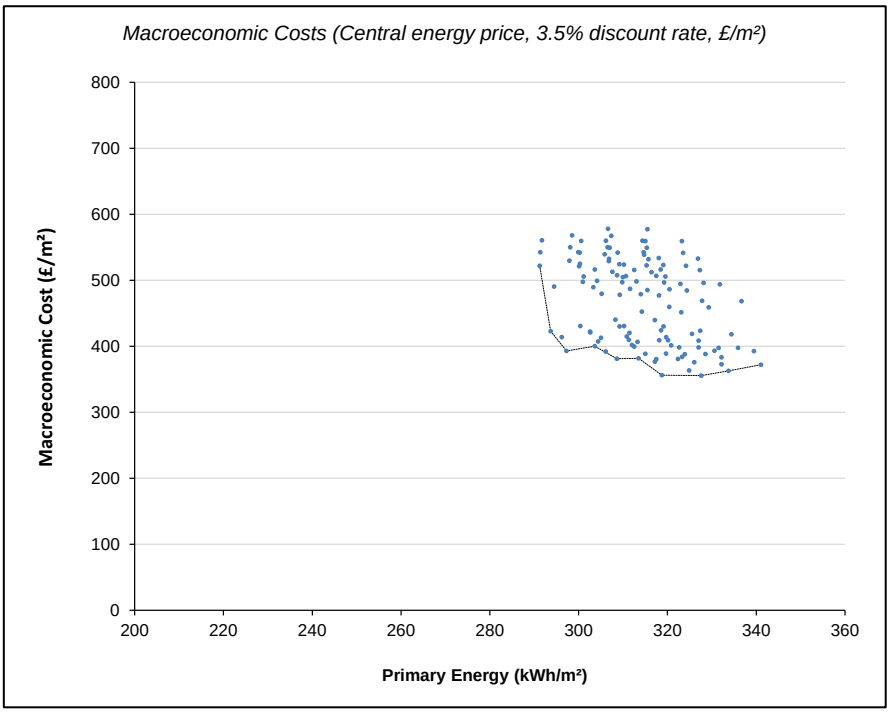


Figure 12.2g: Hotel – EE2

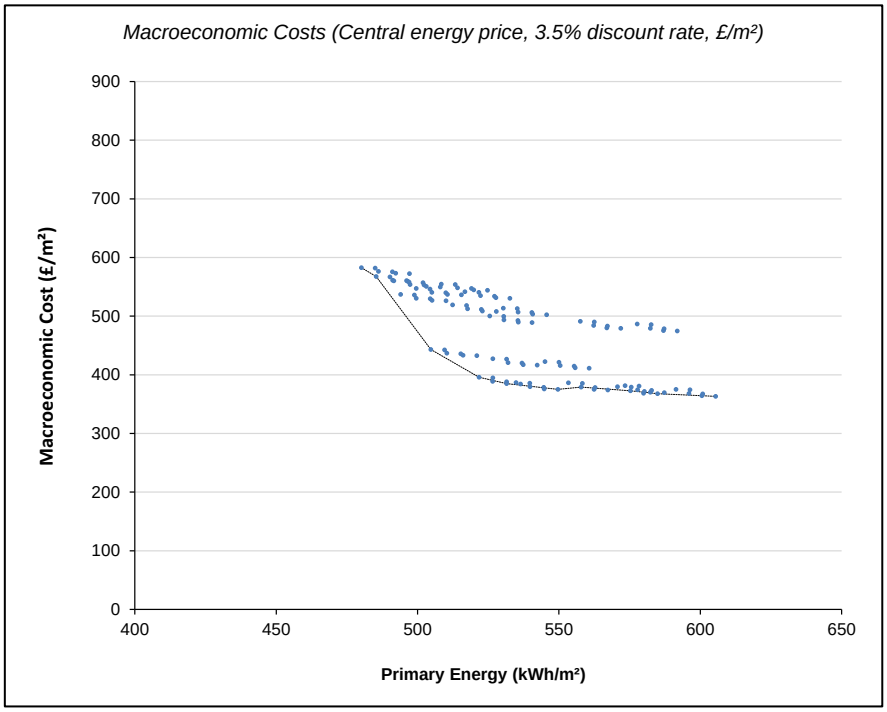


Figure 12.2h: Office – EE2

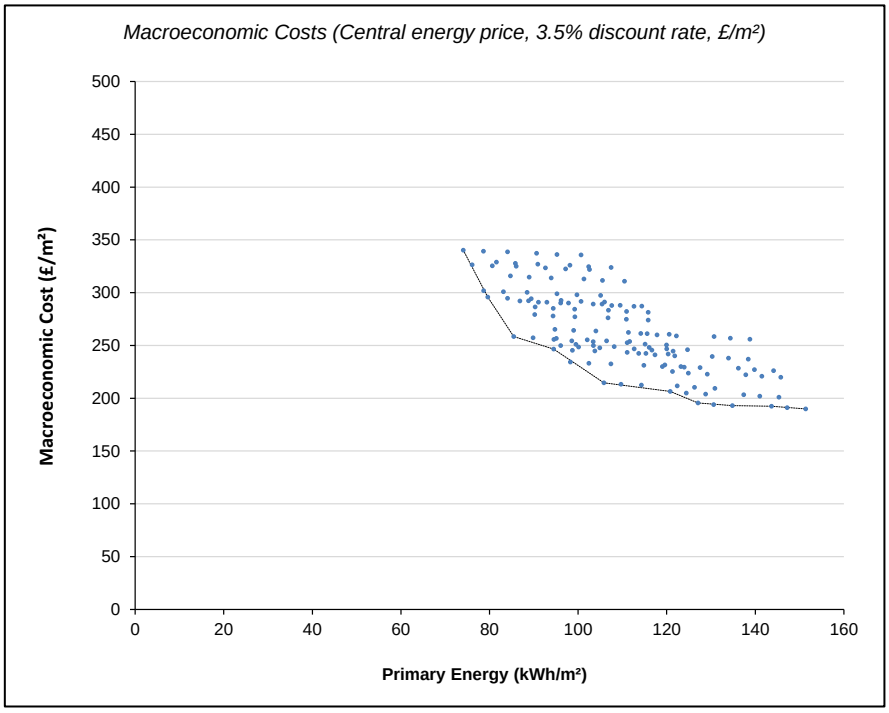


Figure 12.2i: Retail Warehouse – EE2

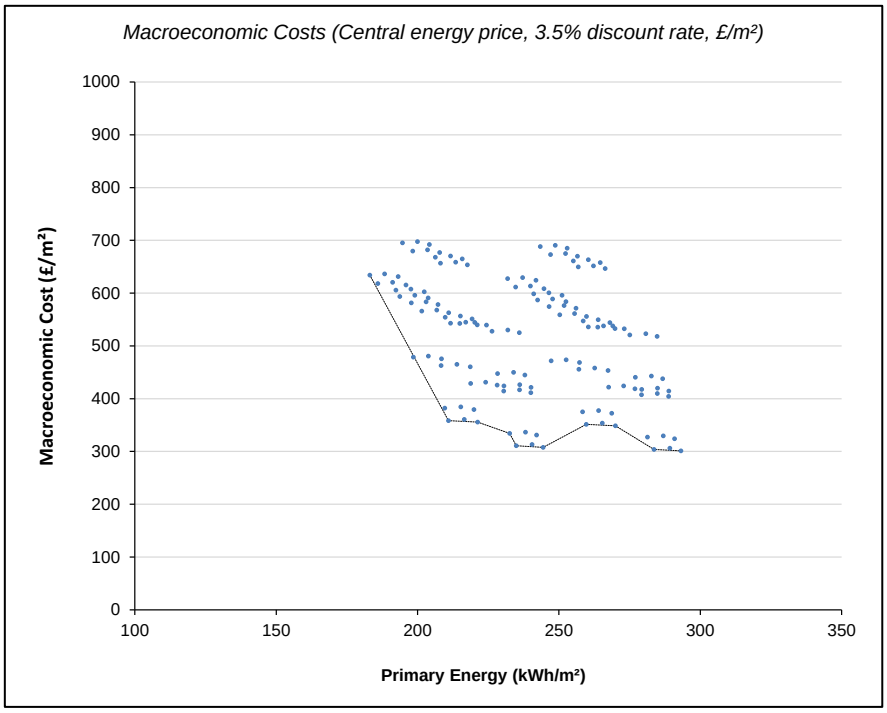
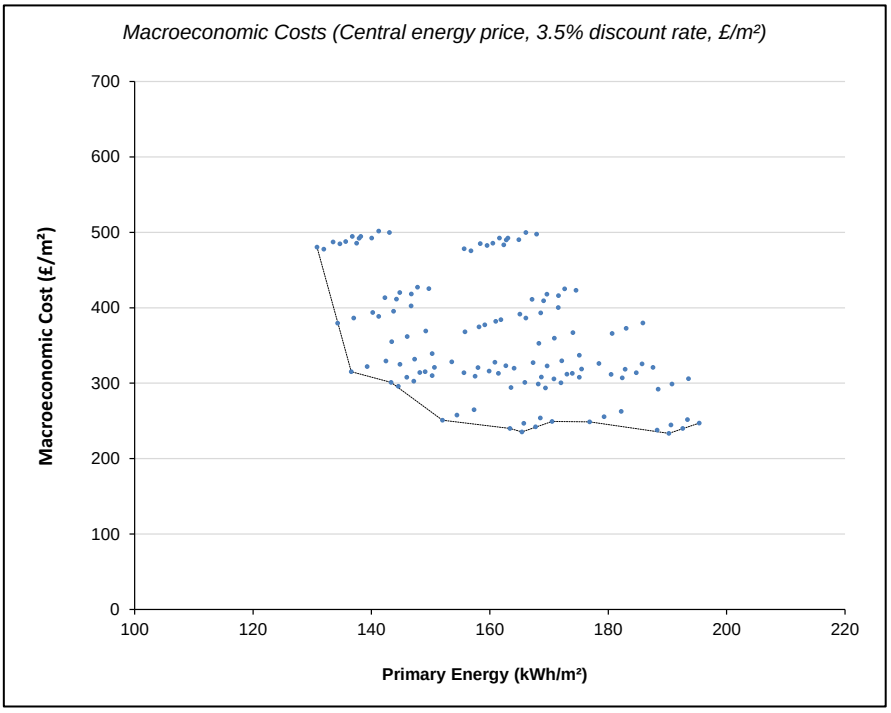


Figure 12.2j: Secondary School – EE2



13. Comparison of Current Regulations and Cost Optimal Level

13.1 New Buildings

For each reference building, Table 13.1 (a-e) shows the current national regulations compared to the cost optimal level.

A positive percentage gap denotes that the national energy requirements are better than the cost optimal level whilst a negative gap denotes that they are poorer than the cost optimal level.

Table 13.1a: Comparison Table (UK Average)

Reference building	*Cost Optimal Level (kWh/m^2/yr)*	*Current Requirements(kWh/m^2/yr)*	*Gap (%)*
Office (AC)	108	114	+ 13%
Office (NV)	102	65	
Secondary School	128	122	
Hospital	302	235	
Hotel (AC)	428	396	
Dist. Warehouse	139	114	
Retail Warehouse (AC)	202	183	
Average	**201**	**175**	

In calculating the overall gap, we have assumed the same weighting across all types of new non-domestic reference building.

The current national energy requirements weighted across the UK as a whole are better than the cost optimal level.

Also the current energy requirements for each building type are better than the cost optimal except for air-conditioned offices which although poorer than the cost optimal level is well within the 15% range described in the cost optimal methodology so there is no significant discrepancy.

Country specific comparisons are shown below and energy requirements for each country weighting across all types of building are better than the cost optimal level.

Table 13.1b: Comparison Table (England)

Reference building	*Cost Optimal Level (kWh/m²/yr)*	*Current Requirements(kWh/m²/yr)*	*Gap (%)*
Office (AC)	108	115	+12%.
Office (NV)	102	66	
Secondary School	128	122	
Hospital	302	237	
Hotel (AC)	428	395	
Dist. Warehouse	139	112	
Retail Warehouse (AC)	202	184	
Average	**201**	**176**	

Table 13.1c: Comparison Table (Wales)

Reference building	*Cost Optimal Level (kWh/m²/yr)*	*Current Requirements(kWh/m²/yr)*	*Gap (%)*
Office (AC)	108	97	+19%
Office (NV)	102	50	
Secondary School	128	107	
Hospital	302	219	
Hotel (AC)	428	386	
Dist. Warehouse	139	104	
Retail Warehouse (AC)	202	168	
Average	**201**	**162**	

Table 13.1d: Comparison Table (Scotland)

Reference building	*Cost Optimal Level (kWh/m²/yr)*	*Current Requirements(kWh/m²/yr)*	*Gap (%)*
Office (AC)	108	101	+14%
Office (NV)	102	59	
Secondary School	128	121	
Hospital	302	225	
Hotel (AC)	428	399	
Dist. Warehouse	139	134	
Retail Warehouse (AC)	202	175	
Average	**201**	**173**	

Table 13.1e: Comparison Table (Northern Ireland)

Reference building	*Cost Optimal Level (kWh/m²/yr)*	*Current Requirements(kWh/m²/yr)*	*Gap (%)*
Office (AC)	108	125	+ 2%
Office (NV)	102	76	
Secondary School	128	135	
Hospital	302	260	
Hotel (AC)	428	461	
Dist. Warehouse	139	130	
Retail Warehouse (AC)	202	194	
Average	**201**	**197**	

13.2 Existing Buildings – Elemental Analysis

For each reference building and improvement measure, Table 13.2 (a – i) shows the current national regulations compared to the cost optimal level. Due to the different energy efficiency, we have calculated EE1 and EE2 separately to assess any significant difference. In calculating the overall gap, we have assumed the same weighting all types of existing non-domestic reference building.

A positive percentage gap denotes that the national energy requirements are better than the cost optimal level whilst a negative gap denotes that they are poorer than the cost optimal level.

Table 13.2a: Comparison Table (Cavity Walls)

Reference building	*Energy Efficiency*	*Cost Optimal Level*	*Current Requirement*	*Gap*
Office (NV)	EE1	-	-	- 80%
Secondary School	EE1	U=0.30W/m²K	England, Wales and NI: U=0.55W/m²K (Scotland: U=0.30W/m²K)	
Hospital	EE1	-	-	
Hotel (AC)	EE1	-	-	
Retail Warehouse (AC)	EE1	-	-	
UK Average		**U=0.30W/m²K**	**U=0.54W/m²K**	
Office (NV)	EE2	-	-	- 80%
Secondary School	EE2	U=0.30W/m²K	England, Wales and NI: U=0.55W/m²K (Scotland: U=0.30W/m²K)	
Hospital	EE2	-	-	
Hotel (AC)	EE2	-	-	
Retail Warehouse (AC)	EE2	-	-	
UK Average		**U=0.30W/m²K**	**U=0.54W/m²K**	

For cavity walls current insulation standards are based on fully filling a 50mm cavity, which is a typical cavity size for older properties. Many buildings in the UK have cavity walls with empty 50mm cavities.

The cost-optimal level has however been calculated based on a 100mm cavity, which is found in more modern buildings only. It appears reasonable and can be argued that fully filling a 50mm cavity is considered to be very cost effective and worthwhile.

Table 13.2b: Comparison Table (Other Walls)

Reference building	*Energy Efficiency*	*Cost Optimal Level*	*Current Requirement*	*Gap*
Office (NV)	EE1	U=0.47W/m²K	U=0.30W/m²K	+ 36%
Secondary School	EE1	-	-	
Hospital	EE1	U=0.47W/m²K	U=0.30W/m²K	
Hotel (AC)	EE1	U=0.47W/m²K	U=0.30W/m²K	
Retail Warehouse (AC)	EE1	U=0.47W/m²K	U=0.30W/m²K	
UK Average		**U=0.47W/m²K**	**U=0.30W/m²K**	
Office (NV)	EE2	U=0.47W/m²K	U=0.30W/m²K	+ 36%
Secondary School	EE2	-	-	
Hospital	EE2	U=0.47W/m²K	U=0.30W/m²K	
Hotel (AC)	EE2	U=0.47W/m²K	U=0.30W/m²K	
Retail Warehouse (AC)	EE2	U=0.47W/m²K	U=0.30W/m²K	
UK Average		**U=0.47W/m²K**	**U=0.30W/m²K**	

For other walls, the current national energy requirements weighted across the UK as a whole are better than the cost optimal level.

Table 13.2c: Comparison Table (Roof)

Reference building	*Energy Efficiency*	*Cost Optimal Level*	*Current Requirement*	*Gap*
Office (NV)	EE1	U=0.25W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	+ 21%
Secondary School	EE1	U=0.25W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	
Hospital	EE1	U=0.25W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	
Hotel (AC)	EE1	U=0.25W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	
Retail Warehouse (AC)	EE1	U=0.18W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	
UK Average		**U=0.24W/m²K**	**U=0.19W/m²K**	
Office (NV)	EE2	U=0.25W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	+ 21%
Secondary School	EE2	U=0.25W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	
Hospital	EE2	U=0.25W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	
Hotel (AC)	EE2	U=0.25W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	
Retail Warehouse (AC)	EE2	U=0.18W/m²K	U=0.18W/m²K (Scot: U=0.25W/m²K)	
UK Average		**U=0.24W/m²K**	**U=0.19W/m²K**	

For roofs, the current national energy requirements weighted across the UK as a whole are better than the cost optimal level. Although requirements in Scotland are slightly poorer than the cost optimal level they are well within the 15% range described in the cost optimal methodology so there is no significant discrepancy.

Table 13.2d: Comparison Table (Heating)

Reference building	*Energy Efficiency*	*Cost Optimal Level*	*Current Requirement*	*Gap*
Office (NV)	EE1	86% (gas boiler)	84% (Scot: 86%)	- 2%
Secondary School	EE1	86% (gas boiler)	84% (Scot: 86%)	
Hospital	EE1	86% (gas boiler)	84% (Scot: 86%)	
Hotel (AC)	EE1	86% (gas boiler)	84% (Scot: 86%)	
Retail Warehouse (AC)	EE1	86% (gas boiler)	84% (Scot: 86%)	
UK Average		**86% (gas boiler)**	**84%**	
Office (NV)	EE2	86% (gas boiler)	84% (Scot: 86%)	- 2%
Secondary School	EE2	86% (gas boiler)	84% (Scot: 86%)	
Hospital	EE2	86% (gas boiler)	84% (Scot: 86%)	
Hotel (AC)	EE2	86% (gas boiler)	84% (Scot: 86%)	
Retail Warehouse (AC)	EE2	86% (gas boiler)	84% (Scot: 86%)	
UK Average		**86% (gas boiler)**	**84%**	

For heating, the current national energy requirements weighted across the UK as a whole are slightly poorer than the cost optimal level but well within the 15% range described in the cost optimal methodology so there is no significant discrepancy. Requirements in Scotland are cost optimal.

Table 13.2e: Comparison Table (Floor)

Reference building	*Energy Efficiency*	*Cost Optimal Level*	*Current Requirement*	*Gap*
Office (NV)	EE1	U=0.25W/m²K	U=0.25W/m²K	- 9%
Secondary School	EE1	U=0.25W/m²K	U=0.25W/m²K	
Hospital	EE1	U=0.25W/m²K	U=0.25W/m²K	
Hotel (AC)	EE1	U=0.15W/m²K	U=0.25W/m²K	
Retail Warehouse (AC)	EE1	U=0.25W/m²K	U=0.25W/m²K	
UK Average		**U=0.22W/m²K**	**U=0.25W/m²K**	
Office (NV)	EE2	U=0.25W/m²K	U=0.25W/m²K	- 9%
Secondary School	EE2	U=0.25W/m²K	U=0.25W/m²K	
Hospital	EE2	U=0.25W/m²K	U=0.25W/m²K	
Hotel (AC)	EE2	U=0.15W/m²K	U=0.25W/m²K	
Retail Warehouse (AC)	EE2	U=0.25W/m²K	U=0.25W/m²K	
UK Average		**U=0.23W/m²K**	**U=0.25W/m²K**	

For floors, the current national energy requirements weighted across the UK as a whole are 9% poorer than the cost optimal level but within the 15% range described in the cost optimal methodology so there is no significant discrepancy.

Table 13.2f: Comparison Table (Windows)

Reference building	*Energy Efficiency*	*Cost Optimal Level*	*Current Requirement*	*Gap*
Office (NV)	EE1	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	cost optimal
Secondary School	EE1	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	
Hospital	EE1	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	
Hotel (AC)	EE1	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	
Retail Warehouse (AC)	EE1	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	
UK Average		**U=1.8W/m²K**	**U=1.8W/m²K**	
Office (NV)	EE2	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	cost optimal
Secondary School	EE2	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	
Hospital	EE2	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	
Hotel (AC)	EE2	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	
Retail Warehouse (AC)	EE2	U=1.8W/m²K	U=1.8W/m²K (Scot: U=1.6W/m²K)	
UK Average		**U=1.8W/m²K**	**U=1.8W/m²K**	

For windows, the current national energy requirements weighted across the UK as a whole are cost optimal. Requirements in Scotland are 11% better than the cost optimal level.

Table 13.2g: Comparison Table (Lighting)

Reference building	*Energy Efficiency*	*Cost Optimal Level*	*Current Requirement*	*Gap*
Office (NV)	EE1	55 lm/W	60 lm/W	+ 2%
Secondary School	EE1	65 lm/W	60 lm/W	
Hospital	EE1	65 lm/W	60 lm/W	
Hotel (AC)	EE1	55 lm/W	60 lm/W	
Retail Warehouse (AC)	EE1	55 lm/W	60 lm/W	
UK Average		**59 lm/W**	**60 lm/W**	
Office (NV)	EE2	55 lm/W	60 lm/W	+ 2%
Secondary School	EE2	65 lm/W	60 lm/W	
Hospital	EE2	65 lm/W	60 lm/W	
Hotel (AC)	EE2	55 lm/W	60 lm/W	
Retail Warehouse (AC)	EE2	55 lm/W	60 lm/W	
UK Average		**59 lm/W**	**60 lm/W**	

For lighting, the current national energy requirements weighted across the UK as a whole are slightly better than the cost optimal level.

Table 13.2h: Comparison Table (Chiller)

Reference building	*Energy Efficiency*	*Cost Optimal Level*	*Current Requirement*	*Gap*
Office (NV)	EE1	-	-	- 30%
Secondary School	EE1	-	-	
Hospital	EE1	-	-	
Hotel (AC)	EE1	4.5	3.5	
Retail Warehouse (AC)	EE1	5.5	3.5	
UK Average		**5.0**	**3.5**	
Office (NV)	EE2	-	-	- 30%
Secondary School	EE2	-	-	
Hospital	EE2	-	-	
Hotel (AC)	EE2	4.5	3.5	
Retail Warehouse (AC)	EE2	5.5	3.5	
UK Average		**5.0**	**3.5**	

Table 13.2i: Comparison Table (AHU)

Reference building	*Energy Efficiency*	*Cost Optimal Level*	*Current Requirement*	*Gap*
Office (NV)	EE1	-	-	- 16%
Secondary School	EE1	-	-	
Hospital	EE1	1.8 W/l/s	2.2 W/l/s	
Hotel (AC)	EE1	1.8 W/l/s	2.2 W/l/s	
Retail Warehouse (AC)	EE1	2.0 W/l/s	2.2 W/l/s	
UK Average		**1.9 W/l/s**	**2.2 W/l/s**	
Office (NV)	EE2	-	-	- 16%
Secondary School	EE2	-	-	
Hospital	EE2	1.8 W/l/s	2.2 W/l/s	
Hotel (AC)	EE2	1.8 W/l/s	2.2 W/l/s	
Retail Warehouse (AC)	EE2	2.0 W/l/s	2.2 W/l/s	
UK Average		**1.9 W/l/s**	**2.2 W/l/s**	

For Air Conditioning Chiller and Air Handling Units (AHUs) the current national energy requirements weighted across the UK as a whole are poorer than the cost optimal level. The next steps for reviewing these requirements are set out in the Governments Clean Growth Strategy[49] and in equivalent publications by the devolved UK administrations (see Section 1 for details).

[49] The Clean Growth Strategy: Leading the way to a low carbon future, October 2017