Cost Optimal Calculations and Gap Analysis for recast EPBD for Buildings: Additional Calculations

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1. Introduction

This report details work undertaken for the Department of the Environment, Community and Local Government. It describes cost-optimal calculations and gap analysis for buildings in accordance with Article 5 of *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)* (hereinafter referred to as the recast EPBD). In doing this work, we have paid regard to *Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements* (hereinafter referred to as the Cost-Optimal Regulation) and the associated *Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements*.

Previously, AECOM produced for the Department of the Environment, Community and Local Government and the Sustainable Energy Authority of Ireland two reports which were the basis of the Irish Government's submission to the European Commission to fulfil the requirements of Article 5. These reports are published as follows:

- Ireland Cost Optimal Report: Residential
  http://www.buildup.eu/sites/default/files/content/Ireland%20Cost%20Optimal%20Report-Section%201%20Residential_0.pdf
- Ireland Cost Optimal Report: Non-Residential
  http://www.buildup.eu/sites/default/files/content/Ireland%20Cost%20Optimal%20Report-Section%202%20Non%20Residential.pdf

This report presents additional work to address the following activities:

a) Additional analysis for new complete apartment block buildings in accordance with Annex 1, point 1(1) of the Delegated regulation (EU) No 244/2012

b) Additional analysis for existing complete apartment block buildings, focussing on cost-optimum at an elemental level in accordance with Annex 1, point 1(1) of the Delegated regulation (EU) No 244/2012

c) Additional analysis for existing complete apartment block buildings, focussing on cost-optimum for packages of whole building renovation measures in accordance with Annex 1, point 1(1) of the Delegated regulation (EU) No 244/2012

d) Additional analysis for existing non-residential buildings[1], focussing on cost-optimum for packages of whole building renovation measures in accordance with Article 4(1), of the Directive 2010/31/EU together with Article 7, first paragraph;

The additional residential building analysis (a-c) builds on the previous work which independently evaluated mid and top floor flats (mid-floor only for (c)). This new analysis considers apartment buildings as a whole. The additional non-residential analysis (d) builds on the previous work which determined the cost-optimum levels for individual building measures and now identifies cost optimum packages of measures.

We have based the format of this report upon the reporting template provided in Annex 3 of the Cost-Optimal Regulation. We have adapted the template where we have found it easier to present the data, although not losing

[1]Analysis for existing residential buildings in accordance (Article 4(1), of the Directive 2010/31/EU together with Article 7, first paragraph was submitted in original report submitted

any of the desired content. Where appropriate, we have made reference to the two previous reports rather than unnecessarily duplicating information here.

2. Reference Buildings

2.1 New Apartment Buildings

According to Annex 1 of Cost Optimal Regulation, member states should establish reference buildings for the following residential building categories: single-family buildings and apartment blocks or multifamily buildings. For each building category, at least one reference building shall be established for new buildings.

The initial Residential Report presented the results for five building types and a rationale for their choice:

1. Bungalow
2. Detached house
3. Semi-detached house
4. Mid-floor flat
5. Top-floor flat.

This report presents results for an apartment block as a whole[2]. It comprises three apartment types: the top and mid-floor apartments previously modelled and a bottom-floor apartment based on the same geometry as that of the top and mid-floor apartments. The apartment building comprises four floors with 8 apartment units on each floor. All apartment units have a floor area of 54 m² calculated by taking linear measurements between the finished internal faces of the walls. It is assumed that all communal spaces (e.g. corridors, stairways) are unheated.

Table 2.1 provides a more detailed summary of this Reference Building using the template provided with the Cost Optimal Regulation. The component level requirements that set the minimum performance standards for new residential buildings are outlined in Appendix 1.

Table 2.1: Reference Buildings for New Buildings

Reference Building	Building Geometry		Shares of window area on the building envelope and windows with no solar access	Floor area m^2	Typical energy performance $kWh/m^2/yr$	Component level requirements
	Area of N/W/S/E exposed facade (m²)	Volume (m³)	Ratio of window area over total facade area separately for N/W/S/E facades		Primary energy for each building model according to current national regulations	These are minimum requirements for different elemental components
Apartment Building	14 / 22 / 0 / 0 (per unit, excludes communal areas)	4,160 (total building)	0 / 0.5 / 0 / 0 (per unit, modelled as E/W orientation as average)	1,728 (total building)	61	See Appendix 1

Table 2.2 provides a summary of the energy performance relevant data used in the modelling for the apartment building modelled to meet current Building Regulations.

[2] The results aggregate the results for the apartment units. The results do not include energy use within communal spaces (e.g. corridors, stairways). National energy efficiency standards for communal spaces are determined by the national non-residential building regulations which are assessed separately within the cost-optimal studies.

Table 2.2: Energy Performance Relevant Data – Apartment Building

			Quantity	Unit
Calculation	Method and tool(s)	DEAP v3.2.1		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.10	kWh/kWh
		Biomass	1.10	
		Solid Multi-Fuel	1.10	
		Grid Supplied Electricity	1.85	
		On-site Generated Electricity	1.85	
Climate	Location	Dublin		
	Climate data	DEAP v3.2.1 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height (per unit)		6 x 9 x 2.4	m
Fabric	Fabric u-values	Wall	0.19	W/m²K
		Roof	0.12	W/m²K
		Floor	0.15	W/m²K
		Window	1.4	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.06	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	5	m³/m².hr
		Heat recovery efficiency	-	%
	Heating system	Fuel	Gas	-
		Generation	91.3	%
		Distribution / Control	102	%
		Secondary Heating Efficiency	80	%
		Secondary Heating Proportion	10	%
	DHW system	Generation	91.3	%
		Distribution / Control	102	%
		Emission	-	%
Setpoints and Schedules	Temperature setpoint	Winter	21 (living area) 18 (rest of dwelling)	ºC
		Summer	21 (living area) 18 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by the DEAP v3.2.1. The heating schedule is 07.00h to 09.00h and 17.00h to 23.00h daily. Oct. - May		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Heating energy		20	kWh/m²/yr
	Cooling energy		-	kWh/m²/yr
	DHW energy		21	kWh/m²/yr
	Lighting energy		4	kWh/m²/yr
	Auxiliary energy		5	kWh/m²/yr
Energy Generation	Generated energy (solar hot water)		16	kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	40	kWh/m²/yr
		Electricity	9	kWh/m²/yr
		Other (SHW)	16	kWh/m²/yr
	Primary energy		61	kWh/m²/yr

2.2 Existing Apartment Buildings (for both elemental and whole building renovation analysis)

Consistent with the previous work described in the Residential Report, we have considered two variations for existing buildings: (i) pre-1978 uninsulated cavity wall constructed buildings and (ii) uninsulated hollow block constructed buildings. These represent two common existing building construction types within Ireland 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 building models have been used for new and existing build (i.e. same size and geometry). The rationale for these models was provided in the previous Residential Report.

The baseline energy performance for the existing buildings has been modelled based upon Ireland's energy performance certificate database, upon the Irish data gathered as part of the Intelligent Energy Europe TABULA project (http://www.energyaction.ie/projects/tabula.php), and upon the government's forthcoming National Code of Practice on Retrofitting (http://www.nsainep.ie/Home/Index?CommitteeFilter=NSAI/TC+40).

The TABULA project ran from 2009-2012 and identified common residential building typologies for participating member states. The energy performance certificate database contains the data used to produce energy performance certificates for existing buildings required under Article 7 of the original Energy Performance of Buildings Directive. There are currently c.340,000 records, with large datasets for each of the building types we are considering for this study (https://ndber.seai.ie/pass/ber/search.aspx).

TABULA provided some approximate baseline building specifications (fabric u-values) and aided the identification of typical refurbishment options which were to be modelled for existing dwellings. The EPC database also allowed us to identify approximate baseline building specifications (fabric u-values, service efficiencies, fuel types). They were used to develop a full set of specifications which could be modelled as the baseline for the different reference buildings.

Table 2.3 provides a summary of the two reference apartment buildings using the template provided in the Cost Optimal Regulation. It 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 requirements under Building Regulations Part L Technical Guidance Document 2011). We have omitted information on the building technologies and base case performance specifications in this table as these are provided in more detail in Tables 2.4a-b.

Tables 2.4a-b provide a summary of the energy performance data based on the base case reference buildings without improvements made. We have omitted information on the buildings themselves which were provided in Table 2.2.

Note that these two reference apartment buildings have been used for both the elemental and whole building renovation analysis.

Capabilities on project:
Building Engineering

Table 2.3: Reference Existing Apartment Buildings

Building Category	Construction Type	Primary energy performance kWh/m^2/yr					
		Primary energy for base case (no improvements)	Wall improved to current standards (u=0.55 cavity, 0.35 solid, i.e. hollow block)	Roof improved to current standards (u=0.16)	Floor improved to current standards (u=0.45)	Heating system improved to current standards (gas or oil boiler 90% eff)	Windows improved to current standards (u=1.6)
Apartment Building	Cavity	308	252	295	301	285	282
	Hollow Block	324	245	311	317	300	299

Table 2.4a: Energy Performance Relevant Data – Apartment Building, Cavity Wall

Building: Apartment Block			**Quantity**	**Unit**
Calculation	Method and tool(s)	DEAP v3.2.1		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.10	kWh/kWh
		Biomass	1.10	
		Solid Multi-Fuel	1.10	
		Grid Supplied Electricity	1.85	
		On-site Generated Electricity	1.85	
Climate	Location	Dublin		
	Climate data	DEAP v3.2.1 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height (per unit)		6 x 9 x 2.4	m
Fabric	Fabric u-values	Wall	1.78	W/m²K
		Roof	0.68	W/m²K
		Floor	0.73	W/m²K
		Window	3.2	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.15	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	11.6	m³/m².hr
		Heat recovery efficiency	-	%
	Heating system	Main Heating Fuel	Electricity	-
		Main Heating Efficiency	100	%
		Secondary Heating Fuel	Electricity	-
		Secondary Heating Efficiency	100	%
		Secondary Heating Proportion	10	%
	DHW system	Efficiency	100	%
Setpoints and Schedules	Temperature setpoint	Winter	21 (living area) 18 (rest of dwelling)	ºC
		Summer	21 (living area) 18 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by the DEAP v3.2.1. The heating schedule is 07.00h to 09.00h and 17.00h to 23.00h daily.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Main Heating energy		108	kWh/m²/yr
	Secondary Heating energy		12	kWh/m²/yr
	DHW energy		37	kWh/m²/yr
	Lighting energy		8	kWh/m²/yr
	Auxiliary energy		2	kWh/m²/yr
Energy Generation	Generated energy			kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	0	kWh/m²/yr
		Electricity	166	kWh/m²/yr
	Primary energy		308	kWh/m²/yr

Table 2.4b: Energy Performance Relevant Data – Apartment Building, Hollow Block Wall

Building: Apartment Block			**Quantity**	**Unit**
Calculation	Method and tool(s)	DEAP v3.2.1		
	Primary energy conversion factors (averaged over calculation period):	Gas	1.10	kWh/kWh
		Biomass	1.10	
		Solid Multi-Fuel	1.10	
		Grid Supplied Electricity	1.85	
		On-site Generated Electricity	1.85	
Climate	Location	Dublin		
	Climate data	DEAP v3.2.1 climate data file		
	Terrain location	Sub-urban. The impact of surrounding buildings has not been included.		
Geometry	Length x Width x Height (per unit)		6 x 9 x 2.4	m
Fabric	Fabric u-values	Wall	1.78	W/m²K
		Roof	0.68	W/m²K
		Floor	0.73	W/m²K
		Window	3.2	W/m²K
	Thermal Bridging y-value	Thermal Bridging	0.15	W/m²K
Systems	Ventilation system	Air changes per hour at 50Pa	11.6	m³/m².hr
		Heat recovery efficiency	-	%
	Heating system	Main Heating Fuel	Electricity	-
		Main Heating Efficiency	100	%
		Secondary Heating Fuel	Electricity	-
		Secondary Heating Efficiency	100	%
		Secondary Heating Proportion	10	%
	DHW system	Efficiency	100	%
Setpoints and Schedules	Temperature setpoint	Winter	21 (living area) 18 (rest of dwelling)	ºC
		Summer	21 (living area) 18 (rest of dwelling)	ºC
	Operation schedules	All schedules are defined by the DEAP v3.2.1. The heating schedule is 07.00h to 09.00h and 17.00h to 23.00h daily.		
Energy Use	Energy contribution of main passive strategies	Natural ventilation	These energy savings are not reported separately.	
	Main Heating energy		116	kWh/m²/yr
	Secondary Heating energy		13	kWh/m²/yr
	DHW energy		37	kWh/m²/yr
	Lighting energy		8	kWh/m²/yr
	Auxiliary energy		2	kWh/m²/yr
Energy Generation	Generated energy			kWh/m²/yr
Energy Consumption	Delivered energy	Fossil fuel	0	kWh/m²/yr
		Electricity	175	kWh/m²/yr
	Primary energy		324	kWh/m²/yr

2.3 Existing Non-Residential Buildings

The previous Non-Residential Report determined cost optimum levels for each fabric and service element for a range of existing non-residential buildings. Hence, for each non-residential building it determined the cost optimal option if renovating the walls or replacing the heating system. This report presents the cost optimum of a set of packages of renovation measures each comprising building fabric, building services and/or the installation of photovoltaics.

We have used the same existing non-residential buildings adopted for the previous work as shown in Table 2.5

Table 2.5: Non-Residential Building Models

Building Category	*Construction type*	
	Cavity Wall	Steel Frame
Retail (Air Conditioned)		1,250 m²
Office (Natural Ventilation)	1,500 m²	
Office (Air Conditioned)		1,500 m²
School (Primary – Natural Ventilation)	2,300 m²	
Hotel (Air Conditioned)	2,500 m²	

In the previous work, we considered two different baseline energy performance levels prior to renovation. However, the choice of baseline level had no impact on the cost optimum renovation option and we fully expect this to be the case here. Hence, for this work, a single baseline energy performance has been adopted (denoted as EE1 in the previous Non-Residential Report).

Table 2.6 provides a summary of the reference buildings using the template provided in the Cost Optimal Regulation. Details of the building geometry, window area and floor area are included in the previous Non-Residential Report. The previous Non-Residential Report provided a summary of the energy performance of the baseline building and the fabric and services specifications assumed.

Table 2.6: Reference Buildings for Existing Buildings

Building Category	Construction type	Typical energy performance kWh/m^2/yr	Component level requirements
Office (Natural Ventilation)	Cavity Wall	353	See Appendix A of previous report
Office (Air Conditioned)	Steel Frame	407	
School (Primary – Natural Ventilation)	Cavity Wall	180	
Hotel (Air Conditioned)	Cavity Wall	578	
Retail (Air Conditioned)	Steel Frame	652	

3. Measures and Packages

3.1 New Apartment Buildings

The packages evaluated are listed in Table 3.1. The packages represent three different components of a building design (fabric, heating, photovoltaics (PV)), so that selecting one package from each component forms a complete building design. In total, 80 alternatives have been considered. It includes solutions that together might comprise a building model that performs more poorly than the primary energy target set by the current regulations. The rationale for the choice of packages and details of the costs assumed were described in the previous Residential Report.

Table 3.1: Measures to be included in analysis – New Apartment Buildings

Fabric (4 options)	***A***	***B***	***C***	***D***
Wall U-value (W/m²K)	0.27	0.20	0.13	0.13
Roof U-value (W/m²K)	0.16	0.14	0.11	0.11
Floor U-value (W/m²K)	0.20	0.18	0.13	0.13
Window U-value (W/m²K)	1.6	1.4	0.9	0.9
Thermal Bridging y-value	0.15	0.08	0.04	0.04
Air Tightness (m³/m².hr @ 50 Pa)	10	7	5	2
Ventilation Strategy	Natural ventilation	Natural ventilation	Natural ventilation	Mechanical Ventilation with Heat Recovery (SFP 0.7 W/l/s, heat recovery efficiency 85%

Heating (5 options)					
Space Heating Source	Condensing Gas boiler (91% efficiency)	Condensing Gas boiler (91% efficiency)	Biomass Boiler (80% efficiency)	Ground Source Heat Pump (SPF = 396)	Air Source Heat Pump (SPF = 374)
Communal Heating System?	No	Yes	Yes	Yes	Yes
Controls	Full time and temperature zone control, weather compensation, modulating boiler with interlock	As for gas boiler	As for gas boiler	Full time and temperature zone control	Full time and temperature zone control
Emitters	Radiators	Radiators	Radiators	Underfloor Heating	Underfloor Heating
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	As for space heating + electric immersion (supplying c.50% of DHW heat)	As for space heating + electric immersion (supplying c.50% of DHW heat)

PV (4 options)				
PV Installation (percentage of foundation area)	0%	10%	20%	30%

3.2 Existing Apartment Buildings – Elemental measures

For part of the analysis of existing buildings each measure has been assessed separately – it is common for individual elements to be renovated. The measures which have been assessed are listed in Table 3.2. The rationale for their selection and details of the costs assumed were provided in the previous Residential Report

Table 3.2: Measures to be included in analysis – Existing Buildings

Fabric - Cavity Walls	***Wall U-value (W/m²K)***	***Insulation***
Option 1	0.31	Fully filled cavity
Option 2	0.19	Fully filled cavity and 50mm internal insulation
Option 3	0.14	Fully filled cavity and 100mm internal insulation
Option 4	0.16	Fully filled cavity and 100mm external insulation
Option 5	0.10	Fully filled cavity and 200mm external insulation
Option 6	0.39	50mm internal insulation (unfilled cavity)
Option 7	0.21	100mm internal insulation (unfilled cavity)

Fabric – Hollow Block Walls	***Wall U-value (W/m²K)***	***Insulation***
Option 1	0.40	50mm internal insulation
Option 2	0.22	100mm internal insulation
Option 3	0.28	100mm external insulation
Option 4	0.15	200mm external insulation

Fabric – Roof	***Roof U-value (W/m²K)***	***Insulation***
Option 1	0.29	150mm mineral wool insulation quilt between joists
Option 2	0.13	150mm mineral wool insulation quilt between joists PLUS 150mm above joists
Option 3	0.11	150mm mineral wool insulation quilt between joists PLUS 200mm above joists

Fabric – Floor	***Floor U-value (W/m²K)***	***Insulation***
Option 1	0.43	20mm insulation

Option 2	0.31	40mm insulation
Option 3	0.24	60mm insulation
Option 4	0.15	120mm insulation

Fabric – Windows	***Window U-value (W/m²K)***	***Type***
Option 1	1.6	Double glazed Upvc windows
Option 2	1.4	Double glazed Upvc windows
Option 3	0.9	Triple glazed Upvc windows

Heating			
Space Heating Source	Condensing Gas boiler (90% efficiency)	Condensing Gas boiler (91% efficiency)	Air Source Heat Pump (SPF = 374)
Communal?	No	Yes	No
Controls	Full time and temperature zone control, weather compensation, modulating boiler with interlock	As for gas boiler	Full time and temperature zone control
Emitters	Radiators	Radiators	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 (supplying c.50% of DHW heat)

3.3 Existing Apartment Buildings – Packages of measures

In addition, this work has evaluated existing dwelling measures assessed on a package basis (i.e. with more than one measure implemented at a time). The measures which have been assessed are listed in Table 3.3. The rationale for the selection of these measures and details of the costs assumed were provided in the previous Residential Report. References to ‘cost optimal’ fabric options are those U-values that were previously determined as being cost-optimal for each element in isolation and are set out again in Section 6.3 of this report.

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

Fabric (9 options)[1] *Reference (used in results tables)*	***Cost Optimal Fabric Package (Roof, Wall, Window)*** ***All***	***Better Than Cost Optimal Fabric Package (Roof, Wall, Window)*** ***All+***	***Worse Than Cost Optimal Fabric Package (Roof, Wall, Window)*** ***All-***	***Roof and Wall Upgrade to Cost Optimal*** ***Roof + Wall***	***Roof and Window Upgrade to Cost Optimal*** ***Roof + Window***	***Roof Only to Cost Optimal*** ***Roof***	***Wall Only to Cost Optimal*** ***Wall***	***Windo to C Opti*** ***Win***
Cavity Wall U-value (W/m²K)	0.31	0.19	0.39	0.31	1.78	1.78	0.31	1.7
Solid Wall (hollow block) U-value (W/m²K)	0.22	0.15	0.28	0.22	2.09	2.09	0.22	2.0
Roof U-value (W/m²K)	0.11	0.11	0.13	0.11	0.11	0.11	0.68	0.6
Window U-value (W/m²K)	1.4	0.9	1.6	3.2	1.4	3.2	3.2	1.

[1] Note: measures for each fabric element are as per existing build individual measures set out in Table 3.2

Heating (6 options) - Flats						
Space Heating Source	Condensing Gas boiler (91% efficiency)	Gas boiler (91% efficiency) with Solar Hot Water	Air Source Heat Pump (SPF = 374)	Ground Source Heat Pump (SPF = 396)	Biomass boiler (80% efficiency)	C
Heating Individual or Communal	Individual	Communal	Individual	Communal	Communal	
Controls	Time and temperature zone control, weather compensation, modulating boiler with interlock	Time and temperature zone control, weather compensation, modulating boiler with interlock	Time and temperature zone control, weather compensation	Time and temperature zone control, weather compensation	Time and temperature zone control, boiler interlock	te c m
Emitters	Radiators	Radiators	Low Temperature Radiators	Low Temperature Radiators	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 (supplying c.50% of DHW heat)	As for space heating + electric immersion (supplying c.50% of DHW heat)	As for space heating	As

PV (3 options)			
PV Installation (percentage of foundation area)	0%	10%	20%

3.4 Existing Non-Residential Buildings – Packages of measures

This work has evaluated existing non-residential building measures assessed on a package basis (i.e. with more than one measure implemented at a time). This has allowed us to test different combinations of building fabric, building services and renewables.

Tables 3.4 to 3.8 provide the specifications for each package for each of the five building types respectively. Each package comprises a combination of 'fabric', 'services', 'heating' and 'PV' options. For most building types, 192 different packages were evaluated (4 'fabric' options, 4 'services' options, 4 'heating' options and 3 'PV' options). An additional heating option has been included for the hotel (gas heating & solar hot water) which was not included for the other buildings as the previous work showed no substantive benefit. As a result, 240 different packages were evaluated for the hotel.

The choice of packages includes options for no change to the current baseline building (denoted as 'EE1' – see Section 2.3). This means that it is possible to test, for example, fabric upgrades without changes to the HVAC systems. The baseline fabric and services specification is slightly different for each building type (the rationale for this is presented in the previous Non-Residential Report).

The packages are arranged around the elemental cost-optimal point for each individual building fabric and services measure identified previously in the Non-Residential Report. 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.

Table 3.4: Measures included in analysis (Retail)

Fabric (4 options)	***EE1***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.45	0.27	**0.2**	0.15
Roof U-value (W/m²K)	0.25	0.18	**0.14**	**0.14**
Floor U-value (W/m²K)	0.45	**0.25**	**0.25**	0.2
Window U-value (W/m²K)	2.8	1.8	**1.4**	1.1

Services (4 options)	***EE1***	***1***	***2***	***3***
Lighting (lm/W)	25	55	60	**65**
Chiller Efficiency (SEER)	2.0	3.5	4.5	**5.5**
AHU SFP	2.2	2.2	2.0	**1.8**

Heating (4 options)				
Heating Source	Gas (74%)	Gas (91%)	**ASHP**	Gas CHP

PV (3 options)			
PV Installation (percentage of foundation area)	0%	10%	20%

Table 3.5: Measures included in analysis (Office NV)

Fabric (4 options)	***EE1***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.55	0.39	**0.3**	0.21
Roof U-value (W/m²K)	0.61	0.2	**0.15**	**0.15**
Floor U-value (W/m²K)	0.45	0.15	**0.1**	**0.1**
Window U-value (W/m²K)	3.6	**1.8**	**1.8**	1.4

Services (4 options)	***EE1***	***1***	***2***	***3***
Lighting (lm/W)	25	55	60	**65**

Heating (4 options)				
Heating Source	Gas (74%)	Gas (91%)	**ASHP**	Gas CHP

PV (3 options)			
PV Installation (percentage of foundation area)	0%	10%	20%

Table 3.6: Measures included in analysis (Office AC)

Fabric (4 options)	***EE1***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.45	0.27	**0.2**	0.15
Roof U-value (W/m²K)	0.25	0.18	**0.14**	**0.14**
Floor U-value (W/m²K)	0.45	0.15	**0.1**	**0.1**
Window U-value (W/m²K)	2.2	1.8	**1.4**	1.1

Services (4 options)	***EE1***	***1***	***2***	***3***
Lighting (lm/W)	45	55	60	**65**
Chiller Efficiency (SEER)	2.2	3.5	4.5	**5.5**
AHU SFP	3.0	2.2	2.0	**1.8**

Heating (4 options)				
Heating Source	Gas (78%)	Gas (91%)	**ASHP**	Gas CHP

PV (3 options)			
PV Installation (percentage of foundation area)	0%	10%	20%

Table 3.7: Measures included in analysis (School)

Fabric (4 options)	***EE1***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.45	0.39	**0.3**	0.21
Roof U-value (W/m²K)	0.50	**0.25**	**0.25**	0.2
Floor U-value (W/m²K)	0.45	0.15	**0.1**	**0.1**
Window U-value (W/m²K)	3.6	**1.8**	**1.8**	1.4

Services (4 options)	***EE1***	***1***	***2***	***3***
Lighting (lm/W)	30	55	60	**65**

Heating (4 options)				
Heating Source	Gas (74%)	Gas (91%)	**ASHP**	Gas CHP

PV (3 options)			
PV Installation (percentage of foundation area)	0%	10%	20%

Table 3.8: Measures included in analysis (Hotel)

Fabric (4 options)	***EE1***	***A***	***B***	***C***
Wall U-value (W/m²K)	0.45	0.39	**0.3**	0.21
Roof U-value (W/m²K)	0.25	0.2	**0.15**	**0.15**
Floor U-value (W/m²K)	0.45	0.15	**0.1**	**0.1**
Window U-value (W/m²K)	3.1	1.8	**1.4**	1.1

Services (4 options)	***EE1***	***1***	***2***	***3***
Lighting (lm/W)	15	**55**	60	65
Chiller Efficiency (SEER)	2.0	3.5	4.5	**5.5**
AHU SFP	3.0	2.2	2.0	**1.8**

Heating (4 options)					
Heating Source	Gas (74%)	Gas (91%)	Gas (91%) + SHW	**ASHP**	Gas CHP

PV (3 options)			
PV Installation (percentage of foundation area)	0%	10%	20%

4. Calculation of Primary Energy Demand for the Measures

4.1 New Apartment Buildings

4.1.1 *Introduction*

The previous Residential Report outlines the procedure for determining the primary energy for each package of measures. In summary, the energy performance of the different packages was modelled in the DEAP calculation spreadsheet. The energy end uses (e.g. space heating, water heating, lighting, pumps and fans) were recorded directly from the DEAP 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.

4.1.2 *Energy demand calculation*

Table 4.1 summarises the results of the energy performance calculation for the most cost-optimal packages in the apartment building. 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 Table 2,2. The delivered energy per carrier has been incorporated into Tables 4.1 as more helpful than producing separate tables.

Table 4.1: Energy Demand Output Table

Building: Apartment Block

Package			Energy Use					Fuel Use					Primary Energy	
Fabric	Heating	PV	Heat	Sec Heat	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Biomass	Multi	Total	Reduction over Reference
			kWh/m²					kWh/m²					kWh/m²	%
D	Gas + SHW	30%	10	1	2	21	5	30	7	-9	0	1	26	58%
C	Gas + SHW	30%	20	3	0	21	5	41	5	-9	0	3	34	45%
C	Gas	30%	15	2	2	42	5	58	7	-9	0	2	56	8%
B	Gas	30%	28	4	2	42	4	71	7	-9	0	4	69	-12%
B	Gas	20%	28	4	2	42	4	71	7	-6	0	4	75	-22%
B	Gas	10%	28	4	2	42	4	71	7	-3	0	4	81	-32%
B	Gas	0%	28	4	2	42	4	71	7	0	0	4	86	-41%
B	Biomass	0%	39	5	1	43	4	0	5	0	82	5	94	-54%
A	Gas	0%	43	6	2	42	4	85	7	0	0	6	101	-65%
A	Biomass	0%	57	7	1	43	4	0	5	0	100	7	113	-84%

4.2 Existing Apartment Buildings – Elemental measures

4.2.1 *Introduction*

The process to modelling building energy performance was the same as for new residential buildings as outlined in section 3.1 of the original report

4.2.2 *Energy demand calculation*

Tables 4.2a – b summarise the results of the energy performance calculation for the most cost-optimal packages for the apartment building. 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 cases are listed in Tables 2.4a – 2.4b. The delivered energy per carrier has been incorporated into Tables 4.2a – 4.2b as more helpful than producing separate tables.

Table 4.2a: Energy Demand Output Table – Cavity Wall

Building: Apartment Block

Measure	Value	Energy Use					Fuel Use						Primary Energy	
		Heat	Sec Heat	Aux	DHW	Light	Gas	Grid Elec.	Gen Elec.	Biomass	Multi	Oil	Total	Reduction over Reference
		kWh/m²					kWh/m²						kWh/m²	%
Wall U-Value	0.1	70	8	2	37	8	0	124	0	0	0	0	231	8%
Wall U-Value	0.14	71	8	2	37	8	0	125	0	0	0	0	233	8%
Wall U-Value	0.16	72	8	2	37	8	0	126	0	0	0	0	234	7%
Wall U-Value	0.19	72	8	2	37	8	0	127	0	0	0	0	235	7%
Wall U-Value	0.21	73	8	2	37	8	0	127	0	0	0	0	236	6%
Wall U-Value	0.31	75	8	2	37	8	0	130	0	0	0	0	240	4%
Wall U-Value	0.39	77	9	2	37	8	0	132	0	0	0	0	244	3%
Roof U-value	0.11	101	11	2	37	8	0	158	0	0	0	0	294	0%
Roof U-value	0.13	101	11	2	37	8	0	159	0	0	0	0	294	0%
Roof U-value	0.29	103	11	2	37	8	0	161	0	0	0	0	298	-1%
Floor U-value	0.15	101	11	2	37	8	0	158	0	0	0	0	293	2%
Floor U-value	0.24	102	11	2	37	8	0	159	0	0	0	0	296	2%
Floor U-value	0.31	103	11	2	37	8	0	160	0	0	0	0	297	1%
Floor U-value	0.43	104	12	2	37	8	0	162	0	0	0	0	300	0%
Heating Source	ASHP	28	10	2	25	8	0	72	0	0	0	0	134	-

Heating Source	Gas + SHW	106	10	1	20	8	126	19	0	0	0	0	174	-
Heating Source	Gas	97	10	2	43	8	139	20	0	0	0	0	190	-
Window U-value	0.9	90	10	2	37	8	0	147	0	0	0	0	272	4%
Window U-value	1.4	93	10	2	37	8	0	150	0	0	0	0	278	1%
Window U-value	1.6	95	11	2	37	8	0	152	0	0	0	0	282	0%

Table 4.2b: Energy Demand Output Table – Hollow Block Wall

Building: Apartment Block

Measure	**Value**	**Energy Use**					**Fuel Use**						**Primary Energy**	
		Heat	Sec Heat	Aux	DHW	Light	Gas	Grid Elec.	Gen Elec.	Biomass	Multi	Oil	Total	Reduction over Reference
		kWh/m²					kWh/m²						kWh/m²	%
Wall U-Value	0.15	73	8	2	37	8	0	127	0	0	0	0	235	4%
Wall U-Value	0.22	74	8	2	37	8	0	129	0	0	0	0	239	2%
Wall U-Value	0.28	76	8	2	37	8	0	130	0	0	0	0	241	1%
Wall U-Value	0.4	78	9	2	37	8	0	133	0	0	0	0	247	-1%
Roof U-value	0.11	109	12	2	37	8	0	167	0	0	0	0	310	0%
Roof U-value	0.13	109	12	2	37	8	0	167	0	0	0	0	310	0%
Roof U-value	0.29	111	12	2	37	8	0	170	0	0	0	0	314	-1%
Floor U-value	0.15	109	12	2	37	8	0	167	0	0	0	0	310	2%
Floor U-value	0.24	110	12	2	37	8	0	168	0	0	0	0	312	2%
Floor U-value	0.31	111	12	2	37	8	0	169	0	0	0	0	314	1%
Floor U-value	0.43	112	12	2	37	8	0	171	0	0	0	0	317	0%
Heating Source	ASHP	30	11	2	25	8	0	75	0	0	0	0	139	-
Heating Source	Gas + SHW	114	11	1	20	8	133	20	0	0	0	0	183	-
Heating Source	Gas	103	11	2	43	8	146	21	0	0	0	0	199	-
Window U-value	0.9	98	11	2	37	8	0	156	0	0	0	0	289	3%
Window U-value	1.4	101	11	2	37	8	0	159	0	0	0	0	295	1%
Window U-value	1.6	103	12	2	37	8	0	161	0	0	0	0	299	0%

4.3 Existing Apartment Buildings – Packages of measures

4.3.1 *Introduction*

The process to modelling building energy performance was the same as for new residential buildings as outlined in section 3.1 of the original report.

4.3.2 *Energy demand calculation*

Tables 4.3a – 4.3b summarise the results of the energy performance calculation for the most cost-optimal packages for the apartment building. 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 cases are listed in Tables 2.4a – 2.4b. The delivered energy per carrier has been incorporated into Tables 4.3a – 4.3b as more helpful than producing separate tables.

Table 4.3a: Energy Demand Output Table – Cavity Wall

Building: Apartment Block Cavity

Package			**Energy Use**					**Fuel Use**						**Primary Energy**
Fabric	Heating	PV	Heat	Sec Heat	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Biomass	Solid Fuel	Oil	Total
			kWh/m²					kWh/m²						kWh/m²
All+	GSHP	20%	27	8	1	13	8	0	56	-6	0	0	0	73
All	GSHP	20%	28	8	1	13	8	0	58	-6	0	0	0	77
Roof + Wall	GSHP	20%	32	9	1	12	8	0	62	-6	0	0	0	86
Roof + Wall	ASHP	20%	26	9	1	25	8	0	69	-6	0	0	0	96
All	Gas	20%	75	8	2	42	8	117	18	-6	0	0	0	114
Roof + Wall	Gas	20%	87	9	2	42	8	129	19	-6	0	0	0	131
Roof + Wall	Gas	0%	87	9	2	42	8	129	19	0	0	0	0	143
Roof + Wall	Biomass	0%	110	9	1	43	8	0	18	0	154	0	0	162
Wall	Biomass	0%	110	9	1	43	8	0	18	0	154	0	0	171
Roof	Biomass	0%	144	12	1	43	8	0	21	0	187	0	0	207

Table 4.3b: Energy Demand Output Table – Hollow Block Wall

Building: Apartment Block Hollow Block

Package			Energy Use					Fuel Use						Primary Energy
Fabric	Heating	PV	Heat	Sec Heat	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	Biomass	Solid Fuel	Oil	Total
			kWh/m²					kWh/m²						kWh/m²
All+	GSHP	20%	27	8	1	13	8	0	56	-6	0	0	0	73
All	GSHP	20%	28	8	1	13	8	0	58	-6	0	0	0	76
Roof + Wall	GSHP	20%	32	9	1	12	8	0	62	-6	0	0	0	85
Roof + Wall	ASHP	20%	26	9	1	25	8	0	69	-6	0	0	0	95
All	Gas	20%	75	8	2	42	8	117	18	-6	0	0	0	112
Roof + Wall	Gas	20%	87	9	2	42	8	129	19	-6	0	0	0	129
Roof + Wall	Gas	0%	87	9	2	42	8	129	19	0	0	0	0	141
Roof + Wall	Biomass	0%	110	9	1	43	8	0	18	0	154	0	0	159
Wall	Biomass	0%	110	9	1	43	8	0	18	0	154	0	0	169
Roof	Biomass	0%	144	12	1	43	8	0	21	0	187	0	0	216

4.4 Existing Non-Residential Buildings – Packages of measures

4.4.1 *Introduction*

The previous Non-Residential Report outlines the procedure for determining the primary energy for existing non-residential buildings. In summary, the energy performance of the different packages for the five non-residential buildings was modelled in SBEM. 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.

4.4.2 *Energy demand calculation*

Tables 4.4a – 4.4e summarise the results of the energy performance calculation for the most cost-optimal packages for the residential 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 cases were provided in the previous Non-Residential Report. The delivered energy per carrier has been incorporated into Tables 4.4a – 4.4e as more helpful than producing separate tables.

Table 4.4a: Energy Demand Output Table – Retail

Package				Energy Use					Fuel Use			Total Primary Energy
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	
				kWh/m²					kWh/m²			kWh/m²
C	ASHP	3	20%	14	21	30	1	101	0	167	14	302
B	ASHP	3	20%	15	20	30	1	101	0	167	14	302
EE1	ASHP	3	20%	20	19	30	1	101	0	171	14	311
EE1	ASHP	3	10%	20	19	30	1	101	0	171	7	324
EE1	ASHP	3	0%	20	19	30	1	101	0	171	0	338
EE1	ASHP	2	0%	20	25	33	1	104	0	182	0	359
EE1	Gas (91%)	3	0%	83	19	30	1	101	83	151	0	390
EE1	Gas (74%)	2	0%	100	25	33	1	104	100	163	0	431
EE1	Gas (74%)	1	0%	98	33	36	1	107	98	178	0	459
EE1	Gas (74%)	EE1	0%	85	88	36	1	158	85	283	0	652

Table 4.4b: Energy Demand Output Table – Office (Nat Vent)

Package				Energy Use					Fuel Use			Total Primary Energy
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	
				kWh/m²					kWh/m²			kWh/m²
B	ASHP	3	20%	24	0	4	5	28	0	60	12	95
EE1	ASHP	3	20%	38	0	4	5	28	0	75	12	124
EE1	ASHP	3	10%	38	0	4	5	28	0	75	6	136
EE1	ASHP	3	0%	38	0	4	5	28	0	75	0	148
EE1	ASHP	2	0%	38	0	4	5	30	0	77	0	152
EE1	ASHP	EE1	0%	34	0	4	5	72	0	115	0	227
EE1	Gas (91%)	2	0%	159	0	4	5	30	159	39	0	252
EE1	Gas (74%)	2	0%	196	0	4	5	30	196	39	0	292
EE1	Gas (91%)	EE1	0%	143	0	4	5	72	143	81	0	316
EE1	Gas (74%)	EE1	0%	175	0	4	5	72	175	81	0	353

Table 4.4c: Energy Demand Output Table – Office (Air Con)

Package				Energy Use					Fuel Use			Total Primary Energy
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	
				kWh/m²					kWh/m²			kWh/m²
C	ASHP	3	20%	23	13	25	5	28	0	93	12	160
B	ASHP	3	20%	24	12	25	5	28	0	94	12	161
EE1	ASHP	3	20%	30	16	25	5	28	0	103	12	180
EE1	ASHP	3	10%	30	16	25	5	28	0	103	6	192
EE1	ASHP	3	0%	30	16	25	5	28	0	103	0	203
EE1	ASHP	2	0%	29	20	28	5	30	0	112	0	220
EE1	ASHP	1	0%	28	27	30	5	33	0	123	0	243
EE1	ASHP	EE1	0%	27	50	34	5	45	0	160	0	316
EE1	Gas (91%)	EE1	0%	113	50	34	5	45	113	133	0	387
EE1	Gas (78%)	EE1	0%	131	50	34	5	45	131	133	0	407

Table 4.4d: Energy Demand Output Table – Primary School

Package				Energy Use					Fuel Use			Total Primary Energy
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	
				kWh/m²					kWh/m²			kWh/m²
C	ASHP	3	20%	11	0	2	4	13	11	20	14	24
B	ASHP	3	20%	12	0	2	4	13	12	20	14	24
EE1	ASHP	3	20%	22	0	2	4	13	22	20	14	35
EE1	ASHP	3	10%	22	0	2	4	13	22	20	7	48
EE1	ASHP	3	0%	22	0	2	4	13	22	20	0	60
EE1	ASHP	1	0%	22	0	2	4	16	22	22	0	65
EE1	ASHP	EE1	0%	20	0	2	4	29	20	35	0	87
EE1	Gas (91%)	1	0%	90	0	2	4	16	90	22	0	140
EE1	Gas (91%)	EE1	0%	85	0	2	4	29	85	35	0	158
EE1	Gas (74%)	EE1	0%	104	0	2	4	29	104	35	0	180

Table 4.4e: Energy Demand Output Table - Hotel

Package				**Energy Use**					**Fuel Use**			**Total Primary Energy**
Fabric	Heating	Services	PV	Heat	Cool	Aux	DHW	Light	Gas	Grid Elec.	Gen. Elec.	
				kWh/m²					kWh/m²			kWh/m²
C	ASHP	3	20%	22	3	33	172	16	172	73	7	321
B	ASHP	3	20%	24	3	33	172	16	172	75	7	325
EE1	ASHP	3	20%	31	4	33	172	16	172	84	7	342
EE1	ASHP	3	10%	31	4	33	172	16	172	84	3	349
EE1	ASHP	3	0%	31	4	33	172	16	172	84	0	355
EE1	ASHP	2	0%	31	5	35	172	17	172	89	0	365
EE1	ASHP	1	0%	30	7	38	172	19	172	95	0	376
EE1	ASHP	EE1	0%	23	24	43	172	69	172	159	0	503
EE1	Gas (91%)	EE1	0%	97	24	43	172	69	269	136	0	564
EE1	Gas (74%)	EE1	0%	110	24	43	172	69	282	136	0	578

5. Global Cost Calculation

5.1 Introduction

In undertaking this work, we have assumed various underpinning costs and assumptions which are consistent with the previous work.

- The costs for the various measures that we have considered in this work were provided in the previous Residential and Non-Residential Reports
- We have assumed a central discount rate for the macroeconomics calculation of 4% (as used by Ireland for Government policy Impact Assessments) with sensitivities of 3% as required by the Commission and an additional sensitivity at 6%.
- We have assumed a central real discount rate for the financial calculation of 7%, with an additional sensitivity at 13%.
- Central energy costs, as well as low and high energy costs for sensitivity analysis, were provided in the previous Residential and Non-Residential Reports.
- For new buildings, we have undertaken a sensitivity analysis on the primary emission factors based on a different set of assumptions on the future source of electricity power generation. Details of these primary emission factors were provided in the previous Residential and Non-Residential Reports.
- For new buildings, we have also undertaken a sensitivity analysis on the cost of carbon, details of which were also provided in the previous reports.
- The assumed cost of greenhouse gas emissions for the macroeconomic calculations was provided in the previous Residential and Non-Residential Reports.
- A calculation period of 30 years has been used for all residential buildings and the primary school. A calculation period of 20 years has been used for all other non-residential buildings.

5.2 New Apartment Buildings

The following Tables summarise the results of the cost calculations for the most cost-optimal packages in the new apartment building. Tables 5.1 relate to the macroeconomic calculations and Tables 5.2 relate to the financial calculations.

- Tables 5.1a/5.2a: Central energy price, central discount factors
- Tables 5.1b/5.2b: Low energy price, central discount factors
- Tables 5.1c/5.2c: High energy price, central discount factors
- Tables 5.1d/5.2d: Central energy price, low discount factors.
- Table 5.1e: Central energy price, high discount factor (macro-economic calculation only)
- Table 5.1f: Central energy price, central discount factors, alternative primary emission factors (macro-economic calculation only)
- Table 5.1g: Central energy price, central discount factors, alternative carbon price (macro-economic calculation only)

The sensitivity analysis shows the following:

- Discount rate and Energy Price: Both reducing the energy prices and increasing the discount rate reduced the cost of energy over the calculation period. This tended to have two impacts. First it made solutions with higher primary energy demand relatively more attractive. However, it also often changed the preferred heating technology – with gas tending to be the cost optimum solution for lower energy prices and biomass tending to be the cost optimum solution at higher energy prices. It is noted that the gas and biomass energy prices do come from different sources and this analysis is based on their comparability.
- Primary emission factor (PEF): The difference in primary emission factors between the central case and the sensitivity case was relatively small when averaged over the calculation period. The higher PEFs in the sensitivity case simply increased the cost optimum primary energy without changing the optimum technology for the lowest cost solution.
- Price of carbon: The sensitivity case for the price of carbon was approximately 25% less than the central case. However, the impact on the overall macroeconomic costs was very small and did not impact on the cost optimal level.

Table 5.1a: Macroeconomic Costs (Central energy price, 4% discount rate, EUR/m²)

Building	**Package**			**PE** (KWh/ m²)	**Initial Investment Cost**	**Annual Costs**		**Cost of Emissions**	**Residual Value**	**Macro Cost**
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	415	46	50	3	-35	479
	C	Gas + SHW	30%	34	355	5	62	4	-28	399
	C	Gas	30%	56	224	5	101	6	-13	323
	B	Gas	30%	69	172	5	121	8	-9	296
	B	Gas	20%	75	164	5	129	8	-9	297
	B	Gas	10%	81	157	5	136	9	-9	298
	B	Gas	0%	86	148	0	144	9	-9	292
	B	Biomass	0%	94	267	0	62	3	-22	310
	A	Gas	0%	101	138	0	167	11	-8	308
	A	Biomass	0%	113	257	0	73	3	-21	311

Table 5.1b: Macroeconomic Costs (Low energy price, 4% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	415	46	35	3	-35	464
	C	Gas + SHW	30%	34	355	5	43	4	-28	380
	C	Gas	30%	56	224	5	71	6	-13	293
	B	Gas	30%	69	172	5	85	8	-9	260
	B	Gas	20%	75	164	5	91	8	-9	259
	B	Gas	10%	81	157	5	97	9	-9	259
	B	Gas	0%	86	148	0	103	9	-9	252
	A	Gas	10%	95	147	5	114	10	-8	268
	A	Gas	0%	101	138	0	120	11	-8	260
	A	Biomass	0%	113	257	0	60	3	-21	299

Table 5.1c: Macroeconomic Costs (High energy price, 4% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	415	46	65	3	-35	494
	C	Gas + SHW	30%	34	355	5	82	4	-28	419
	C	Gas	30%	56	224	5	131	6	-13	354
	B	Gas	30%	69	172	5	157	8	-9	333
	B	Biomass	30%	77	290	5	52	1	-22	326
	B	Biomass	20%	83	282	5	61	2	-22	328
	B	Biomass	10%	89	275	5	70	2	-22	331
	B	Biomass	0%	94	267	0	79	3	-22	327
	A	Biomass	30%	95	280	5	65	2	-22	331
	A	Biomass	0%	113	257	0	92	3	-21	331

Table 5.1d: Macroeconomic Costs (Central energy price, 3% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	431	51	57	3	-46	497
	C	Gas + SHW	30%	34	368	6	71	4	-37	413
	C	Gas	30%	56	228	6	116	7	-17	339
	B	Gas	30%	69	176	6	138	9	-12	317
	B	Gas	20%	75	168	6	147	9	-12	318
	B	Gas	10%	81	160	6	155	10	-12	320
	B	Gas	0%	86	152	0	164	11	-12	315
	B	Biomass	0%	94	278	0	69	3	-29	321
	A	Biomass	20%	101	284	6	63	3	-28	328
	A	Biomass	0%	113	268	0	81	4	-28	324

Table 5.1e: Macroeconomic Costs (Central energy price, 6% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	391	37	39	2	-20	449
	C	Gas + SHW	30%	34	337	4	49	3	-16	377
	C	Gas	30%	56	218	4	79	5	-8	299
	B	Gas	30%	69	166	4	95	6	-5	265
	B	Gas	20%	75	158	4	101	6	-5	264
	B	Gas	10%	81	151	4	107	7	-5	264
	B	Gas	0%	86	143	0	113	7	-5	258
	A	Gas	10%	95	141	4	125	8	-5	274
	A	Gas	0%	101	133	0	131	8	-5	268
	A	Biomass	0%	113	240	0	60	2	-12	290

Table 5.1f: Macroeconomic Costs (Central energy price, 4% discount rate, Alternative PEF, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	25	415	46	50	3	-35	479
	C	Gas + SHW	30%	32	355	5	62	4	-28	399
	C	Gas	30%	56	224	5	101	6	-13	323
	B	Gas	30%	68	172	5	121	7	-9	296
	B	Gas	20%	75	164	5	129	8	-9	297
	B	Gas	10%	81	157	5	136	9	-9	298
	B	Gas	0%	88	148	0	144	9	-9	292
	A	Gas	0%	103	138	0	167	11	-8	308
	A	Biomass	10%	107	265	5	65	3	-21	317
	A	Biomass	0%	114	257	0	73	3	-21	311

Table 5.1g: Macroeconomic Costs (Central energy price, 4% discount rate, Alternative Cost of Carbon, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	415	46	50	2	-35	478
	C	Gas + SHW	30%	34	355	5	62	3	-28	398
	C	Gas	30%	56	224	5	101	4	-13	321
	B	Gas	30%	69	172	5	121	5	-9	294
	B	Gas	20%	75	164	5	129	6	-9	294
	B	Gas	10%	81	157	5	136	6	-9	295
	B	Gas	0%	86	148	0	144	6	-9	289
	B	Biomass	0%	94	267	0	62	2	-22	309
	A	Gas	0%	101	138	0	167	7	-8	305
	A	Biomass	0%	113	257	0	73	2	-21	310

Table 5.2a: Financial Costs (Central energy price, 7% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	434	38	40	-	-17	494
	C	Gas + SHW	30%	34	374	4	50	-	-14	414
	C	Gas	30%	56	245	4	81	-	-7	323
	B	Gas	30%	69	186	4	96	-	-5	282
	B	Gas	20%	75	177	4	103	-	-5	280
	B	Gas	10%	81	169	4	109	-	-5	278
	B	Gas	0%	86	160	0	115	-	-4	271
	A	Gas	10%	95	158	4	128	-	-4	286
	A	Gas	0%	101	149	0	134	-	-4	279
	A	Biomass	0%	113	265	0	63	-	-11	317

Table 5.2b: Financial Costs (Low energy price, 7% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	434	38	28	-	-17	482
	C	Gas + SHW	30%	34	374	4	34	-	-14	399
	C	Gas	30%	56	245	4	56	-	-7	299
	B	Gas	30%	69	186	4	68	-	-5	254
	B	Gas	20%	75	177	4	73	-	-5	250
	B	Gas	10%	81	169	4	78	-	-5	247
	B	Gas	0%	86	160	0	83	-	-4	239
	A	Gas	10%	95	158	4	91	-	-4	249
	A	Gas	0%	101	149	0	96	-	-4	241
	A	Biomass	0%	113	265	0	53	-	-11	307

Table 5.2c: Financial Costs (High energy price, 7% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	434	38	52	-	-17	506
	C	Gas + SHW	30%	34	374	4	65	-	-14	430
	C	Gas	30%	56	245	4	105	-	-7	348
	B	Gas	30%	69	186	4	125	-	-5	311
	B	Gas	20%	75	177	4	133	-	-5	310
	B	Gas	10%	81	169	4	140	-	-5	310
	B	Gas	0%	86	160	0	148	-	-4	304
	A	Gas	10%	95	158	4	165	-	-4	323
	A	Gas	0%	101	149	0	172	-	-4	317
	A	Biomass	0%	113	265	0	79	-	-11	333

Table 5.2d: Financial Costs (Central energy price, 13% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block – 30 year calc	D	Gas + SHW	30%	26	401	23	23	-	-4	444
	C	Gas + SHW	30%	34	349	3	29	-	-3	377
	C	Gas	30%	56	237	3	47	-	-1	286
	B	Gas	30%	69	178	3	57	-	-1	236
	B	Gas	20%	75	170	3	61	-	-1	232
	B	Gas	10%	81	162	3	64	-	-1	228
	B	Gas	0%	86	153	0	68	-	-1	221
	A	Gas	10%	95	151	3	76	-	-1	228
	A	Gas	0%	101	142	0	79	-	-1	220
	A	Biomass	0%	113	242	0	42	-	-2	282

5.3 Existing Apartment Buildings – Elemental measures

The following Tables summarise the results of the cost calculations for the most cost-optimal elemental measures in the existing apartment building. Tables 5.3 relate to the macroeconomic calculations and Tables 5.4 relate to the financial calculations.

- Table 5.3a/5.4a: Central energy price, central discount factor
- Tables 5.3b/5.4b: Low energy price, central discount factor
- Tables 5.3c/5.4c: High energy price, central discount factor
- Tables 5.3d: Central energy price, low discount factor (macro-economic calculation only)
- Table 5.3e/5.4d: Central energy price, high discount factor

Applying sensitivities to the energy price and discount factor make a significant difference to the absolute costs. However, such sensitivities have less impact on the relative cost between alternative options for a given elemental measure and there are no substantial changes to the cost-optimum solutions.

Table 5.3a: Macroeconomic Costs (Central energy price, 4% discount rate, EUR/m²)

Dwelling Type	Wall Type	Package	Value	PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Apartment Block	Cavity	Wall U-Value	0.1	231	57	0	401	21	-9	469
		Wall U-Value	0.14	233	36	0	404	21	-6	456
		Wall U-Value	0.16	234	51	0	406	21	-8	470
		Wall U-Value	0.19	235	23	0	408	22	-4	449
		Wall U-Value	0.21	236	33	0	410	22	-5	459
		Wall U-Value	0.31	240	3	0	418	22	-1	443
		Wall U-Value	0.39	244	19	0	424	22	-3	463
		Roof U-value	0.11	294	2	0	510	27	0	539
		Roof U-value	0.13	294	2	0	511	27	0	539
		Roof U-value	0.29	298	1	0	518	27	0	546
		Floor U-value	0.15	293	4	0	510	27	-1	540
		Floor U-value	0.24	296	2	0	514	27	0	543
		Floor U-value	0.31	297	2	0	517	27	0	546
		Floor U-value	0.43	300	2	0	522	28	0	551
		Heating Source	ASHP	134	241	0	233	12	-27	460
		Heating Source	Gas + SHW	174	194	0	296	18	-21	487
		Heating Source	Gas	190	51	0	324	19	-6	388
		Window U-value	0.9	272	104	0	473	25	0	602
		Window U-value	1.4	278	76	0	483	26	0	585
		Window U-value	1.6	282	71	0	490	26	0	587
Apartment Block	Solid	Wall U-Value	0.15	235	54	0	409	22	-9	476
		Wall U-Value	0.22	239	33	0	415	22	-5	464
		Wall U-Value	0.28	241	48	0	419	22	-8	482
		Wall U-Value	0.4	247	19	0	429	23	-3	468
		Roof U-value	0.11	310	2	0	538	29	0	569
		Roof U-value	0.13	310	2	0	539	29	0	569
		Roof U-value	0.29	314	1	0	546	29	0	576
		Floor U-value	0.15	310	4	0	538	29	-1	570
		Floor U-value	0.24	312	2	0	542	29	0	573
		Floor U-value	0.31	314	2	0	545	29	0	576
		Floor U-value	0.43	317	2	0	550	29	0	581
		Heating Source	ASHP	139	241	0	241	13	-27	469
		Heating Source	Gas + SHW	183	194	0	312	19	-21	504
		Heating Source	Gas	199	51	0	339	20	-6	404
		Window U-value	0.9	289	104	0	502	27	0	633
		Window U-value	1.4	295	76	0	512	27	0	615
		Window U-value	1.6	299	71	0	519	27	0	617

Table 5.3b: Macroeconomic Costs (Low energy price, 4% discount rate, EUR/m²)

Dwelling Type	Wall Type	Package	Value	PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Apartment Block	Cavity	Wall U-Value	0.1	231	57	0	321	21	-9	389
		Wall U-Value	0.14	233	36	0	323	21	-6	375
		Wall U-Value	0.16	234	51	0	325	21	-8	389
		Wall U-Value	0.19	235	23	0	326	22	-4	367
		Wall U-Value	0.21	236	33	0	328	22	-5	377
		Wall U-Value	0.31	240	3	0	334	22	-1	359
		Wall U-Value	0.39	244	19	0	339	22	-3	378
		Roof U-value	0.11	294	2	0	408	27	0	437
		Roof U-value	0.13	294	2	0	409	27	0	437
		Roof U-value	0.29	298	1	0	414	27	0	442
		Floor U-value	0.15	293	4	0	408	27	-1	438
		Floor U-value	0.24	296	2	0	411	27	0	440
		Floor U-value	0.31	297	2	0	413	27	0	442
		Floor U-value	0.43	300	2	0	417	28	0	447
		Heating Source	ASHP	134	241	0	186	12	-27	413
		Heating Source	Gas + SHW	174	194	0	214	18	-21	404
		Heating Source	Gas	190	51	0	233	19	-6	298
		Window U-value	0.9	272	104	0	378	25	0	507
		Window U-value	1.4	278	76	0	387	26	0	488
		Window U-value	1.6	282	71	0	392	26	0	489
Apartment Block	Solid	Wall U-Value	0.15	235	54	0	327	22	-9	394
		Wall U-Value	0.22	239	33	0	332	22	-5	381
		Wall U-Value	0.28	241	48	0	336	22	-8	398
		Wall U-Value	0.4	247	19	0	343	23	-3	382
		Roof U-value	0.11	310	2	0	431	29	0	461
		Roof U-value	0.13	310	2	0	431	29	0	462
		Roof U-value	0.29	314	1	0	437	29	0	467
		Floor U-value	0.15	310	4	0	430	29	-1	462
		Floor U-value	0.24	312	2	0	434	29	0	464
		Floor U-value	0.31	314	2	0	436	29	0	467
		Floor U-value	0.43	317	2	0	440	29	0	471
		Heating Source	ASHP	139	241	0	193	13	-27	421
		Heating Source	Gas + SHW	183	194	0	225	19	-21	416
		Heating Source	Gas	199	51	0	244	20	-6	309
		Window U-value	0.9	289	104	0	402	27	0	532
		Window U-value	1.4	295	76	0	410	27	0	513
		Window U-value	1.6	299	71	0	415	27	0	513

Table 5.3c: Macroeconomic Costs (High energy price, 4% discount rate, EUR/m²)

Dwelling Type	Wall Type	Package	Value	PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Apartment Block	Cavity	Wall U-Value	0.1	231	57	0	481	21	-9	550
		Wall U-Value	0.14	233	36	0	485	21	-6	536
		Wall U-Value	0.16	234	51	0	487	21	-8	551
		Wall U-Value	0.19	235	23	0	490	22	-4	530
		Wall U-Value	0.21	236	33	0	492	22	-5	541
		Wall U-Value	0.31	240	3	0	501	22	-1	526
		Wall U-Value	0.39	244	19	0	509	22	-3	548
		Roof U-value	0.11	294	2	0	612	27	0	641
		Roof U-value	0.13	294	2	0	613	27	0	642
		Roof U-value	0.29	298	1	0	621	27	0	650
		Floor U-value	0.15	293	4	0	612	27	-1	642
		Floor U-value	0.24	296	2	0	616	27	0	646
		Floor U-value	0.31	297	2	0	620	27	0	649
		Floor U-value	0.43	300	2	0	626	28	0	655
		Heating Source	ASHP	134	241	0	279	12	-27	506
		Heating Source	Gas + SHW	174	194	0	379	18	-21	569
		Heating Source	Gas	190	51	0	415	19	-6	479
		Window U-value	0.9	272	104	0	567	25	0	697
		Window U-value	1.4	278	76	0	580	26	0	682
		Window U-value	1.6	282	71	0	588	26	0	685
Apartment Block	Solid	Wall U-Value	0.15	235	54	0	491	22	-9	557
		Wall U-Value	0.22	239	33	0	498	22	-5	547
		Wall U-Value	0.28	241	48	0	503	22	-8	566
		Wall U-Value	0.4	247	19	0	515	23	-3	554
		Roof U-value	0.11	310	2	0	646	29	0	676
		Roof U-value	0.13	310	2	0	647	29	0	677
		Roof U-value	0.29	314	1	0	656	29	0	685
		Floor U-value	0.15	310	4	0	646	29	-1	678
		Floor U-value	0.24	312	2	0	650	29	0	681
		Floor U-value	0.31	314	2	0	654	29	0	685
		Floor U-value	0.43	317	2	0	660	29	0	691
		Heating Source	ASHP	139	241	0	290	13	-27	517
		Heating Source	Gas + SHW	183	194	0	400	19	-21	591
		Heating Source	Gas	199	51	0	434	20	-6	500
		Window U-value	0.9	289	104	0	602	27	0	733
		Window U-value	1.4	295	76	0	615	27	0	718
		Window U-value	1.6	299	71	0	623	27	0	721

Table 5.3d: Macroeconomic Costs (Central energy price, 3% discount rate, EUR/m²)

Dwelling Type	Wall Type	Package	Value	PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Apartment Block	Cavity	Wall U-Value	0.1	231	57	0	452	24	-12	520
		Wall U-Value	0.14	233	36	0	455	24	-8	508
		Wall U-Value	0.16	234	51	0	457	25	-11	522
		Wall U-Value	0.19	235	23	0	460	25	-5	502
		Wall U-Value	0.21	236	33	0	462	25	-7	512
		Wall U-Value	0.31	240	3	0	471	25	-1	499
		Wall U-Value	0.39	244	19	0	478	26	-4	519
		Roof U-value	0.11	294	2	0	575	31	0	607
		Roof U-value	0.13	294	2	0	576	31	0	608
		Roof U-value	0.29	298	1	0	584	31	0	616
		Floor U-value	0.15	293	4	0	574	31	-1	608
		Floor U-value	0.24	296	2	0	579	31	-1	612
		Floor U-value	0.31	297	2	0	582	31	0	615
		Floor U-value	0.43	300	2	0	588	32	0	621
		Heating Source	ASHP	134	257	0	262	14	-35	499
		Heating Source	Gas + SHW	174	207	0	338	20	-28	537
		Heating Source	Gas	190	54	0	370	22	-7	439
		Window U-value	0.9	272	104	0	533	29	0	666
		Window U-value	1.4	278	76	0	545	29	0	650
		Window U-value	1.6	282	71	0	552	30	0	653
Apartment Block	Solid	Wall U-Value	0.15	235	54	0	461	25	-11	528
		Wall U-Value	0.22	239	33	0	467	25	-7	518
		Wall U-Value	0.28	241	48	0	473	25	-10	536
		Wall U-Value	0.4	247	19	0	484	26	-4	525
		Roof U-value	0.11	310	2	0	607	33	0	641
		Roof U-value	0.13	310	2	0	608	33	0	642
		Roof U-value	0.29	314	1	0	616	33	0	649
		Floor U-value	0.15	310	4	0	606	33	-1	642
		Floor U-value	0.24	312	2	0	611	33	-1	646
		Floor U-value	0.31	314	2	0	614	33	0	649
		Floor U-value	0.43	317	2	0	620	33	0	655
		Heating Source	ASHP	139	257	0	272	15	-35	509
		Heating Source	Gas + SHW	183	207	0	356	22	-28	557
		Heating Source	Gas	199	54	0	387	23	-7	457
		Window U-value	0.9	289	104	0	566	30	0	700
		Window U-value	1.4	295	76	0	577	31	0	684
		Window U-value	1.6	299	71	0	585	31	0	687

Table 5.3e: Macroeconomic Costs (Central energy price, 6% discount rate, EUR/m²)

Dwelling Type	Wall Type	Package	Value	PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Apartment Block	Cavity	Wall U-Value	0.1	231	57	0	323	17	-5	391
		Wall U-Value	0.14	233	36	0	325	17	-3	375
		Wall U-Value	0.16	234	51	0	327	17	-5	390
		Wall U-Value	0.19	235	23	0	329	17	-2	366
		Wall U-Value	0.21	236	33	0	330	17	-3	377
		Wall U-Value	0.31	240	3	0	336	17	0	357
		Wall U-Value	0.39	244	19	0	341	18	-2	377
		Roof U-value	0.11	294	2	0	411	21	0	434
		Roof U-value	0.13	294	2	0	411	21	0	434
		Roof U-value	0.29	298	1	0	417	22	0	439
		Floor U-value	0.15	293	4	0	410	21	0	435
		Floor U-value	0.24	296	2	0	413	21	0	437
		Floor U-value	0.31	297	2	0	416	22	0	439
		Floor U-value	0.43	300	2	0	420	22	0	443
		Heating Source	ASHP	134	217	0	187	10	-15	399
		Heating Source	Gas + SHW	174	175	0	233	13	-12	409
		Heating Source	Gas	190	46	0	255	15	-3	312
		Window U-value	0.9	272	104	0	381	20	0	505
		Window U-value	1.4	278	76	0	389	20	0	485
		Window U-value	1.6	282	71	0	394	20	0	486
Apartment Block	Solid	Wall U-Value	0.15	235	54	0	329	17	-5	395
		Wall U-Value	0.22	239	33	0	334	17	-3	381
		Wall U-Value	0.28	241	48	0	338	18	-4	398
		Wall U-Value	0.4	247	19	0	345	18	-2	381
		Roof U-value	0.11	310	2	0	433	22	0	458
		Roof U-value	0.13	310	2	0	434	23	0	458
		Roof U-value	0.29	314	1	0	440	23	0	463
		Floor U-value	0.15	310	4	0	433	22	0	459
		Floor U-value	0.24	312	2	0	436	23	0	461
		Floor U-value	0.31	314	2	0	439	23	0	463
		Floor U-value	0.43	317	2	0	443	23	0	468
		Heating Source	ASHP	139	217	0	194	10	-15	406
		Heating Source	Gas + SHW	183	175	0	246	14	-12	423
		Heating Source	Gas	199	46	0	267	15	-3	325
		Window U-value	0.9	289	104	0	404	21	0	529
		Window U-value	1.4	295	76	0	412	21	0	510
		Window U-value	1.6	299	71	0	418	22	0	510

Table 5.4a: Financial Costs (Central energy price, 7% discount rate, EUR/m²)

Dwelling Type	Wall Type	Package	Value	PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Apartment Block	Cavity	Wall U-Value	0.1	231	64	0	332	-	-5	392
		Wall U-Value	0.14	233	41	0	335	-	-3	373
		Wall U-Value	0.16	234	58	0	336	-	-4	390
		Wall U-Value	0.19	235	26	0	338	-	-2	362
		Wall U-Value	0.21	236	37	0	339	-	-3	374
		Wall U-Value	0.31	240	4	0	346	-	0	349
		Wall U-Value	0.39	244	22	0	351	-	-2	372
		Roof U-value	0.11	294	2	0	422	-	0	425
		Roof U-value	0.13	294	2	0	423	-	0	425
		Roof U-value	0.29	298	1	0	429	-	0	430
		Floor U-value	0.15	293	5	0	422	-	0	426
		Floor U-value	0.24	296	3	0	425	-	0	428
		Floor U-value	0.31	297	2	0	428	-	0	430
		Floor U-value	0.43	300	2	0	432	-	0	434
		Heating Source	ASHP	134	237	0	193	-	-13	416
		Heating Source	Gas + SHW	174	190	0	238	-	-11	417
		Heating Source	Gas	190	50	0	260	-	-3	307
		Window U-value	0.9	272	118	0	392	-	0	510
		Window U-value	1.4	278	86	0	400	-	0	487
		Window U-value	1.6	282	80	0	406	-	0	486
Apartment Block	Solid	Wall U-Value	0.15	235	61	0	339	-	-4	395
		Wall U-Value	0.22	239	37	0	343	-	-3	378
		Wall U-Value	0.28	241	54	0	347	-	-4	398
		Wall U-Value	0.4	247	22	0	355	-	-2	376
		Roof U-value	0.11	310	2	0	446	-	0	448
		Roof U-value	0.13	310	2	0	447	-	0	449
		Roof U-value	0.29	314	1	0	452	-	0	453
		Floor U-value	0.15	310	5	0	446	-	0	450
		Floor U-value	0.24	312	3	0	449	-	0	452
		Floor U-value	0.31	314	2	0	451	-	0	453
		Floor U-value	0.43	317	2	0	456	-	0	458
		Heating Source	ASHP	139	237	0	200	-	-13	423
		Heating Source	Gas + SHW	183	190	0	250	-	-11	430
		Heating Source	Gas	199	50	0	272	-	-3	319
		Window U-value	0.9	289	118	0	416	-	0	534
		Window U-value	1.4	295	86	0	424	-	0	511
		Window U-value	1.6	299	80	0	430	-	0	510

Table 5.4b: Financial Costs (Low energy price, 7% discount rate, EUR/m²)

Dwelling Type	Wall Type	Package	Value	PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Apartment Block	Cavity	Wall U-Value	0.1	231	64	0	266	-	-5	325
		Wall U-Value	0.14	233	41	0	268	-	-3	306
		Wall U-Value	0.16	234	58	0	269	-	-4	322
		Wall U-Value	0.19	235	26	0	270	-	-2	294
		Wall U-Value	0.21	236	37	0	271	-	-3	306
		Wall U-Value	0.31	240	4	0	277	-	0	280
		Wall U-Value	0.39	244	22	0	281	-	-2	301
		Roof U-value	0.11	294	2	0	338	-	0	340
		Roof U-value	0.13	294	2	0	339	-	0	340
		Roof U-value	0.29	298	1	0	343	-	0	344
		Floor U-value	0.15	293	5	0	338	-	0	342
		Floor U-value	0.24	296	3	0	340	-	0	343
		Floor U-value	0.31	297	2	0	342	-	0	344
		Floor U-value	0.43	300	2	0	346	-	0	348
		Heating Source	ASHP	134	237	0	154	-	-13	378
		Heating Source	Gas + SHW	174	190	0	171	-	-11	351
		Heating Source	Gas	190	50	0	187	-	-3	234
		Window U-value	0.9	272	118	0	313	-	0	432
		Window U-value	1.4	278	86	0	320	-	0	407
		Window U-value	1.6	282	80	0	325	-	0	405
Apartment Block	Solid	Wall U-Value	0.15	235	61	0	271	-	-4	328
		Wall U-Value	0.22	239	37	0	275	-	-3	309
		Wall U-Value	0.28	241	54	0	278	-	-4	328
		Wall U-Value	0.4	247	22	0	284	-	-2	305
		Roof U-value	0.11	310	2	0	357	-	0	359
		Roof U-value	0.13	310	2	0	357	-	0	359
		Roof U-value	0.29	314	1	0	362	-	0	363
		Floor U-value	0.15	310	5	0	357	-	0	361
		Floor U-value	0.24	312	3	0	359	-	0	362
		Floor U-value	0.31	314	2	0	361	-	0	363
		Floor U-value	0.43	317	2	0	365	-	0	366
		Heating Source	ASHP	139	237	0	160	-	-13	383
		Heating Source	Gas + SHW	183	190	0	180	-	-11	360
		Heating Source	Gas	199	50	0	196	-	-3	243
		Window U-value	0.9	289	118	0	333	-	0	451
		Window U-value	1.4	295	86	0	339	-	0	426
		Window U-value	1.6	299	80	0	344	-	0	424

Table 5.4c: Financial Costs (High energy price, 7% discount rate, EUR/m²)

Dwelling Type	Wall Type	Package	Value	PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Apartment Block	Cavity	Wall U-Value	0.1	231	64	0	398	-	-5	458
		Wall U-Value	0.14	233	41	0	402	-	-3	440
		Wall U-Value	0.16	234	58	0	403	-	-4	457
		Wall U-Value	0.19	235	26	0	406	-	-2	430
		Wall U-Value	0.21	236	37	0	407	-	-3	442
		Wall U-Value	0.31	240	4	0	415	-	0	419
		Wall U-Value	0.39	244	22	0	422	-	-2	442
		Roof U-value	0.11	294	2	0	507	-	0	509
		Roof U-value	0.13	294	2	0	508	-	0	510
		Roof U-value	0.29	298	1	0	515	-	0	516
		Floor U-value	0.15	293	5	0	507	-	0	511
		Floor U-value	0.24	296	3	0	510	-	0	513
		Floor U-value	0.31	297	2	0	513	-	0	515
		Floor U-value	0.43	300	2	0	519	-	0	521
		Heating Source	ASHP	134	237	0	231	-	-13	455
		Heating Source	Gas + SHW	174	190	0	304	-	-11	483
		Heating Source	Gas	190	50	0	332	-	-3	379
		Window U-value	0.9	272	118	0	470	-	0	588
		Window U-value	1.4	278	86	0	480	-	0	567
		Window U-value	1.6	282	80	0	487	-	0	567
Apartment Block	Solid	Wall U-Value	0.15	235	61	0	407	-	-4	463
		Wall U-Value	0.22	239	37	0	412	-	-3	447
		Wall U-Value	0.28	241	54	0	417	-	-4	467
		Wall U-Value	0.4	247	22	0	426	-	-2	447
		Roof U-value	0.11	310	2	0	535	-	0	537
		Roof U-value	0.13	310	2	0	536	-	0	538
		Roof U-value	0.29	314	1	0	543	-	0	544
		Floor U-value	0.15	310	5	0	535	-	0	539
		Floor U-value	0.24	312	3	0	539	-	0	541
		Floor U-value	0.31	314	2	0	542	-	0	544
		Floor U-value	0.43	317	2	0	547	-	0	549
		Heating Source	ASHP	139	237	0	240	-	-13	463
		Heating Source	Gas + SHW	183	190	0	320	-	-11	500
		Heating Source	Gas	199	50	0	348	-	-3	395
		Window U-value	0.9	289	118	0	499	-	0	617
		Window U-value	1.4	295	86	0	509	-	0	595
		Window U-value	1.6	299	80	0	516	-	0	596

Table 5.4d: Financial Costs (Central energy price, 10% discount rate, EUR/m²)

Dwelling Type	Wall Type	Package	Value	PE (kWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
						Maintenance	Energy			
Apartment Block	Cavity	Wall U-Value	0.1	231	64	0	207	-	-1	271
		Wall U-Value	0.14	233	41	0	209	-	-1	249
		Wall U-Value	0.16	234	58	0	210	-	-1	267
		Wall U-Value	0.19	235	26	0	211	-	0	236
		Wall U-Value	0.21	236	37	0	212	-	-1	248
		Wall U-Value	0.31	240	4	0	216	-	0	220
		Wall U-Value	0.39	244	22	0	219	-	0	241
		Roof U-value	0.11	294	2	0	264	-	0	266
		Roof U-value	0.13	294	2	0	264	-	0	266
		Roof U-value	0.29	298	1	0	268	-	0	269
		Floor U-value	0.15	293	5	0	264	-	0	268
		Floor U-value	0.24	296	3	0	266	-	0	268
		Floor U-value	0.31	297	2	0	267	-	0	269
		Floor U-value	0.43	300	2	0	270	-	0	272
		Heating Source	ASHP	134	204	0	120	-	-3	322
		Heating Source	Gas + SHW	174	164	0	141	-	-2	303
		Heating Source	Gas	190	43	0	154	-	-1	197
		Window U-value	0.9	272	118	0	244	-	0	363
		Window U-value	1.4	278	86	0	250	-	0	336
		Window U-value	1.6	282	80	0	253	-	0	334
Apartment Block	Solid	Wall U-Value	0.15	235	61	0	212	-	-1	271
		Wall U-Value	0.22	239	37	0	214	-	-1	251
		Wall U-Value	0.28	241	54	0	217	-	-1	270
		Wall U-Value	0.4	247	22	0	222	-	0	244
		Roof U-value	0.11	310	2	0	278	-	0	281
		Roof U-value	0.13	310	2	0	279	-	0	281
		Roof U-value	0.29	314	1	0	283	-	0	283
		Floor U-value	0.15	310	5	0	278	-	0	283
		Floor U-value	0.24	312	3	0	280	-	0	283
		Floor U-value	0.31	314	2	0	282	-	0	284
		Floor U-value	0.43	317	2	0	285	-	0	287
		Heating Source	ASHP	139	204	0	125	-	-3	326
		Heating Source	Gas + SHW	183	164	0	149	-	-2	311
		Heating Source	Gas	199	43	0	161	-	-1	204
		Window U-value	0.9	289	118	0	260	-	0	378
		Window U-value	1.4	295	86	0	265	-	0	351
		Window U-value	1.6	299	80	0	268	-	0	349

5.4 Existing Apartment Buildings – Packages of measures

The following Tables summarise the results of the cost calculations for the most cost-optimal packages in the existing apartment building. Tables 5.3 relate to the macroeconomic calculations and Tables 5.4 relate to the financial calculations.

- Table 5.5a/5.6a: Central energy price, central discount factor
- Tables 5.5b/5.6b: Low energy price, central discount factor
- Tables 5.5c/5.6c: High energy price, central discount factor
- Tables 5.5d: Central energy price, low discount factor (macro-economic calculation only)
- Table 5.3e/5.6d: Central energy price, high discount factor

The sensitivity analysis shows the following:

- In all cases the cost optimal package has roof and wall improvements. This was consistent within the sensitivity analyses as well.
- The cost optimal packages included an individual gas boiler. In the sensitivity analysis, the cost optimal package sometimes included a biomass boiler instead of a gas boiler.
- The cost optimal package had no PV included in both the central case and sensitivity analyses. However, particularly with the higher energy price sensitivity, the relative cost to add PV was small. Section 6 presents analysis on the impact of uncertainties of the cost data adopted for this study. In doing this additional analysis, cost optimal solutions including PV of up to 20% of the foundation area were identified.

Table 5.5a: Macroeconomic Costs (Central energy price, 4% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block Cavity Wall – 30 year calc	All+	GSHP	20%	73	435	5	133	7	-36	544
	All	GSHP	20%	77	388	5	139	7	-33	506
	Roof + Wall	GSHP	20%	86	311	5	154	8	-33	446
	Roof + Wall	ASHP	20%	96	262	5	172	9	-28	421
	All	Gas	20%	114	148	5	199	12	-7	358
	Roof + Wall	Gas	20%	131	72	5	229	13	-7	313
	Roof + Wall	Gas	0%	143	56	0	244	15	-6	308
	Roof + Wall	Biomass	0%	162	210	0	120	4	-23	310
	Wall	Biomass	0%	171	208	0	126	5	-23	315
	Roof	Biomass	0%	207	206	0	151	5	-23	340
Apartment Block Hollow Block Wall – 30 year calc	All+	GSHP	20%	73	466	5	132	7	-41	569
	All	GSHP	20%	76	417	5	136	7	-38	528
	Roof + Wall	GSHP	20%	85	341	5	152	8	-38	469
	Roof + Wall	ASHP	20%	95	292	5	170	9	-32	443
	All	Gas	20%	112	177	5	195	11	-11	378
	Roof + Wall	Gas	20%	129	101	5	225	13	-11	334
	Roof + Wall	Gas	0%	141	86	0	240	14	-11	329
	Roof + Wall	Biomass	0%	159	239	0	118	4	-28	333
	Wall	Biomass	0%	169	237	0	124	5	-28	338
	Roof	Biomass	0%	216	206	0	157	6	-23	347

Table 5.5b: Macroeconomic Costs (Low energy price, 4% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block Cavity Wall – 30 year calc	All+	GSHP	20%	73	435	5	106	7	-36	517
	All	GSHP	20%	77	388	5	111	7	-33	478
	Roof + Wall	GSHP	20%	86	311	5	123	8	-33	415
	Roof + Wall	ASHP	20%	96	262	5	138	9	-28	387
	All	Gas	20%	114	148	5	143	12	-7	301
	Roof + Wall	Gas	20%	131	72	5	164	13	-7	248
	Roof + Wall	Gas	0%	143	56	0	176	15	-6	240
	Wall	Gas	0%	151	54	0	186	15	-6	249
	Roof	Gas	0%	181	53	0	222	18	-6	287
	Roof	Biomass	0%	207	206	0	125	5	-23	314
Apartment Block Hollow Block Wall – 30 year calc	All+	GSHP	20%	73	466	5	105	7	-41	542
	All	GSHP	20%	76	417	5	109	7	-38	501
	Roof + Wall	GSHP	20%	85	341	5	122	8	-38	438
	Roof + Wall	ASHP	20%	95	292	5	136	9	-32	409
	All	Gas	20%	112	177	5	140	11	-11	323
	Roof + Wall	Gas	20%	129	101	5	161	13	-11	270
	Roof + Wall	Gas	0%	141	86	0	173	14	-11	262
	Wall	Gas	0%	149	83	0	183	15	-11	271
	Roof	Gas	0%	188	53	0	231	19	-6	297
	Roof	Biomass	0%	216	206	0	130	6	-23	319

Table 5.5c: Macroeconomic Costs (High energy price, 4% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block Cavity Wall – 30 year calc	All+	GSHP	20%	73	435	5	159	7	-36	570
	All	GSHP	20%	77	388	5	166	7	-33	533
	Roof + Wall	GSHP	20%	86	311	5	185	8	-33	477
	Roof + Wall	ASHP	20%	96	262	5	207	9	-28	455
	All	Gas	20%	114	148	5	256	12	-7	414
	Roof + Wall	Gas	20%	131	72	5	294	13	-7	378
	Roof + Wall	Biomass	20%	150	225	5	132	3	-24	343
	Roof + Wall	Biomass	0%	162	210	0	151	4	-23	341
	Wall	Biomass	0%	171	208	0	159	5	-23	349
	Roof	Biomass	0%	207	206	0	191	5	-23	380
Apartment Block Hollow Block Wall – 30 year calc	All+	GSHP	20%	73	466	5	158	7	-41	595
	All	GSHP	20%	76	417	5	164	7	-38	555
	Roof + Wall	GSHP	20%	85	341	5	183	8	-38	499
	Roof + Wall	ASHP	20%	95	292	5	204	9	-32	477
	All	Gas	20%	112	177	5	251	11	-11	434
	Roof + Wall	Gas	20%	129	101	5	289	13	-11	397
	Roof + Wall	Biomass	20%	147	255	5	130	3	-28	365
	Roof + Wall	Biomass	0%	159	239	0	148	4	-28	364
	Wall	Biomass	0%	169	237	0	157	5	-28	371
	Roof	Biomass	0%	216	206	0	199	6	-23	388

Table 5.5d: Macroeconomic Costs (Central energy price, 3% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block Cavity Wall – 30 year calc	All+	GSHP	20%	73	455	6	150	8	-48	570
	All	GSHP	20%	77	407	6	156	8	-44	534
	Roof + Wall	GSHP	20%	86	331	6	174	9	-44	476
	Roof + Wall	ASHP	20%	96	279	6	194	10	-37	452
	All	Gas	20%	114	152	6	228	14	-9	390
	Roof + Wall	Gas	20%	131	75	6	261	16	-9	350
	Roof + Wall	Biomass	20%	150	239	6	116	4	-31	334
	Roof + Wall	Biomass	0%	162	223	0	133	5	-31	331
	Wall	Biomass	0%	171	221	0	141	5	-30	337
	Roof	Biomass	0%	207	220	0	168	6	-30	364
Apartment Block Hollow Block Wall – 30 year calc	All+	GSHP	20%	73	486	6	148	8	-54	593
	All	GSHP	20%	76	437	6	154	8	-50	555
	Roof + Wall	GSHP	20%	85	361	6	172	9	-50	497
	Roof + Wall	ASHP	20%	95	308	6	191	10	-43	473
	All	Gas	20%	112	181	6	223	13	-15	408
	Roof + Wall	Gas	20%	129	105	6	257	15	-15	368
	Roof + Wall	Biomass	20%	147	269	6	114	4	-37	355
	Roof + Wall	Biomass	0%	159	253	0	131	5	-37	352
	Wall	Biomass	0%	169	251	0	139	5	-37	358
	Roof	Biomass	0%	216	220	0	175	6	-30	372

Table 5.5e: Macroeconomic Costs (Central energy price, 6% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block Cavity Wall – 30 year calc	All+	GSHP	20%	73	406	4	107	5	-21	502
	All	GSHP	20%	77	358	4	112	6	-19	461
	Roof + Wall	GSHP	20%	86	282	4	124	6	-19	398
	Roof + Wall	ASHP	20%	96	238	4	139	7	-16	372
	All	Gas	20%	114	142	4	157	9	-4	309
	Roof + Wall	Gas	20%	131	66	4	180	10	-4	257
	Roof + Wall	Gas	0%	143	51	0	192	11	-4	251
	Roof + Wall	Biomass	0%	162	189	0	98	3	-13	278
	Wall	Biomass	0%	171	187	0	104	4	-13	281
	Roof	Biomass	0%	207	186	0	124	4	-13	301
Apartment Block Hollow Block Wall – 30 year calc	All+	GSHP	20%	73	437	4	106	5	-24	529
	All	GSHP	20%	76	388	4	110	5	-22	486
	Roof + Wall	GSHP	20%	85	312	4	123	6	-22	423
	Roof + Wall	ASHP	20%	95	267	4	137	7	-19	397
	All	Gas	20%	112	172	4	154	9	-7	332
	Roof + Wall	Gas	20%	129	96	4	177	10	-7	281
	Roof + Wall	Gas	0%	141	81	0	189	11	-6	274
	Roof + Wall	Biomass	0%	159	219	0	97	3	-16	303
	Wall	Biomass	0%	169	217	0	102	3	-16	307
	Roof	Biomass	0%	216	186	0	129	4	-13	307

Table 5.6a: Financial Costs (Central energy price, 7% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Financ. Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block Cavity Wall – 30 year calc	All+	GSHP	20%	73	448	4	110	-	-18	545
	All	GSHP	20%	77	394	4	115	-	-16	497
	Roof + Wall	GSHP	20%	86	308	4	128	-	-16	424
	Roof + Wall	ASHP	20%	96	260	4	143	-	-14	393
	All	Gas	20%	114	159	4	160	-	-3	320
	Roof + Wall	Gas	20%	131	73	4	183	-	-3	257
	Roof + Wall	Gas	0%	143	56	0	196	-	-3	248
	Wall	Gas	0%	151	53	0	207	-	-3	257
	Roof	Gas	0%	181	52	0	247	-	-3	296
	Roof	Biomass	0%	207	203	0	129	-	-11	320
Apartment Block Hollow Block Wall – 30 year calc	All+	GSHP	20%	73	484	4	109	-	-20	577
	All	GSHP	20%	76	428	4	113	-	-19	527
	Roof + Wall	GSHP	20%	85	342	4	126	-	-19	453
	Roof + Wall	ASHP	20%	95	293	4	141	-	-16	422
	All	Gas	20%	112	193	4	156	-	-6	348
	Roof + Wall	Gas	20%	129	106	4	180	-	-6	285
	Roof + Wall	Gas	0%	141	89	0	193	-	-6	276
	Wall	Gas	0%	149	87	0	204	-	-5	285
	Roof	Gas	0%	188	52	0	257	-	-3	307
	Roof	Biomass	0%	216	203	0	134	-	-11	326

Table 5.6b: Financial Costs (Low energy price, 7% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Financ. Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block Cavity Wall – 30 year calc	All+	GSHP	20%	73	448	4	88	-	-18	523
	All	GSHP	20%	77	394	4	92	-	-16	474
	Roof + Wall	GSHP	20%	86	308	4	102	-	-16	398
	Roof + Wall	ASHP	20%	96	260	4	114	-	-14	365
	All	Gas	20%	114	159	4	114	-	-3	275
	Roof + Wall	Gas	20%	131	73	4	131	-	-3	205
	Roof + Wall	Gas	0%	143	56	0	141	-	-3	194
	Wall	Gas	0%	151	53	0	149	-	-3	200
	Roof	Gas	0%	181	52	0	178	-	-3	227
	Roof	Biomass	0%	207	203	0	107	-	-11	298
Apartment Block Hollow Block Wall – 30 year calc	All+	GSHP	20%	73	484	4	87	-	-20	555
	All	GSHP	20%	76	428	4	90	-	-19	504
	Roof + Wall	GSHP	20%	85	342	4	101	-	-19	428
	Roof + Wall	ASHP	20%	95	293	4	113	-	-16	394
	All	Gas	20%	112	193	4	112	-	-6	304
	Roof + Wall	Gas	20%	129	106	4	129	-	-6	234
	Roof + Wall	Gas	0%	141	89	0	139	-	-6	223
	Wall	Gas	0%	149	87	0	147	-	-5	229
	Roof	Gas	0%	188	52	0	185	-	-3	235
	Roof	Biomass	0%	216	203	0	112	-	-11	303

Table 5.6c: Financial Costs (High energy price, 7% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Financ. Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block Cavity Wall – 30 year calc	All+	GSHP	20%	73	448	4	132	-	-18	567
	All	GSHP	20%	77	394	4	138	-	-16	520
	Roof + Wall	GSHP	20%	86	308	4	153	-	-16	449
	Roof + Wall	ASHP	20%	96	260	4	171	-	-14	422
	All	Gas	20%	114	159	4	205	-	-3	365
	Roof + Wall	Gas	20%	131	73	4	235	-	-3	309
	Roof + Wall	Gas	0%	143	56	0	250	-	-3	303
	Roof + Wall	Biomass	0%	162	206	0	127	-	-12	322
	Wall	Biomass	0%	171	204	0	135	-	-11	327
	Roof	Biomass	0%	207	203	0	161	-	-11	352
Apartment Block Hollow Block Wall – 30 year calc	All+	GSHP	20%	73	484	4	131	-	-20	598
	All	GSHP	20%	76	428	4	136	-	-19	549
	Roof + Wall	GSHP	20%	85	342	4	151	-	-19	479
	Roof + Wall	ASHP	20%	95	293	4	169	-	-16	450
	All	Gas	20%	112	193	4	201	-	-6	392
	Roof + Wall	Gas	20%	129	106	4	231	-	-6	336
	Roof + Wall	Gas	0%	141	89	0	246	-	-6	330
	Roof + Wall	Biomass	0%	159	240	0	125	-	-14	351
	Wall	Biomass	0%	169	238	0	133	-	-14	356
	Roof	Biomass	0%	216	203	0	168	-	-11	359

Table 5.6d: Financial Costs (Central energy price, 13% discount rate, EUR/m²)

Building	Package			PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Financ. Cost
	Fabric	Heating	PV			Maintenance	Energy			
Apartment Block Cavity Wall – 30 year calc	All+	GSHP	20%	73	409	3	69	-	-4	477
	All	GSHP	20%	77	355	3	72	-	-3	426
	Roof + Wall	GSHP	20%	86	269	3	80	-	-3	348
	Roof + Wall	ASHP	20%	96	227	3	89	-	-3	316
	All	Gas	20%	114	152	3	95	-	-1	249
	Roof + Wall	Gas	20%	131	66	3	109	-	-1	176
	Roof + Wall	Gas	0%	143	49	0	116	-	-1	165
	Wall	Gas	0%	151	47	0	123	-	-1	169
	Roof	Gas	0%	181	45	0	147	-	-1	191
	Roof	Biomass	0%	207	175	0	85	-	-2	258
Apartment Block Hollow Block Wall – 30 year calc	All+	GSHP	20%	73	444	3	68	-	-4	511
	All	GSHP	20%	76	389	3	71	-	-4	458
	Roof + Wall	GSHP	20%	85	302	3	79	-	-4	380
	Roof + Wall	ASHP	20%	95	260	3	88	-	-3	348
	All	Gas	20%	112	185	3	93	-	-1	280
	Roof + Wall	Gas	20%	129	99	3	107	-	-1	207
	Roof + Wall	Gas	0%	141	83	0	115	-	-1	196
	Wall	Gas	0%	149	80	0	121	-	-1	200
	Roof	Gas	0%	188	45	0	153	-	-1	198
	Roof	Biomass	0%	216	175	0	89	-	-2	262

5.5 Existing Non-Residential Buildings – Packages of measures

The following Tables summarise the results of the cost calculations for the most cost-optimal packages in the existing non-residential buildings. Tables 5.7 relate to the macroeconomic calculations and Tables 5.8 relate to the financial calculations.

- Table 5.7a/5.8a: Central energy price, central discount factor
- Tables 5.7b/5.8b: Low energy price, central discount factor
- Tables 5.7c/5.8c: High energy price, central discount factor
- Tables 5.7d: Central energy price, low discount factor (macro-economic calculation only)
- Table 5.7e/5.8d: Central energy price, high discount factor
- Table 5.7f: Central energy price, central discount factor, alternative PE factor
- Table 5.7g: Central energy price, central discount factor, alternative Cost of Carbon

The sensitivity analysis shows the following:

- In all cases the cost optimal package has no fabric improvements. This is true for both the central and sensitivity analyses. Improving fabric can lower primary energy demand, but it is expensive and is usually only selected when the other measures have been fully improved.
- In all cases, the cost optimal packages included the replacement of the existing heating system to an ASHP. This is true for both the central and sensitivity analyses..
- The services package was improved in each of the cost optional packages.
- For the central case, the cost optimum package for Retail Building and the Primary School included no PV whereas the other three building types included the maximum amount of PV. However, the relative cost to add PV was limited and there was some variation in PV being present in the sensitivity analysis e.g. with the higher discount factor, no building cost optimum solutions included PV.

Capabilities on project:
Building Engineering

Table 5.7a: Macroeconomic Costs (Central energy price, 4% discount rate, EUR/m²)

Building	Package				PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	240	16	504	26	-31	755
	B	ASHP	3	20%	302	225	16	505	26	-27	745
	EE1	ASHP	3	20%	311	148	16	519	27	-5	704
	EE1	ASHP	3	10%	324	122	15	535	28	-2	698
	EE1	ASHP	3	0%	338*	96	13	552	29	0	691
	EE1	ASHP	2	0%	359	90	13	587	31	0	722
	EE1	Gas (91%)	3	0%	390	66	13	643	35	0	757
	EE1	Gas (74%)	2	0%	431	49	13	711	39	0	813
	EE1	Gas (74%)	1	0%	459	46	13	756	42	0	857
	EE1	Gas (74%)	EE1	0%	652	0	13	1072	58	0	1143
Office (NV) – 20 year calc	B	ASHP	3	20%	95	171	8	165	8	-22	331
	EE1	ASHP	3	20%	124*	80	8	212	11	-2	309
	EE1	ASHP	3	10%	136	67	8	227	12	-1	312
	EE1	ASHP	3	0%	148	54	7	241	13	0	315
	EE1	ASHP	2	0%	152	49	7	248	13	0	317
	EE1	ASHP	EE1	0%	227	26	7	371	20	0	423
	EE1	Gas (91%)	2	0%	252	32	6	422	25	0	486
	EE1	Gas (74%)	2	0%	292	23	6	491	29	0	549
	EE1	Gas (91%)	EE1	0%	316	9	6	527	30	0	573
	EE1	Gas (74%)	EE1	0%	353	0	6	588	34	0	629
Office (AC) – 20 year calc	C	ASHP	3	20%	160	258	8	271	14	-41	510
	B	ASHP	3	20%	161	229	8	273	14	-35	489
	EE1	ASHP	3	20%	180*	92	8	304	16	-2	417
	EE1	ASHP	3	10%	192	79	8	318	17	-1	420
	EE1	ASHP	3	0%	203	66	7	332	18	0	423
	EE1	ASHP	2	0%	220	60	7	360	19	0	445
	EE1	ASHP	1	0%	243	59	7	397	21	0	484
	EE1	ASHP	EE1	0%	316	26	7	517	27	0	577
	EE1	Gas (91%)	EE1	0%	387	9	6	640	36	0	691
	EE1	Gas (78%)	EE1	0%	407	0	6	675	38	0	719
School (Primary) – 30 year calc	C	ASHP	3	20%	24	188	14	71	2	-22	254
	B	ASHP	3	20%	24	160	14	72	2	-18	231
	EE1	ASHP	3	20%	35	107	14	91	4	-14	201
	EE1	ASHP	3	10%	48	92	13	97	5	-11	196
	EE1	ASHP	3	0%	60*	77	12	104	6	-8	190
	EE1	ASHP	1	0%	65	72	12	111	6	-8	194
	EE1	ASHP	EE1	0%	87	43	12	151	8	-5	210
	EE1	Gas (91%)	1	0%	140	40	12	240	14	-4	302

	EE1	Gas (91%)	EE1	0%	158	11	12	271	16	-1	309
	EE1	Gas (74%)	EE1	0%	180	0	12	307	18	0	338
Hotel – 20 year calc	C	ASHP	3	20%	321	280	11	542	31	-33	831
	B	ASHP	3	20%	325	227	11	548	31	-19	797
	EE1	ASHP	3	20%	342*	137	11	576	33	-1	755
	EE1	ASHP	3	10%	349	129	10	584	33	-1	757
	EE1	ASHP	3	0%	355	122	10	593	34	0	758
	EE1	ASHP	2	0%	365	112	10	608	35	0	765
	EE1	ASHP	1	0%	376	103	10	627	36	0	776
	EE1	ASHP	EE1	0%	503	29	10	834	47	0	920
	EE1	Gas (91%)	EE1	0%	564	8	10	940	54	0	1011
	EE1	Gas (74%)	EE1	0%	578	0	10	965	55	0	1030

Table 5.7b: Macroeconomic Costs (Low energy price, 4% discount rate, EUR/m²)

Building	**Package**				**PE** (KWh/m²)	**Initial Investment Cost**	**Annual Costs**		**Cost of Emissions**	**Residual Value**	**Macro Cost**
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	240	16	403	26	-31	654
	B	ASHP	3	20%	302	225	16	404	26	-27	644
	EE1	ASHP	3	20%	311	148	16	415	27	-5	600
	EE1	ASHP	3	10%	324	122	15	428	28	-2	591
	EE1	ASHP	3	0%	338*	96	13	442	29	0	580
	EE1	ASHP	2	0%	359	90	13	470	31	0	604
	EE1	Gas (91%)	3	0%	390	66	13	499	35	0	613
	EE1	Gas (74%)	2	0%	431	49	13	550	39	0	652
	EE1	Gas (74%)	1	0%	459	46	13	587	42	0	687
	EE1	Gas (74%)	EE1	0%	652	0	13	842	58	0	913
Office (NV) – 20 year calc	B	ASHP	3	20%	95	171	8	132	8	-22	298
	EE1	ASHP	3	20%	124*	80	8	170	11	-2	266
	EE1	ASHP	3	10%	136	67	8	181	12	-1	267
	EE1	ASHP	3	0%	148	54	7	193	13	0	267
	EE1	ASHP	2	0%	152	49	7	198	13	0	267
	EE1	ASHP	EE1	0%	227	26	7	297	20	0	349
	EE1	Gas (91%)	2	0%	252	32	6	308	25	0	371
	EE1	Gas (74%)	2	0%	292	23	6	356	29	0	414
	EE1	Gas (91%)	EE1	0%	316	9	6	395	30	0	441
	EE1	Gas (74%)	EE1	0%	353	0	6	438	34	0	478
Office (AC) – 20 year calc	C	ASHP	3	20%	160	258	8	217	14	-41	456
	B	ASHP	3	20%	161	229	8	219	14	-35	434
	EE1	ASHP	3	20%	180*	92	8	243	16	-2	356
	EE1	ASHP	3	10%	192	79	8	254	17	-1	356

	EE1	ASHP	3	0%	203	66	7	266	18	0	356
	EE1	ASHP	2	0%	220	60	7	288	19	0	373
	EE1	ASHP	1	0%	243	59	7	318	21	0	404
	EE1	ASHP	EE1	0%	316	26	7	413	27	0	473
	EE1	Gas (91%)	EE1	0%	387	9	6	491	36	0	542
	EE1	Gas (78%)	EE1	0%	407	0	6	515	38	0	560
School (Primary) – 30 year calc	C	ASHP	3	20%	24	188	14	55	2	-22	237
	B	ASHP	3	20%	24	160	14	56	2	-18	214
	EE1	ASHP	3	20%	35	107	14	69	4	-14	178
	EE1	ASHP	3	10%	48	92	13	74	5	-11	172
	EE1	ASHP	3	0%	60*	77	12	79	6	-8	166
	EE1	ASHP	1	0%	65	72	12	85	6	-8	168
	EE1	ASHP	EE1	0%	87	43	12	117	8	-5	176
	EE1	Gas (91%)	1	0%	140	40	12	175	14	-4	237
	EE1	Gas (91%)	EE1	0%	158	11	12	201	16	-1	239
	EE1	Gas (74%)	EE1	0%	180	0	12	226	18	0	257
Hotel – 20 year calc	C	ASHP	3	20%	321	280	11	401	31	-33	690
	B	ASHP	3	20%	325	227	11	406	31	-19	656
	EE1	ASHP	3	20%	342	137	11	429	33	-1	608
	EE1	ASHP	3	10%	349	129	10	435	33	-1	608
	EE1	ASHP	3	0%	355*	122	10	442	34	0	608
	EE1	ASHP	2	0%	365	112	10	455	35	0	611
	EE1	ASHP	1	0%	376	103	10	469	36	0	618
	EE1	ASHP	EE1	0%	503	29	10	635	47	0	721
	EE1	Gas (91%)	EE1	0%	564	8	10	702	54	0	773
	EE1	Gas (74%)	EE1	0%	578	0	10	719	55	0	784

Table 5.7c: Macroeconomic Costs (High energy price, 4% discount rate, EUR/m²)

Building	**Package**				**PE** (KWh/m²)	**Initial Investment Cost**	**Annual Costs**		**Cost of Emissions**	**Residual Value**	**Macro Cost**
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	240	16	605	26	-31	856
	B	ASHP	3	20%	302	225	16	606	26	-27	846
	EE1	ASHP	3	20%	311	148	16	623	27	-5	808
	EE1	ASHP	3	10%	324	122	15	642	28	-2	805
	EE1	ASHP	3	0%	338*	96	13	662	29	0	801
	EE1	ASHP	2	0%	359	90	13	705	31	0	839
	EE1	Gas (91%)	3	0%	390	66	13	787	35	0	901
	EE1	Gas (74%)	2	0%	431	49	13	872	39	0	974
	EE1	Gas (74%)	1	0%	459	46	13	926	42	0	1027
	EE1	Gas (74%)	EE1	0%	652	0	13	1302	58	0	1373

Office (NV) – 20 year calc	B	ASHP	3	20%	95	171	8	198	8	-22	364
	EE1	ASHP	3	20%	124*	80	8	255	11	-2	351
	EE1	ASHP	3	10%	136	67	8	272	12	-1	357
	EE1	ASHP	3	0%	148	54	7	289	13	0	363
	EE1	ASHP	2	0%	152	49	7	297	13	0	366
	EE1	ASHP	EE1	0%	227	26	7	445	20	0	498
	EE1	Gas (91%)	2	0%	252	32	6	536	25	0	600
	EE1	Gas (74%)	2	0%	292	23	6	625	29	0	683
	EE1	Gas (91%)	EE1	0%	316	9	6	659	30	0	705
	EE1	Gas (74%)	EE1	0%	353	0	6	739	34	0	779
Office (AC) – 20 year calc	C	ASHP	3	20%	160	258	8	325	14	-41	564
	B	ASHP	3	20%	161	229	8	328	14	-35	544
	EE1	ASHP	3	20%	180*	92	8	364	16	-2	477
	EE1	ASHP	3	10%	192	79	8	382	17	-1	484
	EE1	ASHP	3	0%	203	66	7	399	18	0	489
	EE1	ASHP	2	0%	220	60	7	432	19	0	517
	EE1	ASHP	1	0%	243	59	7	476	21	0	563
	EE1	ASHP	EE1	0%	316	26	7	620	27	0	680
	EE1	Gas (91%)	EE1	0%	387	9	6	789	36	0	840
	EE1	Gas (78%)	EE1	0%	407	0	6	834	38	0	879
School (Primary) – 30 year calc	C	ASHP	3	20%	24	188	14	88	2	-22	270
	B	ASHP	3	20%	24	160	14	89	2	-18	248
	EE1	ASHP	3	20%	35	107	14	113	4	-14	223
	EE1	ASHP	3	10%	48	92	13	121	5	-11	219
	EE1	ASHP	3	0%	60*	77	12	129	6	-8	215
	EE1	ASHP	1	0%	65	72	12	138	6	-8	220
	EE1	ASHP	EE1	0%	87	43	12	185	8	-5	244
	EE1	Gas (91%)	1	0%	140	40	12	304	14	-4	366
	EE1	Gas (91%)	EE1	0%	158	11	12	341	16	-1	379
	EE1	Gas (74%)	EE1	0%	180	0	12	388	18	0	418
Hotel – 20 year calc	C	ASHP	3	20%	321	280	11	683	31	-33	971
	B	ASHP	3	20%	325	227	11	689	31	-19	939
	EE1	ASHP	3	20%	342*	137	11	724	33	-1	903
	EE1	ASHP	3	10%	349	129	10	734	33	-1	906
	EE1	ASHP	3	0%	355	122	10	743	34	0	909
	EE1	ASHP	2	0%	365	112	10	762	35	0	919
	EE1	ASHP	1	0%	376	103	10	785	36	0	933
	EE1	ASHP	EE1	0%	503	29	10	1033	47	0	1118
	EE1	Gas (91%)	EE1	0%	564	8	10	1178	54	0	1249
	EE1	Gas (74%)	EE1	0%	578	0	10	1210	55	0	1275

Capabilities on project:
Building Engineering

Table 5.7d: Macroeconomic Costs (Central energy price, 3% discount rate, EUR/m²)

Building	Package				PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	240	17	568	30	-37	818
	B	ASHP	3	20%	302	225	17	569	30	-32	808
	EE1	ASHP	3	20%	311	148	17	585	31	-6	774
	EE1	ASHP	3	10%	324	122	16	603	32	-3	770
	EE1	ASHP	3	0%	338*	96	14	622	33	0	766
	EE1	ASHP	2	0%	359	90	14	662	35	0	802
	EE1	Gas (91%)	3	0%	390	66	14	727	41	0	848
	EE1	Gas (74%)	2	0%	431	49	14	805	45	0	913
	EE1	Gas (74%)	1	0%	459	46	14	856	48	0	963
	EE1	Gas (74%)	EE1	0%	652	0	14	1211	67	0	1291
Office (NV) – 20 year calc	B	ASHP	3	20%	95	171	9	186	9	-27	349
	EE1	ASHP	3	20%	124*	80	9	239	12	-3	338
	EE1	ASHP	3	10%	136	67	8	255	13	-1	343
	EE1	ASHP	3	0%	148	54	7	272	15	0	348
	EE1	ASHP	2	0%	152	49	7	279	15	0	350
	EE1	ASHP	EE1	0%	227	26	7	418	22	0	474
	EE1	Gas (91%)	2	0%	252	32	7	481	29	0	549
	EE1	Gas (74%)	2	0%	292	23	7	559	34	0	623
	EE1	Gas (91%)	EE1	0%	316	9	7	599	35	0	650
	EE1	Gas (74%)	EE1	0%	353	0	7	669	39	0	715
Office (AC) – 20 year calc	C	ASHP	3	20%	160	258	9	305	16	-50	539
	B	ASHP	3	20%	161	229	9	308	16	-42	519
	EE1	ASHP	3	20%	180*	92	9	342	18	-3	458
	EE1	ASHP	3	10%	192	79	8	358	19	-1	463
	EE1	ASHP	3	0%	203	66	7	375	20	0	468
	EE1	ASHP	2	0%	220	60	7	406	22	0	494
	EE1	ASHP	1	0%	243	59	7	447	24	0	537
	EE1	ASHP	EE1	0%	316	26	7	582	31	0	647
	EE1	Gas (91%)	EE1	0%	387	9	7	725	41	0	782
	EE1	Gas (78%)	EE1	0%	407	0	7	765	43	0	815
School (Primary) – 30 year calc	C	ASHP	3	20%	24	196	15	81	3	-29	266
	B	ASHP	3	20%	24	168	15	82	3	-24	244
	EE1	ASHP	3	20%	35	114	15	103	4	-19	218
	EE1	ASHP	3	10%	48	98	15	110	5	-15	214
	EE1	ASHP	3	0%	60*	82	14	118	7	-11	209
	EE1	ASHP	1	0%	65	77	14	126	7	-10	214
	EE1	ASHP	EE1	0%	87	46	14	171	10	-6	234
	EE1	Gas (91%)	1	0%	140	43	14	273	16	-6	340

	EE1	Gas (91%)	EE1	0%	158	12	14	308	18	-2	351
	EE1	Gas (74%)	EE1	0%	180	0	14	350	21	0	384
Hotel – 20 year calc	C	ASHP	3	20%	321	280	12	616	36	-40	904
	B	ASHP	3	20%	325	227	12	623	36	-23	874
	EE1	ASHP	3	20%	342*	137	12	655	38	-2	840
	EE1	ASHP	3	10%	349	129	11	664	39	-1	842
	EE1	ASHP	3	0%	355	122	11	673	39	0	845
	EE1	ASHP	2	0%	365	112	11	691	40	0	854
	EE1	ASHP	1	0%	376	103	11	712	41	0	867
	EE1	ASHP	EE1	0%	503	29	11	945	54	0	1039
	EE1	Gas (91%)	EE1	0%	564	8	11	1068	62	0	1148
	EE1	Gas (74%)	EE1	0%	578	0	11	1096	64	0	1171

Table 5.7e: Macroeconomic Costs (Central energy price, 6% discount rate, EUR/m²)

Building	**Package**				**PE** (KWh/m²)	**Initial Investment Cost**	**Annual Costs**		**Cost of Emissions**	**Residual Value**	**Macro Cost**
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	240	13	406	21	-22	658
	B	ASHP	3	20%	302	225	13	406	21	-19	646
	EE1	ASHP	3	20%	311	148	13	418	21	-3	596
	EE1	ASHP	3	10%	324	122	12	431	22	-2	586
	EE1	ASHP	3	0%	338*	96	11	444	23	0	575
	EE1	ASHP	2	0%	359	90	11	473	25	0	599
	EE1	Gas (91%)	3	0%	390	66	11	514	28	0	619
	EE1	Gas (74%)	2	0%	431	49	11	568	31	0	659
	EE1	Gas (74%)	1	0%	459	46	11	605	32	0	694
	EE1	Gas (74%)	EE1	0%	652	0	11	859	45	0	916
Office (NV) – 20 year calc	B	ASHP	3	20%	95	171	7	133	6	-15	302
	EE1	ASHP	3	20%	124	80	7	171	8	-2	265
	EE1	ASHP	3	10%	136	67	6	183	9	-1	265
	EE1	ASHP	3	0%	148*	54	6	194	10	0	264
	EE1	ASHP	2	0%	152	49	6	200	10	0	264
	EE1	ASHP	EE1	0%	227	26	6	299	15	0	346
	EE1	Gas (91%)	2	0%	252	32	5	333	19	0	390
	EE1	Gas (74%)	2	0%	292	23	5	387	22	0	437
	EE1	Gas (91%)	EE1	0%	316	9	5	418	23	0	456
	EE1	Gas (74%)	EE1	0%	353	0	5	466	26	0	498
Office (AC) – 20 year calc	C	ASHP	3	20%	160	258	7	218	11	-29	466
	B	ASHP	3	20%	161	229	7	220	11	-25	442
	EE1	ASHP	3	20%	180	92	7	244	12	-2	354
	EE1	ASHP	3	10%	192	79	6	256	13	-1	354

	EE1	ASHP	3	0%	203*	66	6	268	14	0	353
	EE1	ASHP	2	0%	220	60	6	290	15	0	370
	EE1	ASHP	1	0%	243	59	6	320	17	0	401
	EE1	ASHP	EE1	0%	316	26	6	416	22	0	469
	EE1	Gas (91%)	EE1	0%	387	9	5	510	28	0	553
	EE1	Gas (78%)	EE1	0%	407	0	5	538	29	0	573
School (Primary) – 30 year calc	C	ASHP	3	20%	24	178	11	57	2	-12	235
	B	ASHP	3	20%	24	150	11	58	2	-10	210
	EE1	ASHP	3	20%	35	96	11	72	3	-8	174
	EE1	ASHP	3	10%	48	82	11	78	4	-6	168
	EE1	ASHP	3	0%	60*	69	10	83	5	-5	161
	EE1	ASHP	1	0%	65	65	10	89	5	-5	164
	EE1	ASHP	EE1	0%	87	39	10	121	6	-3	173
	EE1	Gas (91%)	1	0%	140	36	10	189	11	-3	243
	EE1	Gas (91%)	EE1	0%	158	10	10	215	12	-1	246
	EE1	Gas (74%)	EE1	0%	180	0	10	243	14	0	267
Hotel – 20 year calc	C	ASHP	3	20%	321	280	9	429	24	-23	719
	B	ASHP	3	20%	325	227	9	434	24	-13	680
	EE1	ASHP	3	20%	342	137	9	457	25	-1	627
	EE1	ASHP	3	10%	349	129	9	463	26	0	627
	EE1	ASHP	3	0%	355*	122	8	470	26	0	626
	EE1	ASHP	2	0%	365	112	8	483	27	0	629
	EE1	ASHP	1	0%	376	103	8	498	28	0	636
	EE1	ASHP	EE1	0%	503	29	8	664	36	0	738
	EE1	Gas (91%)	EE1	0%	564	8	8	745	41	0	803
	EE1	Gas (74%)	EE1	0%	578	0	8	765	43	0	816

Table 5.7f: Macroeconomic Costs (Central energy price, 4% discount rate, Alternative PEF, EUR/m²)

Building	**Package**				**PE** (KWh/m²)	**Initial Investment Cost**	**Annual Costs**		**Cost of Emissions**	**Residual Value**	**Macro Cost**
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	329	240	16	504	30	-31	759
	B	ASHP	3	20%	330	225	16	505	31	-27	749
	EE1	ASHP	3	20%	339	148	16	519	31	-5	709
	EE1	ASHP	3	10%	354	122	15	535	33	-2	702
	EE1	ASHP	3	0%	368*	96	13	552	34	0	695
	EE1	ASHP	2	0%	392	90	13	587	36	0	727
	EE1	Gas (91%)	3	0%	417	66	13	643	40	0	761
	EE1	Gas (74%)	2	0%	460	49	13	711	44	0	817
	EE1	Gas (74%)	1	0%	491	46	13	756	47	0	862
	EE1	Gas (74%)	EE1	0%	703	0	13	1072	66	0	1151

Office (NV) – 20 year calc	B	ASHP	3	20%	104	171	8	165	10	-22	332
	EE1	ASHP	3	20%	135*	80	8	212	13	-2	311
	EE1	ASHP	2	20%	140	75	8	219	13	-2	312
	EE1	ASHP	3	0%	161	54	7	241	15	0	317
	EE1	ASHP	2	0%	165	49	7	248	15	0	319
	EE1	ASHP	1	0%	171	49	7	255	16	0	327
	EE1	ASHP	EE1	0%	248	26	7	371	23	0	427
	EE1	Gas (74%)	2	0%	299	23	6	491	30	0	550
	EE1	Gas (91%)	EE1	0%	331	9	6	527	32	0	575
	EE1	Gas (74%)	EE1	0%	367	0	6	588	36	0	631
Office (AC) – 20 year calc	C	ASHP	3	20%	175	258	8	271	16	-41	512
	B	ASHP	3	20%	176	229	8	273	16	-35	492
	EE1	ASHP	3	20%	196*	92	8	304	18	-2	419
	EE1	ASHP	3	10%	209	79	8	318	19	-1	423
	EE1	ASHP	3	0%	222	66	7	332	21	0	426
	EE1	ASHP	2	0%	240	60	7	360	22	0	448
	EE1	ASHP	1	0%	265	59	7	397	25	0	487
	EE1	ASHP	EE1	0%	345	26	7	517	32	0	581
	EE1	Gas (91%)	EE1	0%	411	9	6	640	39	0	695
	EE1	Gas (78%)	EE1	0%	431	0	6	675	42	0	723
School (Primary) – 30 year calc	C	ASHP	3	20%	25	188	14	71	2	-22	254
	B	ASHP	3	20%	26	160	14	72	3	-18	231
	EE1	ASHP	3	20%	37	107	14	91	4	-14	201
	EE1	ASHP	3	10%	51	92	13	97	5	-11	196
	EE1	ASHP	2	0%	68*	73	12	107	7	-8	192
	EE1	ASHP	1	0%	70	72	12	111	7	-8	195
	EE1	ASHP	EE1	0%	96	43	12	151	9	-5	211
	B	Gas (91%)	EE1	0%	123	65	12	197	12	-5	281
	EE1	Gas (91%)	EE1	0%	167	11	12	271	17	-1	310
	EE1	Gas (74%)	EE1	0%	189	0	12	307	19	0	339
Hotel – 20 year calc	C	ASHP	3	20%	333	280	11	542	33	-33	833
	B	ASHP	3	20%	337	227	11	548	33	-19	799
	EE1	ASHP	3	20%	356*	137	11	576	35	-1	757
	EE1	ASHP	3	10%	363	129	10	584	36	-1	759
	EE1	ASHP	3	0%	370	122	10	593	36	0	761
	EE1	ASHP	2	0%	381	112	10	608	37	0	767
	EE1	ASHP	1	0%	393	103	10	627	39	0	778
	EE1	ASHP	EE1	0%	531	29	10	834	51	0	924
	EE1	Gas (91%)	EE1	0%	588	8	10	940	58	0	1015
	EE1	Gas (74%)	EE1	0%	603	0	10	965	59	0	1034

Capabilities on project:
Building Engineering

Table 5.7g: Macroeconomic Costs (Central energy price, 4% discount rate, Alternative Cost of Carbon, EUR/m²)

Building	Package				PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	240	16	504	17	-31	746
	B	ASHP	3	20%	302	225	16	505	17	-27	736
	EE1	ASHP	3	20%	311	148	16	519	18	-5	695
	EE1	ASHP	3	10%	324	122	15	535	19	-2	688
	EE1	ASHP	3	0%	338*	96	13	552	19	0	681
	EE1	ASHP	2	0%	359	90	13	587	21	0	711
	EE1	Gas (91%)	3	0%	390	66	13	643	24	0	746
	EE1	Gas (74%)	2	0%	431	49	13	711	26	0	800
	EE1	Gas (74%)	1	0%	459	46	13	756	28	0	843
	EE1	Gas (74%)	EE1	0%	652	0	13	1072	39	0	1124
Office (NV) – 20 year calc	B	ASHP	3	20%	95	171	8	165	5	-22	328
	EE1	ASHP	3	20%	124*	80	8	212	7	-2	305
	EE1	ASHP	3	10%	136	67	8	227	8	-1	308
	EE1	ASHP	3	0%	148	54	7	241	8	0	310
	EE1	ASHP	2	0%	152	49	7	248	9	0	312
	EE1	ASHP	EE1	0%	227	26	7	371	13	0	417
	EE1	Gas (91%)	2	0%	252	32	6	422	17	0	478
	EE1	Gas (74%)	2	0%	292	23	6	491	20	0	540
	EE1	Gas (91%)	EE1	0%	316	9	6	527	20	0	563
	EE1	Gas (74%)	EE1	0%	353	0	6	588	23	0	618
Office (AC) – 20 year calc	C	ASHP	3	20%	160	258	8	271	9	-41	505
	B	ASHP	3	20%	161	229	8	273	9	-35	484
	EE1	ASHP	3	20%	180*	92	8	304	10	-2	411
	EE1	ASHP	3	10%	192	79	8	318	11	-1	414
	EE1	ASHP	3	0%	203	66	7	332	12	0	417
	EE1	ASHP	2	0%	220	60	7	360	13	0	439
	EE1	ASHP	1	0%	243	59	7	397	14	0	476
	EE1	ASHP	EE1	0%	316	26	7	517	18	0	567
	EE1	Gas (91%)	EE1	0%	387	9	6	640	24	0	680
	EE1	Gas (78%)	EE1	0%	407	0	6	675	25	0	707
School (Primary) – 30 year calc	C	ASHP	3	20%	24	188	14	71	2	-22	253
	B	ASHP	3	20%	24	160	14	72	2	-18	230
	EE1	ASHP	3	20%	35	107	14	91	2	-14	200
	EE1	ASHP	3	10%	48	92	13	97	3	-11	194
	EE1	ASHP	3	0%	60*	77	12	104	4	-8	189
	EE1	ASHP	1	0%	65	72	12	111	4	-8	192
	EE1	ASHP	EE1	0%	87	43	12	151	6	-5	207
	EE1	Gas (91%)	1	0%	140	40	12	240	10	-4	297

	EE1	Gas (91%)	EE1	0%	158	11	12	271	11	-1	304
	EE1	Gas (74%)	EE1	0%	180	0	12	307	12	0	332
Hotel – 20 year calc	C	ASHP	3	20%	321	280	11	542	21	-33	821
	B	ASHP	3	20%	325	227	11	548	21	-19	787
	EE1	ASHP	3	20%	342*	137	11	576	22	-1	745
	EE1	ASHP	3	10%	349	129	10	584	23	-1	746
	EE1	ASHP	3	0%	355	122	10	593	23	0	747
	EE1	ASHP	2	0%	365	112	10	608	24	0	754
	EE1	ASHP	1	0%	376	103	10	627	24	0	764
	EE1	ASHP	EE1	0%	503	29	10	834	32	0	904
	EE1	Gas (91%)	EE1	0%	564	8	10	940	37	0	994
	EE1	Gas (74%)	EE1	0%	578	0	10	965	38	0	1012

Capabilities on project:
Building Engineering

Table 5.8a: Financial Costs (Central energy price, 7% discount rate, EUR/m²)

Building	Package				PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	273	12	418	-	-21	682
	B	ASHP	3	20%	302	255	12	418	-	-18	668
	EE1	ASHP	3	20%	311	168	12	430	-	-3	606
	EE1	ASHP	3	10%	324	138	12	443	-	-2	592
	EE1	ASHP	3	0%	338*	109	10	457	-	0	577
	EE1	ASHP	2	0%	359	103	10	486	-	0	599
	EE1	Gas (91%)	3	0%	390	75	10	527	-	0	612
	EE1	Gas (74%)	2	0%	431	56	10	583	-	0	649
	EE1	Gas (74%)	1	0%	459	52	10	620	-	0	683
	EE1	Gas (74%)	EE1	0%	652	0	10	882	-	0	893
Office (NV) – 20 year calc	B	ASHP	3	20%	95	194	6	137	-	-15	323
	EE1	ASHP	3	20%	124	91	6	176	-	-2	272
	EE1	ASHP	3	10%	136	76	6	188	-	-1	269
	EE1	ASHP	3	0%	148	62	5	200	-	0	267
	EE1	ASHP	2	0%	152*	56	5	205	-	0	266
	EE1	ASHP	EE1	0%	227	30	5	307	-	0	342
	EE1	Gas (91%)	2	0%	252	36	5	340	-	0	381
	EE1	Gas (74%)	2	0%	292	26	5	394	-	0	425
	EE1	Gas (91%)	EE1	0%	316	11	5	428	-	0	443
	EE1	Gas (74%)	EE1	0%	353	0	5	476	-	0	481
Office (AC) – 20 year calc	C	ASHP	3	20%	160	293	6	224	-	-27	497
	B	ASHP	3	20%	161	260	6	226	-	-23	469
	EE1	ASHP	3	20%	180	104	6	252	-	-2	360
	EE1	ASHP	3	10%	192	89	6	263	-	-1	358
	EE1	ASHP	3	0%	203*	75	5	275	-	0	355
	EE1	ASHP	2	0%	220	68	5	298	-	0	371
	EE1	ASHP	1	0%	243	67	5	329	-	0	401
	EE1	ASHP	EE1	0%	316	30	5	428	-	0	463
	EE1	Gas (91%)	EE1	0%	387	11	5	523	-	0	539
	EE1	Gas (78%)	EE1	0%	407	0	5	551	-	0	556
School (Primary) – 30 year calc	C	ASHP	3	20%	24	197	10	58	-	-11	255
	B	ASHP	3	20%	24	166	10	59	-	-9	226
	EE1	ASHP	3	20%	35	104	10	74	-	-7	181
	EE1	ASHP	3	10%	48	90	10	79	-	-6	173
	EE1	ASHP	3	0%	60*	75	9	85	-	-4	165
	EE1	ASHP	1	0%	65	71	9	91	-	-4	166
	EE1	ASHP	EE1	0%	87	42	9	124	-	-2	173
	EE1	Gas (91%)	1	0%	140	39	9	193	-	-2	239

	EE1	Gas (91%)	EE1	0%	158	11	9	219	-	-1	239
	EE1	Gas (74%)	EE1	0%	180	0	9	248	-	0	257
Hotel – 20 year calc	C	ASHP	3	20%	321	318	8	438	-	-22	743
	B	ASHP	3	20%	325	258	8	443	-	-13	696
	EE1	ASHP	3	20%	342	155	8	467	-	-1	629
	EE1	ASHP	3	10%	349	147	8	473	-	0	628
	EE1	ASHP	3	0%	355*	138	8	480	-	0	626
	EE1	ASHP	2	0%	365	127	8	493	-	0	628
	EE1	ASHP	1	0%	376	117	8	509	-	0	633
	EE1	ASHP	EE1	0%	503	33	8	680	-	0	721
	EE1	Gas (91%)	EE1	0%	564	9	8	762	-	0	778
	EE1	Gas (74%)	EE1	0%	578	0	8	781	-	0	789

Table 5.8b: Financial Costs (Low energy price, 7% discount rate, EUR/m²)

Building	**Package**				**PE** (KWh/m²)	**Initial Investment Cost**	**Annual Costs**		**Cost of Emissions**	**Residual Value**	**Macro Cost**
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	273	12	334	-	-21	599
	B	ASHP	3	20%	302	255	12	335	-	-18	584
	EE1	ASHP	3	20%	311	168	12	344	-	-3	521
	EE1	ASHP	3	10%	324	138	12	355	-	-2	503
	EE1	ASHP	3	0%	338*	109	10	366	-	0	485
	EE1	ASHP	2	0%	359	103	10	389	-	0	502
	EE1	Gas (91%)	3	0%	390	75	10	409	-	0	495
	EE1	Gas (74%)	2	0%	431	56	10	451	-	0	517
	EE1	Gas (74%)	1	0%	459	52	10	482	-	0	544
	EE1	Gas (74%)	EE1	0%	652	0	10	693	-	0	703
Office (NV) – 20 year calc	B	ASHP	3	20%	95	194	6	109	-	-15	296
	EE1	ASHP	3	20%	124	91	6	141	-	-2	236
	EE1	ASHP	3	10%	136	76	6	150	-	-1	232
	EE1	ASHP	3	0%	148	62	5	160	-	0	227
	EE1	ASHP	2	0%	152*	56	5	164	-	0	225
	EE1	ASHP	EE1	0%	227	30	5	246	-	0	281
	EE1	Gas (91%)	2	0%	252	36	5	248	-	0	290
	EE1	Gas (74%)	2	0%	292	26	5	286	-	0	317
	EE1	Gas (91%)	EE1	0%	316	11	5	321	-	0	337
	EE1	Gas (74%)	EE1	0%	353	0	5	355	-	0	360
Office (AC) – 20 year calc	C	ASHP	3	20%	160	293	6	180	-	-27	452
	B	ASHP	3	20%	161	260	6	181	-	-23	424
	EE1	ASHP	3	20%	180	104	6	201	-	-2	310
	EE1	ASHP	3	10%	192	89	6	211	-	-1	305

	EE1	ASHP	3	0%	203*	75	5	220	-	0	300
	EE1	ASHP	2	0%	220	68	5	239	-	0	311
	EE1	ASHP	1	0%	243	67	5	263	-	0	335
	EE1	ASHP	EE1	0%	316	30	5	342	-	0	377
	EE1	Gas (91%)	EE1	0%	387	11	5	402	-	0	417
	EE1	Gas (78%)	EE1	0%	407	0	5	421	-	0	426
School (Primary) – 30 year calc	C	ASHP	3	20%	24	197	10	45	-	-11	241
	B	ASHP	3	20%	24	166	10	46	-	-9	212
	EE1	ASHP	3	20%	35	104	10	56	-	-7	163
	EE1	ASHP	3	10%	48	90	10	60	-	-6	154
	EE1	ASHP	3	0%	60*	75	9	65	-	-4	145
	EE1	ASHP	1	0%	65	71	9	69	-	-4	145
	EE1	ASHP	EE1	0%	87	42	9	96	-	-2	145
	EE1	Gas (91%)	1	0%	140	39	9	141	-	-2	187
	EE1	Gas (91%)	EE1	0%	158	11	9	163	-	-1	182
	EE1	Gas (74%)	EE1	0%	180	0	9	183	-	0	192
Hotel – 20 year calc	C	ASHP	3	20%	321	318	8	325	-	-22	629
	B	ASHP	3	20%	325	258	8	329	-	-13	582
	EE1	ASHP	3	20%	342	155	8	348	-	-1	510
	EE1	ASHP	3	10%	349	147	8	353	-	0	507
	EE1	ASHP	3	0%	355	138	8	358	-	0	504
	EE1	ASHP	2	0%	365*	127	8	369	-	0	503
	EE1	ASHP	1	0%	376	117	8	381	-	0	506
	EE1	ASHP	EE1	0%	503	33	8	518	-	0	559
	EE1	Gas (91%)	EE1	0%	564	9	8	569	-	0	585
	EE1	Gas (74%)	EE1	0%	578	0	8	583	-	0	591

Table 5.8c: Financial Costs (High energy price, 7% discount rate, EUR/m²)

Building	**Package**				**PE** (KWh/m²)	**Initial Investment Cost**	**Annual Costs**		**Cost of Emissions**	**Residual Value**	**Macro Cost**
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	273	12	501	-	-21	766
	B	ASHP	3	20%	302	255	12	502	-	-18	752
	EE1	ASHP	3	20%	311	168	12	516	-	-3	692
	EE1	ASHP	3	10%	324	138	12	532	-	-2	681
	EE1	ASHP	3	0%	338*	109	10	549	-	0	668
	EE1	ASHP	2	0%	359	103	10	584	-	0	697
	EE1	Gas (91%)	3	0%	390	75	10	645	-	0	730
	EE1	Gas (74%)	2	0%	431	56	10	714	-	0	780
	EE1	Gas (74%)	1	0%	459	52	10	759	-	0	821
	EE1	Gas (74%)	EE1	0%	652	0	10	1072	-	0	1082

Office (NV) – 20 year calc	B	ASHP	3	20%	95	194	6	164	-	-15	350
	EE1	ASHP	3	20%	124	91	6	211	-	-2	307
	EE1	ASHP	3	10%	136	76	6	225	-	-1	307
	EE1	ASHP	3	0%	148*	62	5	240	-	0	306
	EE1	ASHP	2	0%	152	56	5	246	-	0	307
	EE1	ASHP	EE1	0%	227	30	5	369	-	0	404
	EE1	Gas (91%)	2	0%	252	36	5	431	-	0	473
	EE1	Gas (74%)	2	0%	292	26	5	502	-	0	533
	EE1	Gas (91%)	EE1	0%	316	11	5	534	-	0	550
	EE1	Gas (74%)	EE1	0%	353	0	5	598	-	0	603
Office (AC) – 20 year calc	C	ASHP	3	20%	160	293	6	269	-	-27	542
	B	ASHP	3	20%	161	260	6	272	-	-23	515
	EE1	ASHP	3	20%	180	104	6	302	-	-2	411
	EE1	ASHP	3	10%	192	89	6	316	-	-1	411
	EE1	ASHP	3	0%	203*	75	5	330	-	0	410
	EE1	ASHP	2	0%	220	68	5	358	-	0	431
	EE1	ASHP	1	0%	243	67	5	395	-	0	467
	EE1	ASHP	EE1	0%	316	30	5	514	-	0	548
	EE1	Gas (91%)	EE1	0%	387	11	5	644	-	0	660
	EE1	Gas (78%)	EE1	0%	407	0	5	680	-	0	685
School (Primary) – 30 year calc	C	ASHP	3	20%	24	197	10	72	-	-11	268
	B	ASHP	3	20%	24	166	10	73	-	-9	239
	EE1	ASHP	3	20%	35	104	10	92	-	-7	199
	EE1	ASHP	3	10%	48	90	10	98	-	-6	192
	EE1	ASHP	3	0%	60*	75	9	105	-	-4	185
	EE1	ASHP	1	0%	65	71	9	112	-	-4	188
	EE1	ASHP	EE1	0%	87	42	9	152	-	-2	201
	EE1	Gas (91%)	1	0%	140	39	9	245	-	-2	291
	EE1	Gas (91%)	EE1	0%	158	11	9	276	-	-1	295
	EE1	Gas (74%)	EE1	0%	180	0	9	313	-	0	322
Hotel – 20 year calc	C	ASHP	3	20%	321	318	8	551	-	-22	856
	B	ASHP	3	20%	325	258	8	557	-	-13	810
	EE1	ASHP	3	20%	342	155	8	585	-	-1	748
	EE1	ASHP	3	10%	349	147	8	594	-	0	748
	EE1	ASHP	3	0%	355*	138	8	602	-	0	747
	EE1	ASHP	2	0%	365	127	8	617	-	0	752
	EE1	ASHP	1	0%	376	117	8	636	-	0	760
	EE1	ASHP	EE1	0%	503	33	8	841	-	0	882
	EE1	Gas (91%)	EE1	0%	564	9	8	954	-	0	970
	EE1	Gas (74%)	EE1	0%	578	0	8	979	-	0	987

Capabilities on project:
Building Engineering

Table 5.8d: Financial Costs (Central energy price, 13% discount rate, EUR/m²)

Building	Package				PE (KWh/m²)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
	Fabric	Heating	Services	PV			Maintenance	Energy			
Retail – 20 year calc	C	ASHP	3	20%	302	273	8	261	-	-7	535
	B	ASHP	3	20%	302	255	8	261	-	-6	518
	EE1	ASHP	3	20%	311	168	8	268	-	-1	443
	EE1	ASHP	3	10%	324	138	8	277	-	-1	423
	EE1	ASHP	3	0%	338*	109	7	285	-	0	402
	EE1	ASHP	2	0%	359	103	7	304	-	0	413
	EE1	Gas (91%)	3	0%	390	75	7	324	-	0	406
	EE1	Gas (74%)	2	0%	431	56	7	358	-	0	421
	EE1	Gas (74%)	1	0%	459	52	7	382	-	0	441
	EE1	Gas (74%)	EE1	0%	652	0	7	546	-	0	553
Office (NV) – 20 year calc	B	Gas CHP	3	20%	95	194	4	85	-	-5	279
	EE1	Gas CHP	3	20%	124	91	4	110	-	-1	204
	EE1	Gas CHP	3	10%	136	76	4	117	-	0	197
	EE1	Gas CHP	3	0%	148	62	3	125	-	0	190
	EE1	Gas CHP	2	0%	152*	56	3	128	-	0	187
	EE1	Gas CHP	EE1	0%	227	30	3	192	-	0	225
	EE1	Gas(91%)+SHW	2	0%	252	36	3	203	-	0	243
	EE1	Gas(86%)	2	0%	292	26	3	235	-	0	264
	EE1	Gas(91%)+SHW	EE1	0%	316	11	3	259	-	0	273
	EE1	Gas(86%)	EE1	0%	353	0	3	287	-	0	291
Office (AC) – 20 year calc	C	ASHP	3	20%	160	293	4	140	-	-10	428
	B	ASHP	3	20%	161	260	4	141	-	-8	397
	EE1	ASHP	3	20%	180	104	4	157	-	-1	265
	EE1	ASHP	3	10%	192	89	4	164	-	0	258
	EE1	ASHP	3	0%	203*	75	3	172	-	0	250
	EE1	ASHP	2	0%	220	68	3	186	-	0	257
	EE1	ASHP	1	0%	243	67	3	205	-	0	276
	EE1	ASHP	EE1	0%	316	30	3	267	-	0	300
	EE1	Gas (91%)	EE1	0%	387	11	3	320	-	0	334
	EE1	Gas (78%)	EE1	0%	407	0	3	336	-	0	340
School (Primary) – 30 year calc	C	ASHP	3	20%	24	183	6	36	-	-2	223
	B	ASHP	3	20%	24	152	6	36	-	-2	193
	EE1	ASHP	3	20%	35	91	6	45	-	-1	140
	EE1	ASHP	3	10%	48	78	6	48	-	-1	131
	EE1	ASHP	3	0%	60	65	6	52	-	-1	121
	EE1	ASHP	1	0%	65	61	6	55	-	-1	121
	EE1	ASHP	EE1	0%	87*	37	6	76	-	0	118

	EE1	Gas (91%)	1	0%	140	34	6	115	-	0	154
	EE1	Gas (91%)	EE1	0%	158	10	6	132	-	0	147
	EE1	Gas (74%)	EE1	0%	180	0	6	149	-	0	154
Hotel – 20 year calc	C	ASHP	3	20%	321	318	6	264	-	-8	579
	B	ASHP	3	20%	325	258	6	267	-	-5	525
	EE1	ASHP	3	20%	342	155	6	281	-	0	442
	EE1	ASHP	3	10%	349	147	5	286	-	0	438
	EE1	ASHP	3	0%	355	138	5	290	-	0	433
	EE1	ASHP	2	0%	365	127	5	298	-	0	430
	EE1	ASHP	1	0%	376*	117	5	308	-	0	430
	EE1	ASHP	EE1	0%	503	33	5	415	-	0	453
	EE1	Gas (91%)	EE1	0%	564	9	5	460	-	0	474
	EE1	Gas (74%)	EE1	0%	578	0	5	472	-	0	477

6. Cost Optimal Level for Reference Buildings

6.1 Introduction

As described in the previous Residential and Non-Residential Reports, the 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 4% to mirror that used by the Government policy analysis.

6.2 New Apartment Buildings

The macro-economic cost optimal curve for the apartment buildings is shown in Figure 6.1. The costs are based on the central energy price and 4% discount rate.

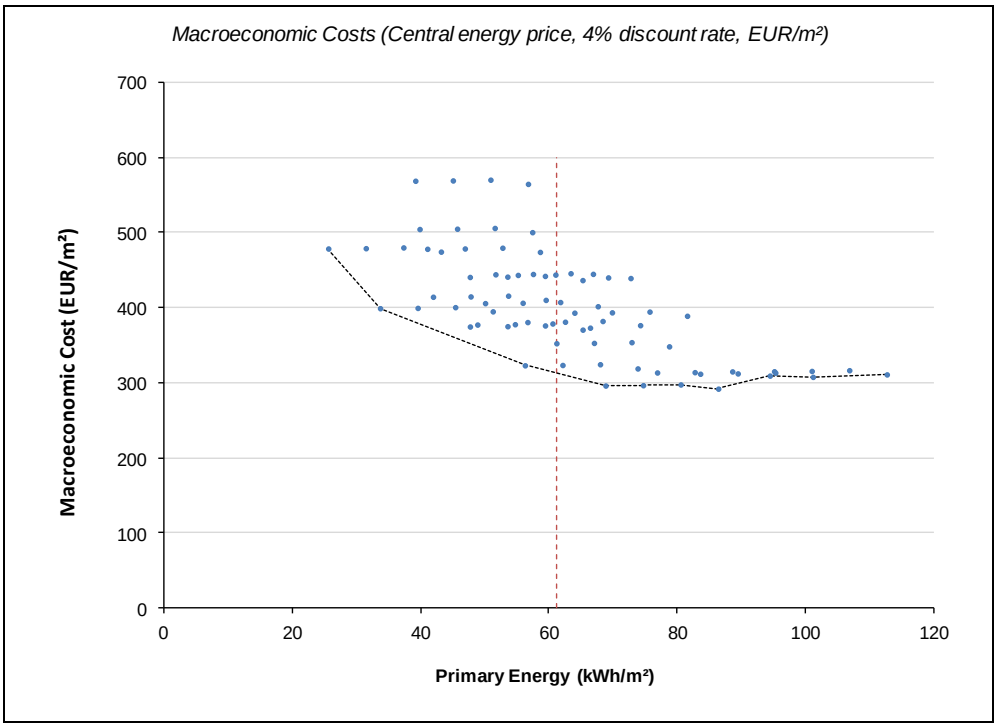

Figure 6.1: Results of the cost-optimal analysis (New apartment building, macro-economic costs, 4% discount rate)

From this curves, the economic optimal energy performance level in primary energy (kWh/m2/yr) is shown in Table 6.1. We have also included a range to cover the sensitivity cases investigated in Section 5. Furthermore, to provide some allowance for sensitivity in the price of the fabric/services/LZC measures, we have included those primary energies within around 5% of the lowest macro-economic cost on the cost optimum curve.

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)*
Apartment Building	86	69-101

6.3 Existing Apartment Buildings – Elemental Measures

The macro-economic cost optimal graphs for the cavity wall apartment building are shown in Figures 6.2 to 6.6, and in Figures 6.7 to 6.11 for the hollow block apartment building. The costs are based on the central energy price and 4% discount rate.

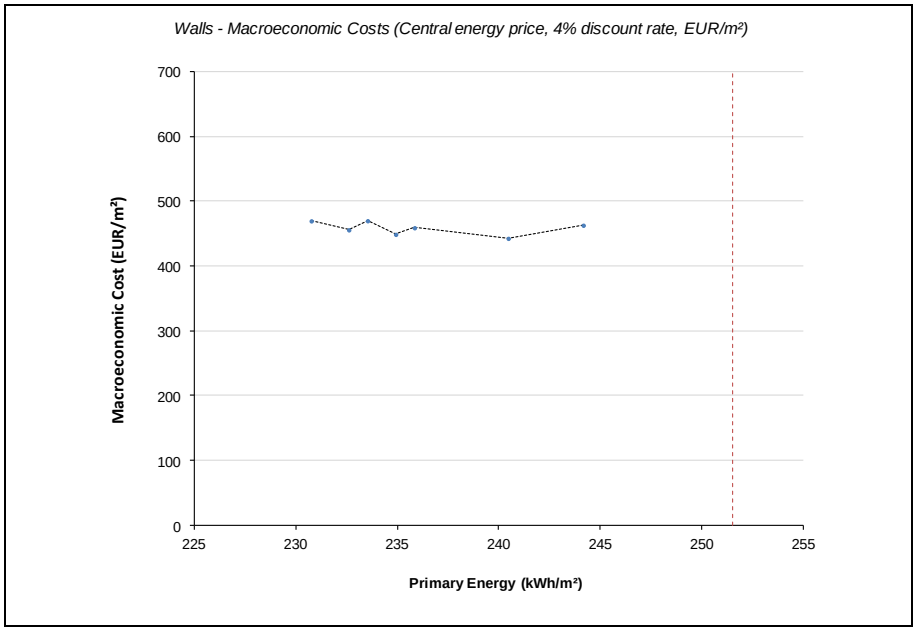

Figure 6.2: Results of the cost-optimal analysis (Existing cavity wall apartment building elemental measure: walls, macro-economic costs, 4% discount rate)

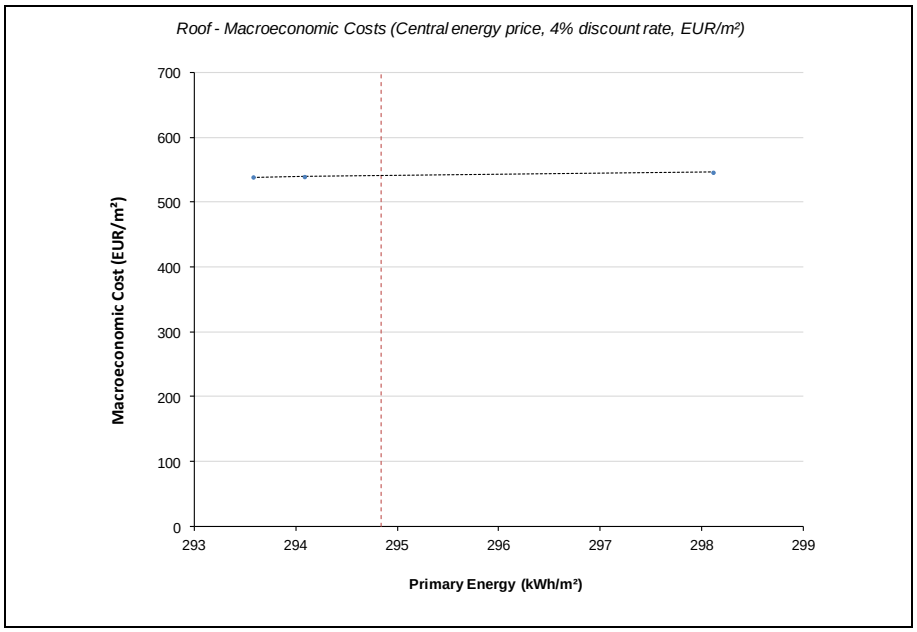

Figure 6.3: Results of the cost-optimal analysis (Existing cavity wall apartment building elemental measure: roof, macro-economic costs, 4% discount rate)

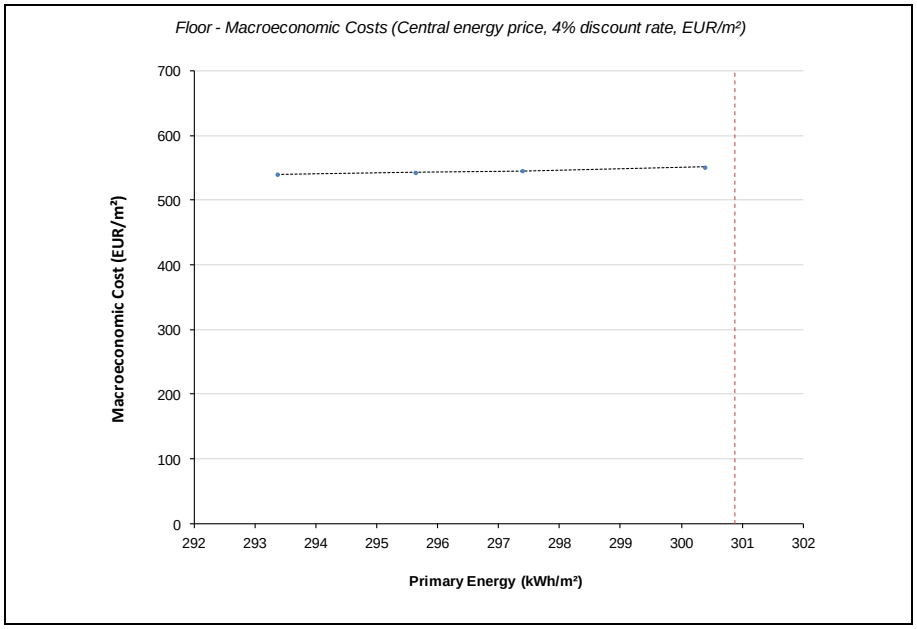

Figure 6.4: Results of the cost-optimal analysis (Existing cavity wall apartment building elemental measure: floor, macro-economic costs, 4% discount rate)

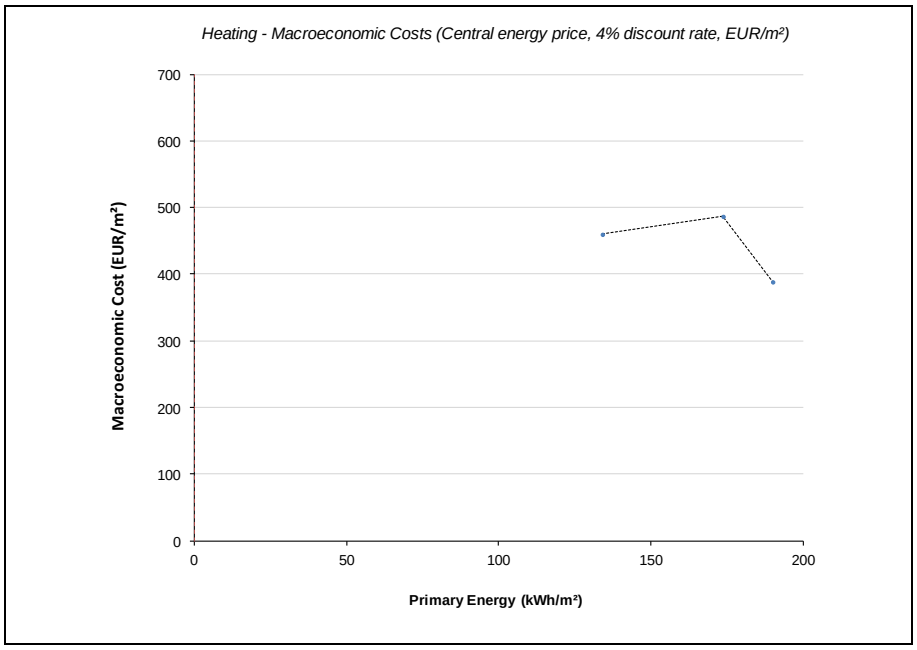

Figure 6.5: Results of the cost-optimal analysis (Existing cavity wall apartment building elemental measure: heating, macro-economic costs, 4% discount rate)

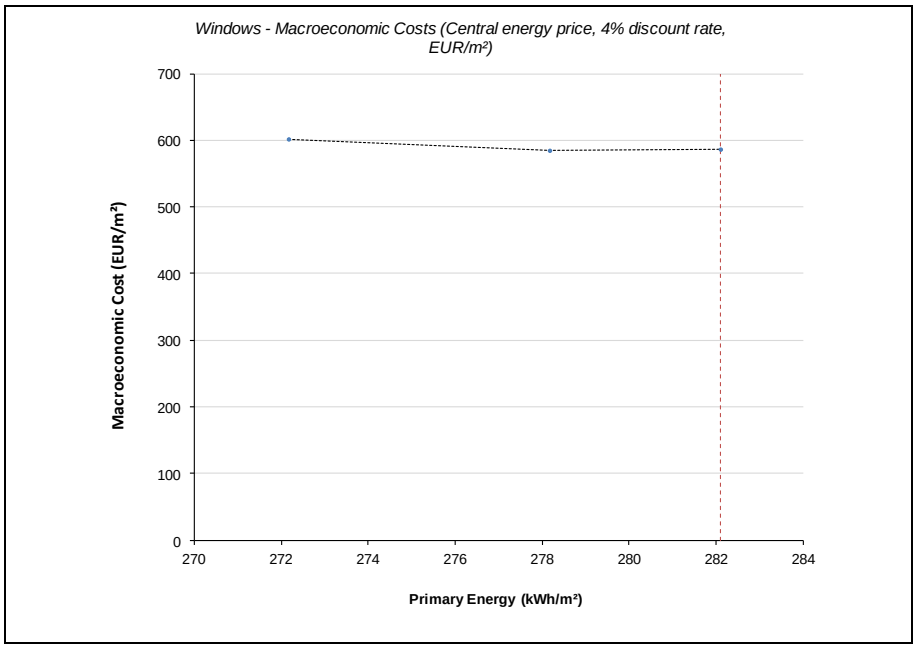

Figure 6.6: Results of the cost-optimal analysis (Existing cavity wall apartment building elemental measure: windows, macro-economic costs, 4% discount rate)

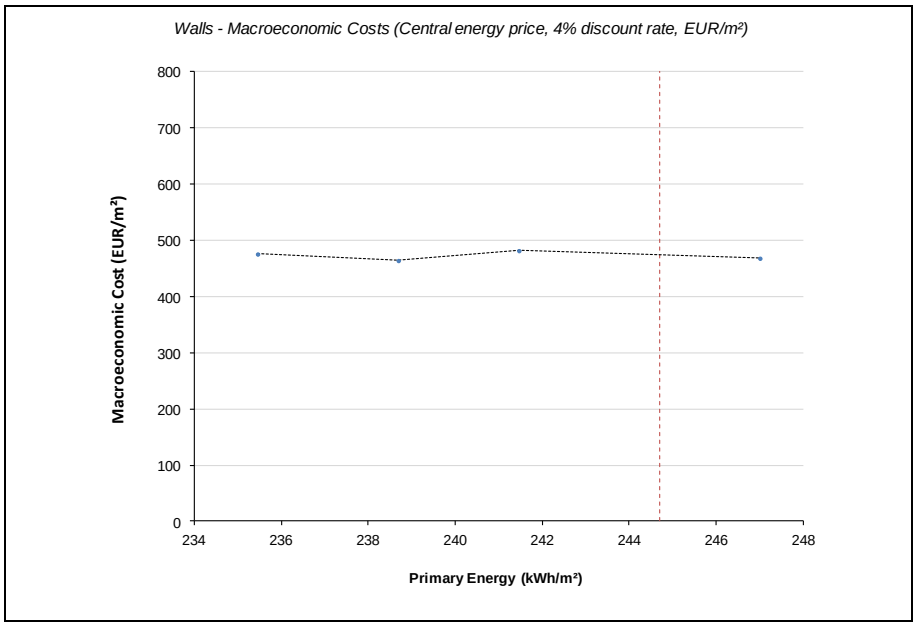

Figure 6.7: Results of the cost-optimal analysis (Existing hollow block wall apartment building elemental measure: walls, macro-economic costs, 4% discount rate)

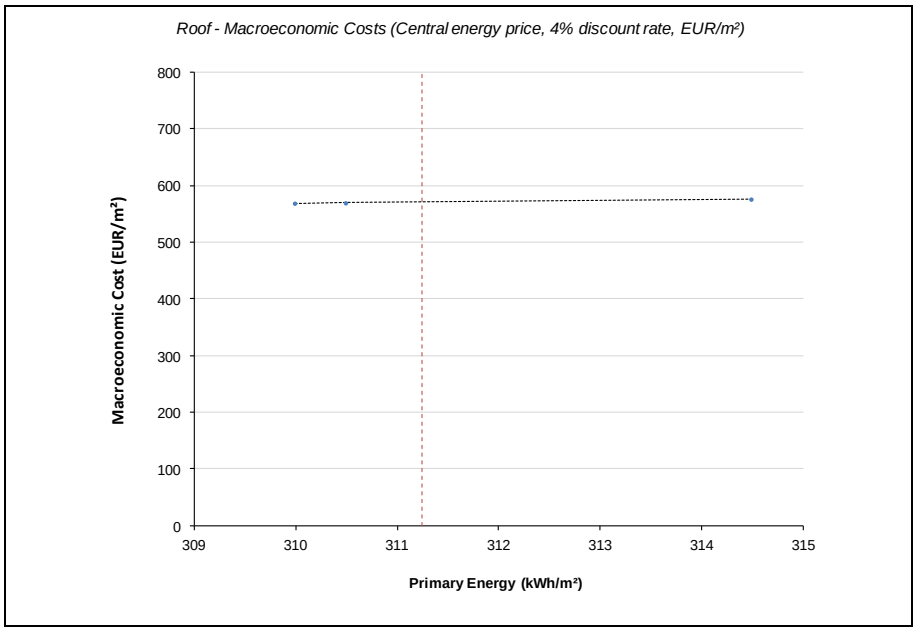

Figure 6.8: Results of the cost-optimal analysis (Existing hollow block wall apartment building elemental measure: roof, macro-economic costs, 4% discount rate)

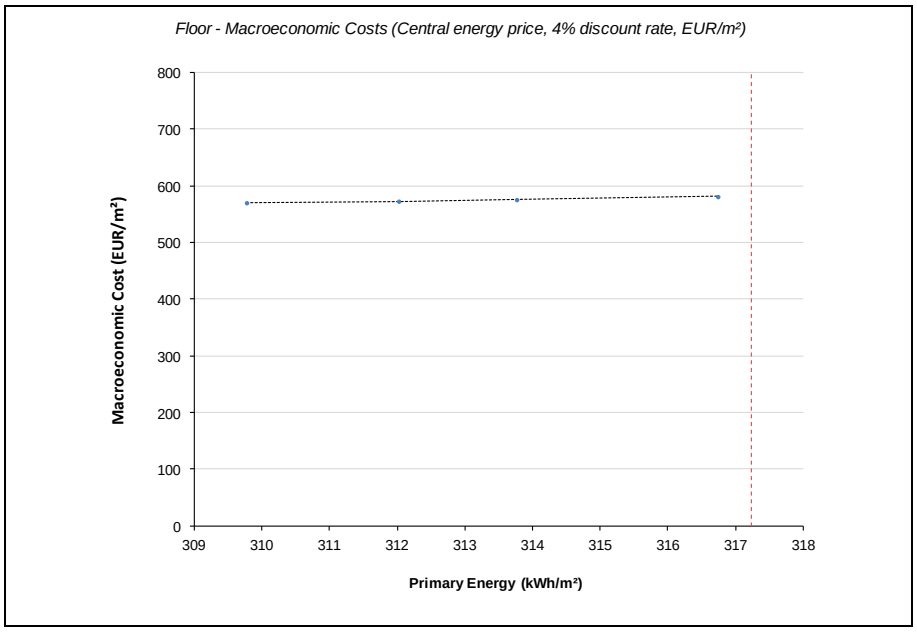

Figure 6.9: Results of the cost-optimal analysis (Existing hollow block wall apartment building elemental measure: floor, macro-economic costs, 4% discount rate)

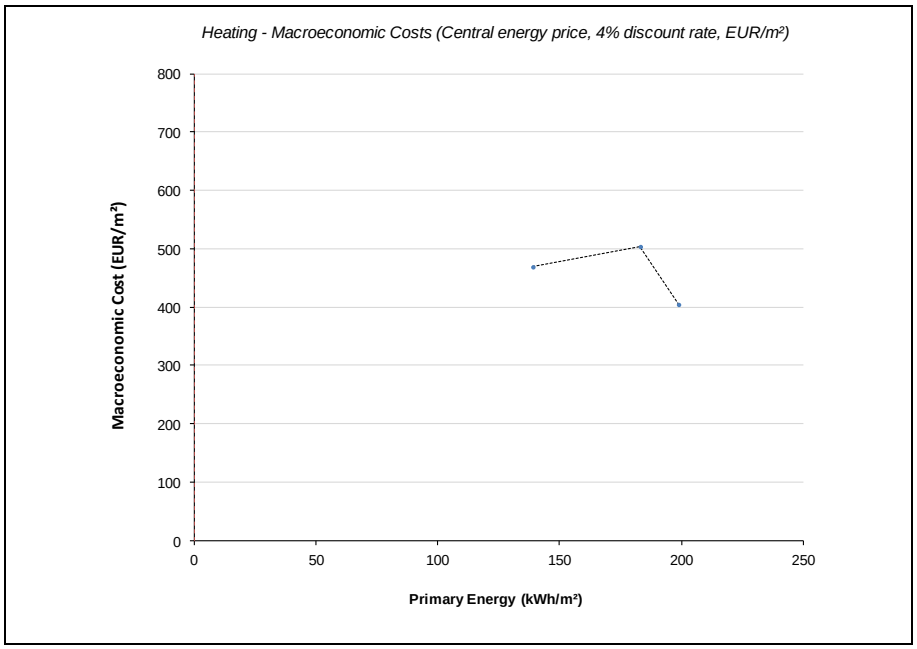

Figure 6.10: Results of the cost-optimal analysis (Existing hollow block wall apartment building elemental measure: heating, macro-economic costs, 4% discount rate)

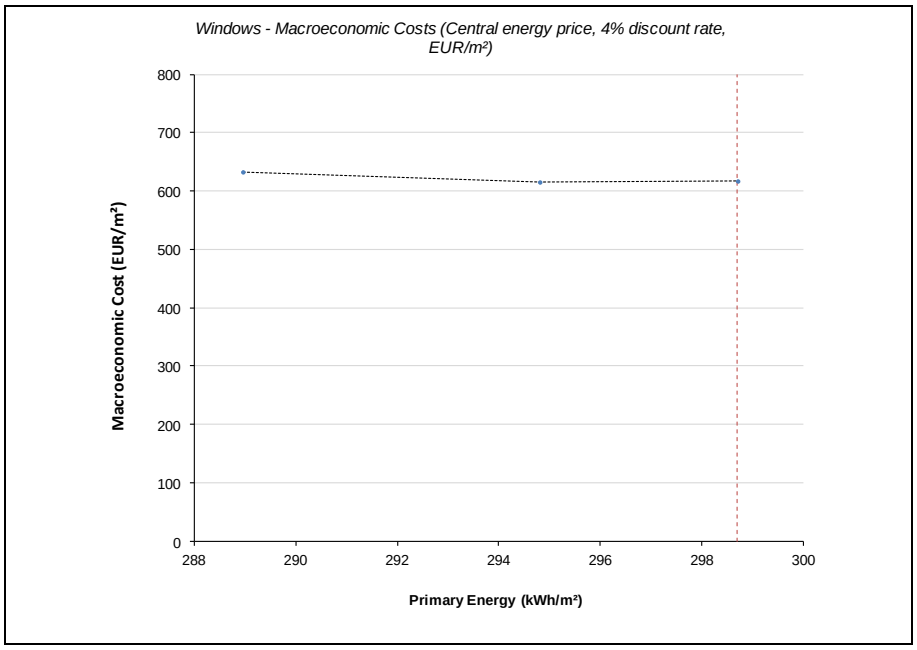

Figure 6.11: Results of the cost-optimal analysis (Existing hollow block wall apartment building elemental measure: windows, macro-economic costs, 4% discount rate)

From these curves, the economic optimal energy performance level in component units (e.g. U-value for fabric elements) is shown in Table 6.2. We have also included 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, and where no variation was found this is shown by the following symbol: '-'. We have not included sensitivity in the price of the fabric measures as we assume affects on the capital cost will be similar for each scenario on a given curve. Whilst we have not done so, it may be appropriate to consider cost sensitivity for the different types of heating system.

Table 6.2: Economic Optimal Energy Performance Level

Reference building	*Measure*	*Optimum component level*	*Sensitivity Range*
Apartment Building, Cavity Wall	Walls	U-value = 0.31	-
	Roof	U-value = 0.11	-
	Floor	U-value = 0.15 W/m^{2}K	-
	Heating	90% (gas boiler)	-
	Window	U-value = 1.4 W/m^{2}K	1.4 - 1.6 W/m^{2}K
Apartment Building, Hollow Block Wall	Walls	U-value = 0.22 W/m^{2}K	0.22 - 0.40 W/m^{2}K
	Roof	U-value = 0.11 W/m^{2}K	-

	Floor	U-value = 0.15 W/m^{2}K	-
	Heating	90% (gas boiler)	-
	Window	U-value = 1.4 W/m^{2}K	1.4 - 1.6 W/m^{2}K

6.4 Existing Apartment Buildings – Packages of Measures

The macro-economic cost optimal curves for the cavity wall and hollow block wall apartment buildings are shown in Figures 6.12 and 6.13. The costs are based on the central energy price and 4% discount rate.

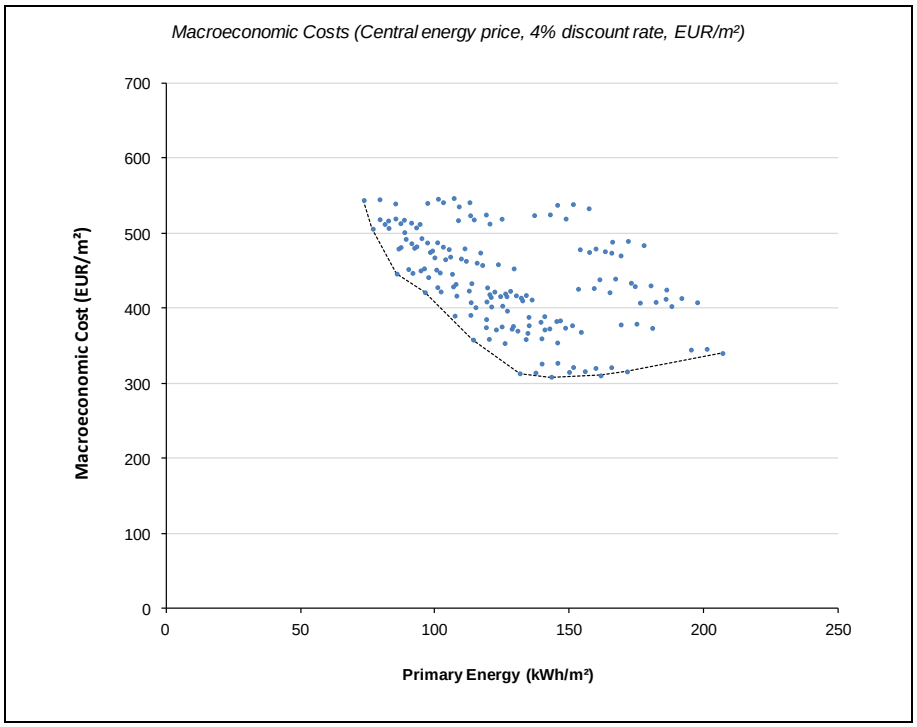

Figure 6.12: Results of the cost-optimal analysis (Existing cavity wall apartment building packages, macro-economic costs, 4% discount rate)

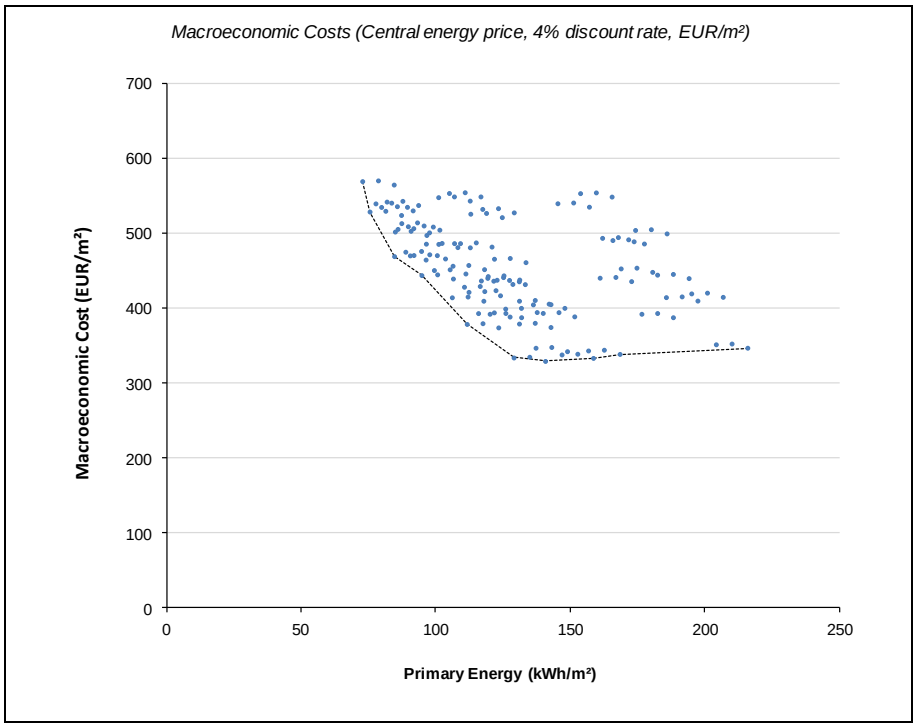

Figure 6.13: Results of the cost-optimal analysis (Existing hollow block wall apartment building packages, macro-economic costs, 4% discount rate)

From these curves, the economic optimal performance level is shown in Table 6.34. The sensitivity highlighted alternative options either within 5% of the macroeconomic cost in the central case on the cost optimum curve or the optimum solution in the sensitivity analyses.

Table 6.3: Economic Optimal Energy Performance Level Packages

Reference building	*Optimal*	*Sensitivity Range*
Apartment Building, Cavity Wall	Roof and wall improvements to cost optimum, gas boiler	Wall improvement to cost optimum, gas boiler Wall improvement to cost optimum, biomass boiler, 0/10/20% PV Roof and wall improvements to cost optimum, gas boiler, 10/20% PV Roof and wall improvements to cost optimum, biomass boiler, 0/10/20% PV
Apartment Building, Hollow Block Wall	Roof and wall improvements to cost optimum, gas boiler	Wall improvement to cost optimum, gas boiler Wall improvement to cost optimum, biomass boiler, 0/10/20% PV Roof and wall improvements to cost optimum, gas boiler, 10/20% PV Roof and wall improvements to cost optimum, biomass boiler, 0/10/20% PV

6.5 Existing Non-Domestic Buildings – Packages of Measures

The macro-economic cost optimal curves for the five buildings are shown in Figures 6.14 – 6.18. The costs are based on the central energy price and 4% discount rate.

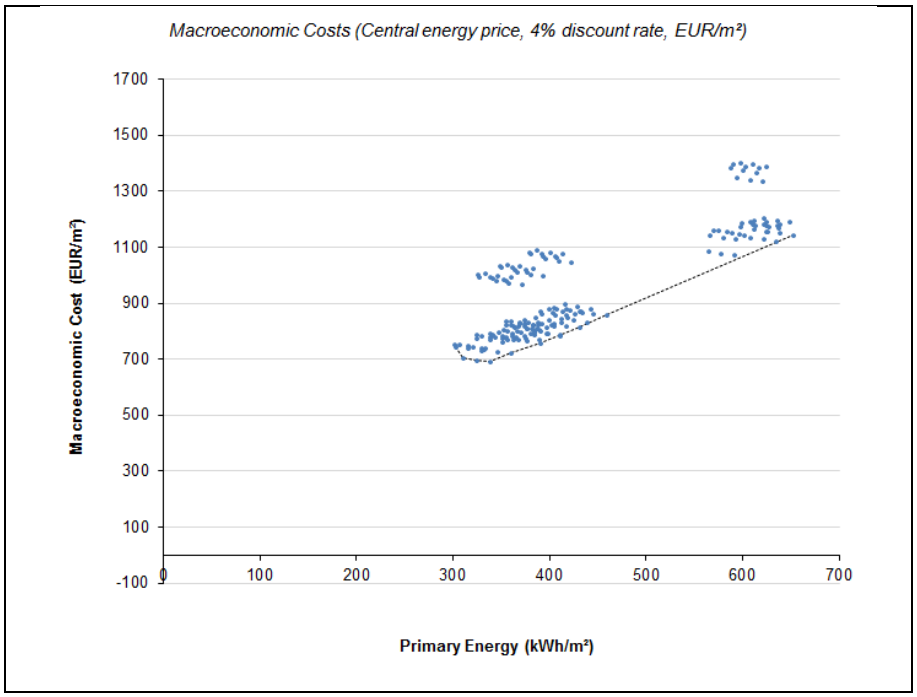

Figure 6.14: Results of the cost-optimal analysis (Retail, macro-economic costs, 4% discount rate)

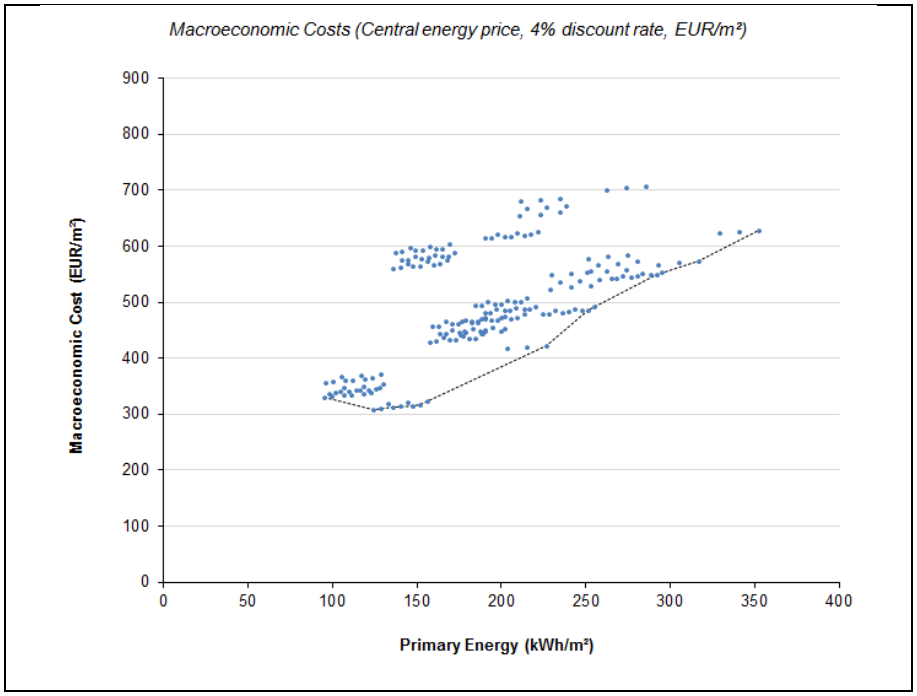

Figure 6.15: Results of the cost-optimal analysis (Office (NV), macro-economic costs, 4% discount rate)

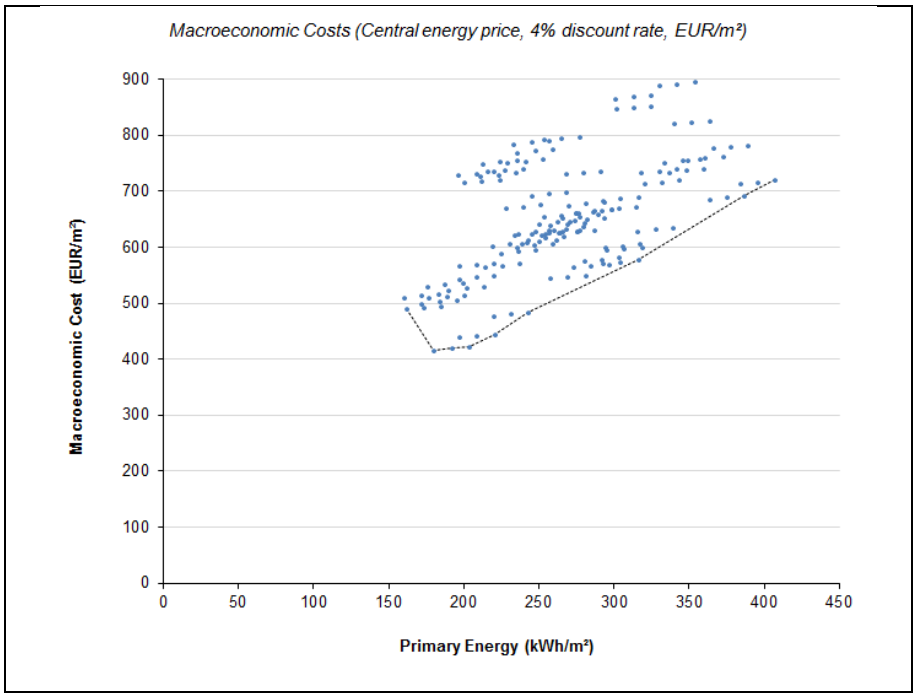

Figure 6.16: Results of the cost-optimal analysis (Office (AC), macro-economic costs, 4% discount rate)

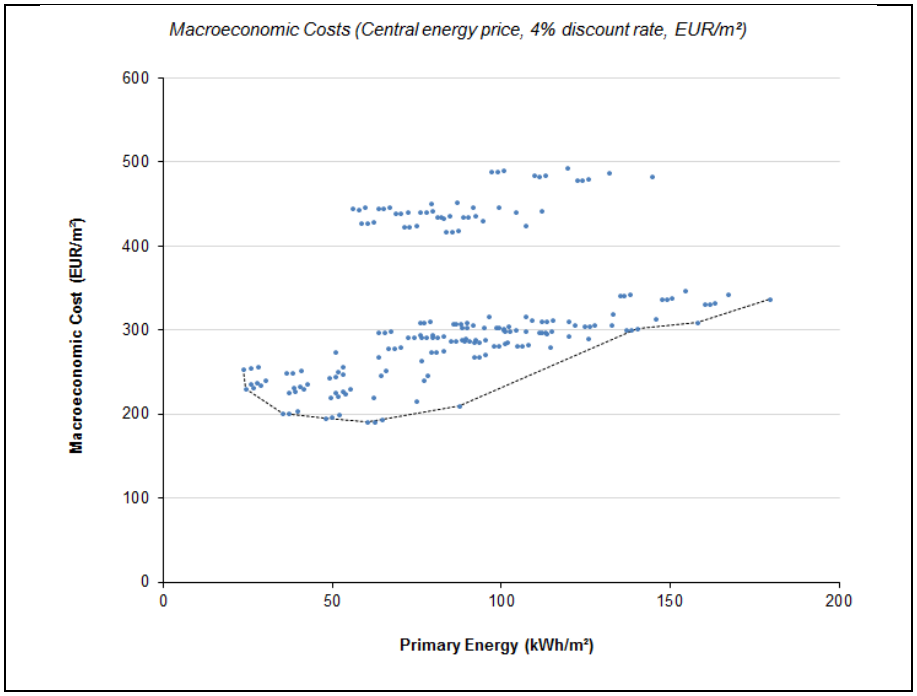

Figure 6.17: Results of the cost-optimal analysis (Primary School, macro-economic costs, 4% discount rate)

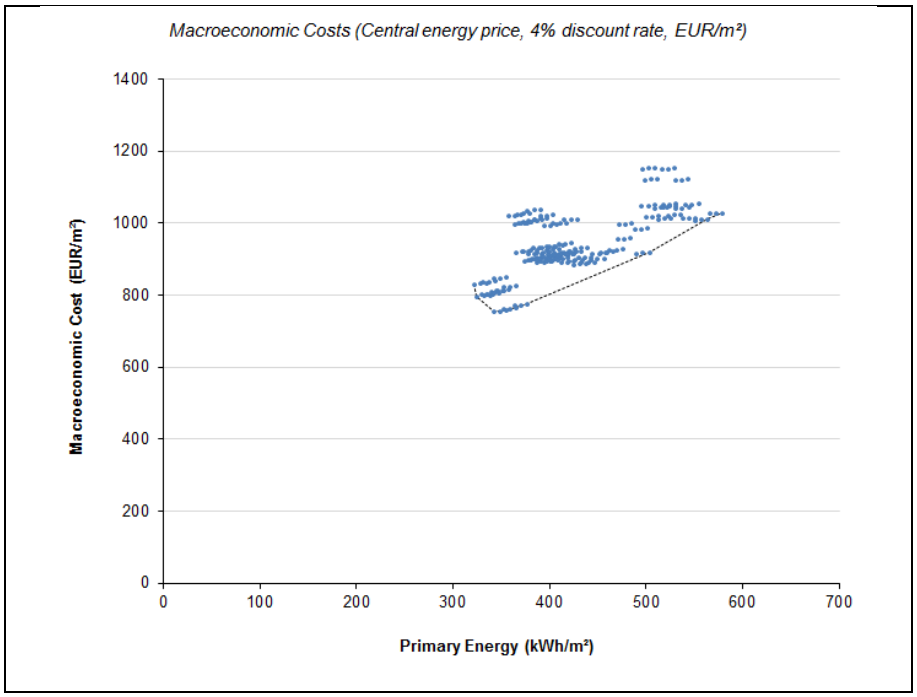

Figure 6.18: Results of the cost-optimal analysis (Hotel, macro-economic costs, 4% discount rate)

From these curves, the economic optimal energy performance level shown in Table 6.4. The sensitivity highlighted alternative options on the cost optimum curve either within 5% of the macroeconomic cost in the central case or the optimum solution in other of the sensitivity analyses.

Table 6.4: Economic Optimal Energy Performance Level Packages

Reference building	*Optimal*	*Sensitivity Range*
Retail	ASHP, Services Package 3,	None.
Office (NV)	ASHP, Services Package 3, 20% PV	ASHP, Services Package 3
Office (AC)	ASHP, Services Package 3, 20% PV	ASHP, Services Package 3
Primary School	ASHP, Services Package 3	ASHP, Services Package 2
Hotel	ASHP, Services Package 3, 20% PV	ASHP, Services Package 3

7. Comparison of Current Regulations and Cost Optimal Level

7.1 New Residential Buildings

Table 7.1 shows the current national regulations compared to the cost optimal sensitivity range described in Section 6. In calculating the overall gap, we have assumed the same weighting for all reference buildings, including results from the previous Residential Report

Table 7.1: Comparison Table, New Dwellings

Reference building	*Cost Optimal Level (kWh/m^2/yr)*	*Current Requirements(kWh/m^2/yr)*	*Current requirements and cost optimal level*
Bungalow	33-139	67	Current requirements are in or below the Cost Optimal Range
Detached house	45-113	55	
Semi-detached house	49-110	54	
Apartment building	69-101	61	
Average	49-116	59	

The requirements for all new dwelling types with the exception of the apartment block are within the cost optimal range. For the Bungalow, Detached House and Semi Detached House the current requirement is between the midpoint of the cost optimal range and the lower bound of the range. In the case of the apartment the current requirement is slightly better than the lower bound of the cost optimal range. This confirms that there is no negative gap between the cost optimal levels and current technical standards, and indeed that the current technical standards are better than cost optimal.

The cost optimal ranges in Table 7.1 have been chosen to represent the range of lowest points on the cost optimal curve as described in Section 7. This facilitates the use of a variety of technical solutions for the range of new dwellings.

The results would be different if the actual build mix was included rather than assuming a similar weighting for all reference buildings. However, the current requirements are within or below the cost optimal range for each building type so the overall outcome would not significantly change.

Plan to address gap for new residential buildings

As the requirements for new dwellings are already in the cost optimal range and are better than the cost optimal level in many cases there is no plan to review the current requirements for new dwellings to achieve cost optimal levels.

The cost optimal calculations will be used to inform the Nearly Zero Energy Buildings plan and review requirements for the NZEB target for 2018 and 2020.

7.2 Existing Residential Buildings – Elemental Measures

For each reference building and improvement measure (including results from the previous Residential Report), Tables 7.2 and 7.3 show the current national regulations compared to the cost optimal level. As different construction types have different technical solutions available for retrofitting, we have considered cavity and hollow block walls separately. In calculating the overall gap, we have assumed the same weighting for all reference buildings.

Table 7.2: Comparison Table, Existing Dwellings, Cavity Walls

Reference building	*Cost Optimal Level (kWh/m^2/yr)*	*Current Requirements(kWh/m^2/yr)*	*Gap*
Bungalow Cavity – Walls	*Cost Optimal Level*	*Current Requirements*	The gap between current requirements and cost optimal is greater than 15%
Detached Cavity – Walls	0.31 W/m^{2}K	0.55 W/m^{2}K	
Semi-Detached Cavity – Walls	0.31 W/m^{2}K	0.55 W/m^{2}K	
Apartment Block Cavity – Walls	0.31 W/m^{2}K	0.55 W/m^{2}K	
Average	**0.31 W/m^{2}K**	**0.55 W/m^{2}K**	
Bungalow Cavity – Roof	0.11 W/m^{2}K	0.16 W/m^{2}K	The gap between current requirements and cost optimal is greater than 15%
Detached Cavity – Roof	0.11 W/m^{2}K	0.16 W/m^{2}K	
Semi-Detached Cavity – Roof	0.11 W/m^{2}K	0.16 W/m^{2}K	
Apartment Block Cavity – Roof	0.11 W/m^{2}K	0.16 W/m^{2}K	
Average	**0.11 W/m^{2}K**	**0.16 W/m^{2}K**	
Bungalow Cavity – Floor	0.15 W/m^{2}K	0.45 W/m^{2}K	The gap between current requirements and cost optimal is greater than 15%
Detached Cavity – Floor	0.15 W/m^{2}K	0.45 W/m^{2}K	
Semi-Detached Cavity – Floor	0.15 W/m^{2}K	0.45 W/m^{2}K	
Apartment Block Cavity – Floor	0.15 W/m^{2}K	0.45 W/m^{2}K	
Average	**0.15 W/m^{2}K**	**0.45 W/m^{2}K**	

Bungalow Cavity – Heating	90% (gas boiler)	90% (gas boiler)	There is no gap between current requirements and cost optimal
Detached Cavity – Heating	90% (gas boiler)	90% (gas boiler)	
Semi-Detached Cavity – Heating	ASHP	90% (gas boiler)	
Apartment Block Cavity – Heating	90% (gas boiler)	90% (gas boiler)	
Average	**90% (gas boiler)**	**90% (gas boiler)**	
Bungalow Cavity – Windows	1.4 W/m^{2}K	1.6 W/m^{2}K	The gap between current requirements and cost optimal is less than 15%
Detached Cavity – Windows	1.4 W/m^{2}K	1.6 W/m^{2}K	
Semi-Detached Cavity – Windows	1.4 W/m^{2}K	1.6 W/m^{2}K	
Apartment Block Cavity – Windows	1.4 W/m^{2}K	1.6 W/m^{2}K	
Average	**1.4 W/m^{2}K**	**1.6 W/m^{2}K**	

Table 7.3: Comparison Table, Existing Dwellings, Hollow Block Walls

Reference building	*Cost Optimal Level (kWh/m^2/yr)*	*Current Requirements(kWh/m^2/yr)*	*Gap*
Bungalow Hollow Block – Walls	0.22 W/m^{2}K	0.35 W/m^{2}K	The gap between current requirements and cost optimal is greater than 15%
Detached Hollow Block – Walls	0.22 W/m^{2}K	0.35 W/m^{2}K	
Semi-Detached Hollow Block – Walls	0.22 W/m^{2}K	0.35 W/m^{2}K	
Apartment Block Hollow Block – Walls	0.22 W/m^{2}K	0.35 W/m^{2}K	
Average	**0.22 W/m^{2}K**	**0.35 W/m^{2}K**	
Bungalow Hollow Block – Roof	0.11 W/m^{2}K	0.16 W/m^{2}K	The gap between current requirements and cost optimal is greater than 15%
Detached Hollow Block – Roof	0.11 W/m^{2}K	0.16 W/m^{2}K	
Semi-Detached Hollow Block – Roof	0.11 W/m^{2}K	0.16 W/m^{2}K	
Apartment Block Hollow Block – Roof	0.11 W/m^{2}K	0.16 W/m^{2}K	
Average	**0.11 W/m^{2}K**	**0.16 W/m^{2}K**	

Bungalow Hollow Block – Floor	0.15 W/m^{2}K	0.45 W/m^{2}K	The gap between current requirements and cost optimal is greater than 15%
Detached Hollow Block – Floor	0.15 W/m^{2}K	0.45 W/m^{2}K	
Semi-Detached Hollow Block – Floor	0.15 W/m^{2}K	0.45 W/m^{2}K	
Apartment Block Hollow Block – Floor	0.15 W/m^{2}K	0.45 W/m^{2}K	
Average	**0.15 W/m^{2}K**	**0.45 W/m^{2}K**	
Bungalow Hollow Block – Heating	90% (gas boiler)	90% (gas boiler)	There is no gap between current requirements and cost optimal
Detached Hollow Block – Heating	ASHP	90% (gas boiler)	
Semi-Detached Hollow Block – Heating	90% (gas boiler)	90% (gas boiler)	
Apartment Block Hollow Block – Heating	90% (gas boiler)	90% (gas boiler)	
Average	**90% (gas boiler)**	**90% (gas boiler)**	
Bungalow Hollow Block – Windows	1.4 W/m^{2}K	1.6 W/m^{2}K	The gap between current requirements and cost optimal is less than 15%
Detached Hollow Block – Windows	1.4 W/m^{2}K	1.6 W/m^{2}K	
Semi-Detached Hollow Block – Windows	1.4 W/m^{2}K	1.6 W/m^{2}K	
Apartment Block Hollow Block – Windows	1.4 W/m^{2}K	1.6 W/m^{2}K	
Average	**1.4 W/m^{2}K**	**1.6 W/m^{2}K**	

We could include the actual build mix rather than assuming a similar weighting for all reference buildings. However, the results are similar, if not the same in most cases, across building types and hence the overall outcome would not change.

There are several cases where the current requirements are greater than 15% from cost optimal. These are discussed below.

- Cavity walls: The standard for renovated cavity walls is 0.55 W/m^{2}K, which is equivalent to a fully insulated 50mm cavity. The cost optimal U-value is 0.31 W/m^{2}K which is a fully filled 100mm cavity. It appears reasonable that for a 50mm cavity, the current standard of 0.55 W/m^{2}K is also cost optimal.
- Solid walls: The standard for renovated solid walls is 0.35 W/m^{2}K. The cost optimal U-value is 0.22 W/m^{2}K which is equivalent to 100mm of internal insulation. We note the sensitivity of the results - for example, the low energy sensitivity has a cost optimum of 0.4 W/m^{2}K which is equivalent to 50mm of internal insulation only and the current technical standard is better than this optimum. The depth of internal insulation to be used in retrofitting is dependent on the impact to the internal floor area and this would need to be taken into account.

- Roofs: The standard for renovated roofs 0.16 W/m^{2}K. The cost optimal U-value is 0.11 W/m^{2}K which is equivalent to 150mm mineral wool insulation quilt between the joists plus 200mm above the joists. In practice, the cost optimal would need to take account of the impact on the usable space between the joists and the rafters and this may restrict the depth of insulation that may be practically installed.
- Floors: The standard for renovated floors is 0.45 W/m^{2}K. The cost optimal U-value is 0.15 W/m^{2}K which is equivalent to 120mm of insulation. For a room with a height of 2.4m, this is equivalent to reducing the room volume by 5% which is on the borderline of acceptability. Such a level of insulation may be dependent on available foundation depth to avoid such impact on room volume.

Plans to address gap for existing residential buildings

Energy performance levels for existing buildings are set on a component basis as set out in Part L of the Building Regulations TGD L Conservation of Fuel and Energy- Dwellings. The component level performance standards in this regulation were last reviewed in 2011. The Department of Environment Community and Local Government is committed to reviewing performance standards for components in light of cost optimal levels.

In comparing cost optimal levels with individual elemental values given in current regulations, there appears to be a significant gap. However, the above explanations have shown there are physical constraints that may make achieving the cost optimal levels impractical. In light of this information and in the context of the next review of the regulations we intend to study the effect on grouping technical measures and assessing the cost optimal points of certain packages.

It is intended as part of the Technical Guidance Document L –Conservation of Fuel and Energy –Dwellings that further analysis of the sensitivities produced for these calculations will be taken into account including low and high energy prices and the investor perspective discount rates. Other influencing parameters such as buildability, available spread of technologies to achieve cost optimal performance and robustness of technologies across all sectors of the residential building stock will also be taken into account.

7.3 Existing Residential Buildings – Packages of Measures

The cost-optimal packages for existing apartment buildings are shown in Table 6.3 in Section 6 above. The cost-optimal packages for other existing residential building types were shown in the original Residential Report.

National regulations state minimum energy efficiency standards for those elements which are replaced or undergo renovation as part of work on existing buildings. The national regulations do not state minimum packages of measures that should be undertaken during any (or major) renovation works. Hence there is no regulatory whole building retrofit package for comparison to the cost-optimal packages.

7.4 Existing Non-Domestic Buildings – Packages of Measures

The cost-optimal packages for existing non-residential buildings are shown in Table 6.4 in Section 6 above.

National regulations state minimum energy efficiency standards for those elements which are replaced or undergo renovation as part of work on existing buildings. The national regulations do not state minimum packages of measures that should be undertaken during any (or major) renovation works. Hence there is no regulatory whole building retrofit package for comparison to the cost-optimal packages.

Capabilities on project:
Building Engineering

Appendix 1: Current Regulations

Table A.1: Relevant Standards for New Residential Buildings

BUILDING ELEMENT	STANDARD	SOURCE
Wall	Maximum average area-weighted U=0.21 Maximum for individual element U=0.6	Building Regulations 2011, Technical Guidance Document L, Table 1, columns 2 and 3
Roof (pitched, insulation at ceiling)	Maximum average area-weighted U=0.16 Maximum for individual element U=0.3	Building Regulations 2011, Technical Guidance Document L, Table 1, columns 2 and 3
Ground floor	Maximum average area-weighted U=0.21 Maximum for individual element U=0.6 (Note: U=0.15 advised for floors with underfloor heating)	Building Regulations 2011, Technical Guidance Document L, Table 1, columns 2 and 3
Window	Maximum average area-weighted U=1.6 Maximum for individual element U=3.0 (Note: based on dwelling where total window area = 25% of total floor area)	Building Regulations 2011, Technical Guidance Document L, Table 1, columns 2 and 3
Thermal Bridging	Adopt ACDs for all key junctions	Building Regulations 2011, Technical Guidance Document L, section 1.3.3.2
Gas boiler	Minimum 90% seasonal efficiency	Building Regulations 2011, Technical Guidance Document L, section 1.4.1.1
Biomass boiler	Minimum 77% seasonal efficiency	Building Regulations 2011, Technical Guidance Document L, section 1.4.2.2
Controls	Automatic control of space heating on the basis of room temperature Automatic control of heat input to stored hot water on the basis of stored water temperature Separate and independent automatic time control of space heating and hot water Shut down of boiler or other heat source when there is no demand for either space or water heating from that source.	Building Regulations 2011, Technical Guidance Document L, section 1.4.3.1
Insulation of pipes, ducts and vessels	All hot water storage vessels, pipes and ducts associated with the provision of heating and hot water in a dwelling should be insulated to prevent heat loss. 50mm factory applied PU-foam for hot water tanks having zero ozone depletion potential and a minimum density of 30 kg/m3 satisfies the criterion for insulation of the hot water tank when installed within the normally heated area of the dwelling.	Building Regulations 2011, Technical Guidance Document L, section 1.4.4.2
MVHR	Minimum Specific Fan Power of 0.8W/litre/sec for continuous supply only and continuous extract only Minimum Specific Fan Power of 1.5W/litre/sec for balanced systems Minimum Heat Recovery Efficiency of 66%	Building Regulations 2011, Technical Guidance Document L, Table 3
All – Maximum Permitted Energy Performance Coefficient	0.4 compared to reference dwelling	Building Regulations 2011, Technical Guidance Document L, section 1.1.2
All - Maximum Permitted Carbon Performance Coefficient	0.46 compared to reference dwelling	Building Regulations 2011, Technical Guidance Document L, section 1.1.2

Table A.2: Relevant Standards for Existing Residential Buildings – Replacement of Individual Elements

BUILDING ELEMENT	**STANDARD**	**SOURCE**
Cavity Wall	U=0.55	Building Regulations 2011, Technical Guidance Document L, Table 5, column 2
Solid Wall	U=0.35	Building Regulations 2011, Technical Guidance Document L, Table 5, column 2
Pitched roof, insulation at ceiling	U=0.16	Building Regulations 2011, Technical Guidance Document L, Table 5, column 2
Ground Floor	U=0.45	Building Regulations 2011, Technical Guidance Document L, Table 5, column 2
Window	U=1.6	Building Regulations 2011, Technical Guidance Document L, Table 5, column 2
Gas/oil boiler	Minimum 90% seasonal efficiency	Building Regulations 2011, Technical Guidance Document L, Section 2.2.2
Controls	Time and temperature control for room and hot water cylinder, boiler interlock.	Building Regulations 2011, Technical Guidance Document L, Section 2.2.3
Insulation of pipes, ducts and vessels	All hot water storage vessels, pipes and ducts associated with the provision of heating and hot water in a dwelling should be insulated to prevent heat loss. Equivalent to 50mm factory applied PU-foam for hot water tanks.	Building Regulations 2011, Technical Guidance Document L, Section 2.2.4