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BRE Client Report

ECO3 Deemed Scores Methodology

Consultation Version

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Making a positive difference
for energy consumers

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1 Introduction

The Energy Company Obligation (ECO) is a government energy efficiency scheme in Great Britain. Under ECO, obligated energy suppliers must install energy efficiency measures in domestic properties, and the related savings can be counted towards their obligations.

The scheme began in April 2013, and over time it has been amended. From 1 April 2017 to September 2018 (ECO2t) the scheme used 'deemed scores' to assign carbon and cost savings from the energy efficiency measures installed by each supplier. These deemed scores were based on the type of measure being installed, the typology of the dwelling, the number of bedrooms in the dwelling and the main heating fuel of the property.

This report outlines the methodology employed in the creation of a new set of deemed scores which are proposed for use in the 2018-2022 phase of ECO, which will be known as ECO3. This has been produced to be published as part of the consultation on these scores, and the approach for using them in ECO3.

The methodology for development of these scores closely follows that used for the ECO2t scores, but has been improved and adjusted in some areas. The changes from the ECO2t approach are outlined in Appendix A.

The deemed scores and methodology were produced on behalf of Ofgem by Jack Hulme, Deborah Morgan, John Henderson, Tad Nowak and Peter Iles of BRE.

2 Methodology employed in calculation of deemed scores

The key objective in this development is to produce deemed scores for use in a variety of different situations. The savings are calculated for various categories of measure installations, where the scores are significantly different and representative of the savings that ECO measures will achieve. At the same time, an additional objective has been to ensure they remain reasonably unambiguous, to reduce the risk of misidentification, to make sure they are easy to use and to make sure they are easy to verify.

In order to achieve this, different deemed scores considering the main heating fuel of a dwelling are produced for different dwelling archetypes. Each archetype is defined by the dwelling typology and the number of bedrooms. The detailed definition of these archetypes include dwelling dimensions, typical heating systems and insulation levels (U-values).

In ECO2t, deemed scores related to both carbon savings and cost savings were developed, in line with the obligations related to ECO. For the ECO3 deemed scores, only cost savings have been developed.

2.1 Dwelling types/sizes

Floor, wall, roof and window dimensions have been derived from the English Housing Survey (EHS) 2013 data[1]. Scottish and Welsh data is available, but differing survey design and conventions make integration difficult. However, previous BRE work[2] allows comparisons to be made in key areas, in particular the key characteristic of dwelling floor area, which indicates that defaults derived from the EHS are able to represent the stock of these nations reasonably well. Although the climate in different regions is different, these calculations assume a standardised climate, as is the case for SAP ratings.

The EHS collects the number of bedrooms and dimensions of dwellings. To ensure the number of archetypes remained manageable to use, while also giving a fair estimation of size, the number of typologies defined have been controlled in a number of ways.

For example, especially large and small dwellings are rarer. Where there are less than 30 dwellings in the sample, the results are unreliable and in these cases data have been combined. For larger numbers of bedrooms, data have been combined to give x+ bedrooms (for example data from 5 or more bedrooms for semi-detached houses was combined to give a 5+ bedrooms category). Similarly, for some dwelling types where the 1 bedroom size was rare (for example in detached properties), the data have been combined to give a 2- (2 or fewer) bedrooms category. As a result, the deemed scores may be

[1] Although EHS 2015 data is available for the production of ECO3 deemed scores, dwelling dimensions are unlikely to show any significant change from the EHS 2013 data used in the production of the ECO2t deemed scores. The EHS 2013 dwelling dimensions data is, therefore, also used for the ECO3 deemed scores.

[2] Housing in the UK: National comparisons in typology, condition and cost of poor housing. Piddington, Garrett and Nowak. BRE Trust 2013.

applied to all sizes of the different types of dwellings based on a robust analysis of floor area and number of storeys data relating to houses with the complete range of number of bedrooms, extracted from the EHS. Following analysis of wall, floor and window data from both the EHS and standard dwellings, gross wall areas have been calculated from the dwelling perimeters and window areas have been calculated using the RdSAP equations.

For each dwelling type and size, average physical characteristics of all dwellings in the stock have been used. On an individual basis some properties have larger or smaller floor areas or other characteristics, however, these archetypes provide reasonable approximations of average savings across all dwellings of each type within the stock as a whole.

For flats, there are a large variety of configurations. The deemed scores archetypes for flats have, therefore, been simplified into single and multi-level flats (of different sizes) with either 2 or 3 walls. In all cases, one wall has been assumed to be a reduced heat loss wall facing a corridor, while the other walls have been assumed to be party or external walls. A top floor flat is also used for the calculation of savings for all flats. Loft insulation savings are generally only applicable to top floor flats, supporting the use of this type. Furthermore, previous work has shown that there is only a small difference in savings between top, mid, and bottom floor flats following the installation of *other* types of measures (the top floor flat gives savings which are intermediate compared with bottom and mid-floor). Additionally, savings for 2 and 3 external wall flats only have been provided (flats with one and four external walls are relatively rare and have therefore not been included as separate scores).

The mean total floor areas for each of the main dwelling archetypes are shown in Table 1 below.

2.1.1 Park Homes

For Park Home External Wall Insulation measures, two types of park home have been specified: single and double width. This is described further in section 2.5.10. When selecting a deemed score for all other improvements to Park Homes (i.e. any measure that is not a Park Home External Wall Insulation measure), detached bungalows should be used as a proxy for a Park Home.

Table 1: Dwelling floor areas used in deemed scores.

Dwelling Type	No. of bedrooms	Mean total floor area (m^2)
1) Mid-terrace House 2) End-terrace House	1	51.0
	2	69.4
	3	88.4
	4	127.8
	5 +	180.5
3) Semi-detached House	2 -	72.5
	3	89.2
	4	134.6
	5 +	191.4
4) Detached House	2 -	99.7
	3	115.7
	4	154.9
	5	228.7
	6 +	320.2
5) Semi-det. or End-terrace Bungalow 6) Mid-terrace Bungalow	1	45.7
	2	58.9
	3 +	87.1
7) Detached Bungalow	2 -	75.9
	3 +	111.9
8) Flats on one level (two or three walled)	1	45.7
	2	65.6
	3 +	86.5
9) Flats on multi levels – i.e. maisonettes (two or three walled)	2-	73.8
	3+	100.7

2.2 Base cases – heating systems and typical insulation level

Insulation savings are significantly affected by the primary heating system in a dwelling, its efficiency and its fuel. Calculations for insulation savings have therefore been undertaken for a variety of heating systems. Savings from insulation have been calculated using an average or typical efficiency and responsiveness for each type of heating system. Similarly, an average insulation level is used in the base position for heating system improvements. As a result the deemed score calculated for each measure is unlikely to match the actual saving for a specific installation in a given dwelling but will be an average or typical saving representative for the stock.

In Table 2 and Table 3, heating systems data from the English Housing Survey have been combined into broad categories where they would give similar savings. For example 'gas central heating' includes systems with both regular and combi boilers, and 'electric storage' includes both 7 and 10 hour off-peak tariffs. Typical 'base cases' for the most common heating types were then defined, and savings calculated for these common heating types. In order to maintain a reasonable number of deemed scores, specific scores were not calculated for the rarest heating fuels (e.g. bottled propane, wood etc.).

Table 2: Heating system types in the housing stock. Those in BOLD are the common heating types used in the deemed scores

	% of housing stock	Number in housing stock (thousands)	Assumed system efficiency (see Table 5)
	Central & Storage Heating		
GAS (MAINS)	***83.9%***	***19519***	***81%***
ELECTRIC STORAGE	***6.1%***	***1414***	***100%***
OIL	***3.6%***	***838***	***81%***
BULK LPG	***0.5%***	***113***	***81%***
SOLID FOSSIL	***0.4%***	***82***	***60%***
ELECTRIC	***0.3%***	***77***	***100%***
Bottled Propane	0.2%	35	
Wood	0.12%	27	
Heat pumps & other	0.08%	18	
	Room Heating		
ELECTRIC	***2.1%***	***486***	***100%***
GAS	***0.6%***	***150***	***60%***
SOLID FOSSIL	***0.2%***	***45***	***50%***
Bottled Propane	0.04%	8	
Wood	0.02%	4	
Oil	0.01%	2	

Table 3: Details of heating types used in the deemed scores (in BOLD in Table 2)

Central & Storage Heating
Gas (mains) boiler with radiators and hot water cylinder
Electric Storage Radiators with electric dual immersion heater
Oil boiler with radiators and hot water cylinder
Bulk LPG boiler with radiators and hot water cylinder
Solid fossil fuel boiler with radiators and hot water cylinder
Electric boiler with radiators and hot water cylinder
Room Heating
Electric room heaters with electric immersion heater
Gas room heaters with electric immersion heater
Solid fossil fuel room heaters with electric immersion heater

Taking account of the efficiency, fuel cost and responsiveness of the system (see examples of rationale as outlined in Appendix B), rare heating types may be represented using the proxy heating systems identified in Table 4. Please note that these are calculated using June 2017 fuel prices, so some proxies have changed for the ECO3 deemed scores.

The base case parameters were derived from a variety of sources. Table 5 outlines the values used, with a brief description of its source, to develop a 'typical dwelling' of the building stock in 2017/18. The various data sources are used to develop typical values (e.g. a weighted average) for each parameter, and an extrapolated value is derived by using time series of data.

For the purposes of the ECO3 deemed scores, the U-values used are those published in the latest version of the RdSAP specification (version 9.93) which includes revised U-values for solid and cavity walls.

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Table 4: Proxy heating systems to be used for rare heating types

Pre-main heating source	Proxy	Has proxy changed from ECO2t?
Air/water heat pump central heating	Gas RH	Yes
Air-oil hybrid heat pump	Gas RH	Yes
Biomass district heating system	Gas CH	No
Biomass/wood central heating	Solid fossil CH	No
Biomass/wood room heating	Solid fossil RH	Yes
Bottled LPG back boiler to radiators	Elec boiler CH	Yes
Bottled LPG central heating**	Elec boiler CH	Yes
Bottled LPG fire with back boiler	Elec RH	No
Bottled LPG range cooker boiler	Elec RH	No
Bottled LPG room heaters**	Elec RH	No
Electric ceiling heaters	Elec RH	No
Electric underfloor heaters	Elec Storage Heaters	No
Electric warm air system	Elec boiler CH	No
Gas back boiler to radiators*	Gas RH	No
Gas district heating system	Gas CH	No
Gas fire with back boiler*	Bulk LPG CH	Yes
Gas range cooker boiler	Gas RH	No
Gas warm air system	Gas CH	No
GSHP central heating	Gas RH	Yes
GSHP district heating system	Gas CH	No
LPG back boiler to radiators	Bulk LPG CH	Yes
LPG boiler - Special Condition 18***	Gas CH	No
LPG district heating system	Gas CH	No
LPG fire with back boiler	Elec RH	No
LPG range cooker boiler	Bulk LPG CH	Yes
LPG room heaters	Bulk LPG CH	Yes
LPG warm air system	Bulk LPG CH	No
No heating present	Elec RH	No
Oil district heating system	Gas CH	No
Oil range cooker boiler	Gas CH	Yes
Oil room heaters	Gas RH	Yes
Oil warm air system	Oil CH	No
Solid fossil fuel back boiler to radiators	Solid fossil CH	No
Solid fossil fuel fire with back boiler	Solid fossil RH	No

* where the measure being installed is not a heating measure
** where the measure being installed is not a heating measure into a park home
*** only applies if the property receives LPG at mains gas prices

Table 5: Values and sources of data used in the ECO3 Deemed Scores base position.

Parameter	**Value**[3]	**Data sources**[4,5,6,7,8] **values extrapolated to year 2017/18**
Loft U-value	0.36 W/m²K	EHS 2013 and Domestic Energy Fact File (DEFF) data to 2011
Wall U-values for heating measures: Wall U-value for other measures:	Solid wall 1.60 W/m²K Cavity wall 0.71 W/m²K 0.97 W/m²K	Annual data from EHS and 'DECC National Statistics, Domestic Green Deal, ECO and Insulation Levels in GB' report (Sept. 2015), RdSAP v9.93.
Window U-value	2.2 W/m²K	EHS 2013 with DEFF data up to 2007 shows nearly all homes have double glazing. This value is between basic double glazing (2.8) and the replacement standard (1.6)
Hot water cylinder insulation	80mm	Depth of insulating jacket equivalent (using adjusted foam insulation depths) from EHS 2013 data
Central heating seasonal efficiency	Gas, LPG & Oil 81% Solid fossil 60%	EHS 2013 and DEFF data to 2011 Estimate from SAP
Room heating efficiency	Gas 60% Solid fossil 50%	Estimate from SAP Estimate from SAP
Heating controls	Timer, Roomstat & TRVs	EHS 2013 and previous EHS data indicates this as the most common controls combination.
Electric storage heating controls	automatic	Estimate using EHS data
Proportion of low energy lighting	40%	Data from EHS 2013, the Energy Follow-Up Survey 2011 and the English Household Electricity Use Study 2010/11

3 Note that these values are those used for the base position for measures that do not directly affect these elements of the property. Different 'before' positions, relevant to specific measures, are used for individual scores. See section 2.4 below.
4 BRE analysis of English Housing Survey data
5 https://www.gov.uk/government/statistics/united-kingdom-housing-energy-fact-file-2013
6 https://www.gov.uk/government/statistics/green-deal-energy-company-obligation-eco-and-insulation-levels-in-great-britain-detailed-report-to-june-2015
7 https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011
8 http://www.energysavingtrust.org.uk/sites/default/files/reports/PoweringthenationreportCO332.pdf

2.3 Fuel prices

Fuel prices current in the Product Characteristics Database (PCBD), and used for the estimate of current costs on Energy Performance Certificates at the time the deemed scores were calculated (June 2017[9]) were used in preference to the values in SAP Table 12. These prices can be located at www.bre.co.uk/sap2012/.

2.4 Average Percentage Of Property Treated

For ECO3, the deemed scores are adjusted to account for an average ‘Percentage of Property Treated’ (POPT). This means that ‘POPT’ will not need to be calculated after the installation of a measure to adjust the standard deemed score. The method used to develop the average ‘POPT’ for each measure type is shown below. The method described below is that as used in the calculation of the POPT averages, and is not intended to describe how measures should or should not be installed for any particular property.

For Cavity Wall Insulation, data from the EHS was used to estimate the average POPT. The areas of unfilled cavity wall (i.e. areas with no existing cavity wall insulation) were the only areas to be assumed treatable. Areas that are immediately behind and above conservatories were assumed to be non-treatable, as were all areas that were covered with tiles, timber or plastic panels. Similarly, all areas of non-cavity wall in the dwelling were assumed to be non-treatable. Based on this, an average cavity wall treatable area was outputted for all properties. A similar approach was followed for the calculation of the average POPT for solid wall insulation measures, with the assumption that all solid wall areas are assumed to be treatable regardless of the existence of conservatories and coverings.

For the calculation of the average POPT value for the flat roof measure, all flat roof areas were considered to be treatable. Based on EHS data, the roof type was identified and the flat roof type areas (i.e. excluding pitched, mansard and chalet types) were calculated using the planar roof area. The proportion of roof that is flat was calculated and the average flat roof treatable area was produced. In the case of the average POPT for loft insulation, a similar approach was followed, by selecting only the pitched roof type. When a room in roof was present the loft treatable area was reduced by 59% in line with the assumed floor area of rooms in roofs. The average flat and loft treatable area was then calculated.

To calculate the average POPT value for underfloor insulation all suspended timber ground floors were assumed to be treatable (and uninsulated, as the EHS does not collect data on this). The number of rooms with and without suspended timber floors which are in contact with the ground were identified using the EHS. The proportion of rooms with suspended timber floor was then calculated, under the assumption that all ground floor rooms are the same area, and used as the average treatable area.

For the average POPT value for the central heating system replacement measure, data from the Energy Follow-Up Survey (EFUS) 2011 was used. Large rooms which might be expected to be heated (living rooms, dining rooms, bedrooms & studies) in which the central heating system was not present were identified. The proportion of the dwelling that was not heated by the main heating system was then

[9] PCDF fuel table 191 (data for 15/Jun/17)

calculated as the number of main rooms where the central heating system was not present divided by the total number of habitable rooms. Finally, the unheated dwelling floor area was calculated and used to identify the average dwelling floor area which is treatable for all properties.

2.5 Specific measures, 'before' and 'after' values

This section presents the 'before' and 'after' values for specific installations of measures used in the calculation of the ECO3 deemed scores.

2.5.1 Solid wall insulation

Savings were calculated for the improvements in U-value indicated in Table 6. These savings may be applied to internal or external wall insulation on either solid or cavity walls. The before and after U-values are taken from Section S5.1 of RdSAP (SAP 2012 v9.93) which assume a typical insulation material.

The scores calculated for ECO3 do not include a base starting U-value of 2.1, as was produced for the ECO2t scores. This reflects the changes in the U-value of uninsulated solid walls in the latest version of RdSAP, in which the assumed U-value of these walls is reduced to 1.7. Although some other types of walls (for example, pre-1950 timber frame dwellings) were able to use the 2.1 value under ECO2t, the relative scarcity of these property types does not justify the retention of a score for a starting value of 2.1.

Table 6: Assumed U-values for solid wall insulation

	Insulation thickness				
	50mm	100mm	150mm	200mm	Variable
Starting U-value (W/m²K)	End U-values (W/m²K)				
1.7	0.55	0.32	0.23	0.18	0.3
1.0	0.45	0.28	0.21	0.17	0.3
0.6	0.35	0.24	0.18	0.15	0.3
0.45	0.3	0.21	0.17	0.14	-

2.5.2 Cavity wall insulation

Savings were calculated for three construction age bands using standard U-value calculation methodology applied to the relevant construction (e.g. brick/brick, brick/block with an average cavity width derived by BRE from installer data, as used for the CERT scheme). These age bands are associated with significant changes in wall U-values due to the introduction of successive new Building Regulations, and are not based on RdSAP assumptions for cavity walls. For cavity wall insulation with a standard thermal conductivity of 0.040 W/mK the U-values are as shown in Table 7 below.

Table 7: Assumed base U-values for cavity wall dwellings as used in the calculation of CWI savings

Year of construction	Uninsulated U-value (W/m²K)	Insulated U-value (W/m²K)	Weighting
(1) Pre 1976	1.435	0.478	73%
(2) 1976 - 83	1.003	0.417	13%
(3) post 1983	0.694	0.343	15%

The U-values for the three age bands are combined to give one uninsulated and one insulated U-value regardless of the age band of the wall. This is consistent with latest research which shows wide variation in measured U-values for each age band. The three values are averaged using the weightings in the table, which are derived from the number of uninsulated cavity wall dwellings for each age band in the national stock.

The method is then repeated using cavity wall insulation with a thermal conductivity of 0.033 W/mK and 0.027 W/mK. This results in the U-values in Table 8 below for all three cavity wall insulation deemed score variants. The resulting U-values after weighting by age band are also given in Table 8.

Table 8: U-values for Cavity Wall Insulation

Thermal conductivity (W/mK)	Weighted average 'before' U-value (W/m²K)	Weighted average 'after' U-value (W/m²K)
0.040	1.272	0.451
0.033	1.272	0.393
0.027	1.272	0.338

Party cavity wall insulation savings were calculated using the standard SAP U-values. The U-value assumptions are shown in Table 9 below.

Table 9: U-values for Cavity Wall Insulation of party walls

	'before' U-value (W/m²K)	'after' U-value (W/m²K)
Party wall insulation	0.5	0.2

Note that flats and maisonettes are assumed to be constructed in such a way as to avoid a thermal bypass. Therefore, there are no scores for party cavity wall insulation for these property types.

2.5.3 Loft insulation

During the previous CERT scheme, a case was made that during 'top-up' of loft insulation, the additional savings from correction of the existing insulation was not taken account of. A survey of 200 lofts was commissioned, collecting data on 'disturbances' such as missing or compressed insulation, and also the fraction of wood (the joists), area of loft hatches and water tanks. From this data, modified U-values were derived, resulting in an increase to the scores. These deemed scores are calculated using these modified U-values to take account of these additional savings, resulting in improved scores.

These loft insulation savings may be used for both roof joist level and rafter-level loft insulation, which is assumed to give similar savings.

The starting U-values were determined from examination of English Housing Survey data, and assessment of the effect on the final U-value. This is shown in Figure 1 and Figure 2 below.

Figures 1 and 2 show:

a) the reduction in savings with existing depth of insulation. This graph indicates very little increase in savings when insulating from a depth above about 125mm,
b) the percentage of homes with different existing depths. This indicates a significant number with 100mm. This is a common depth, being the normal depth of joists, and so usually the maximum level while still allowing storage on the joists without compressing the insulation.

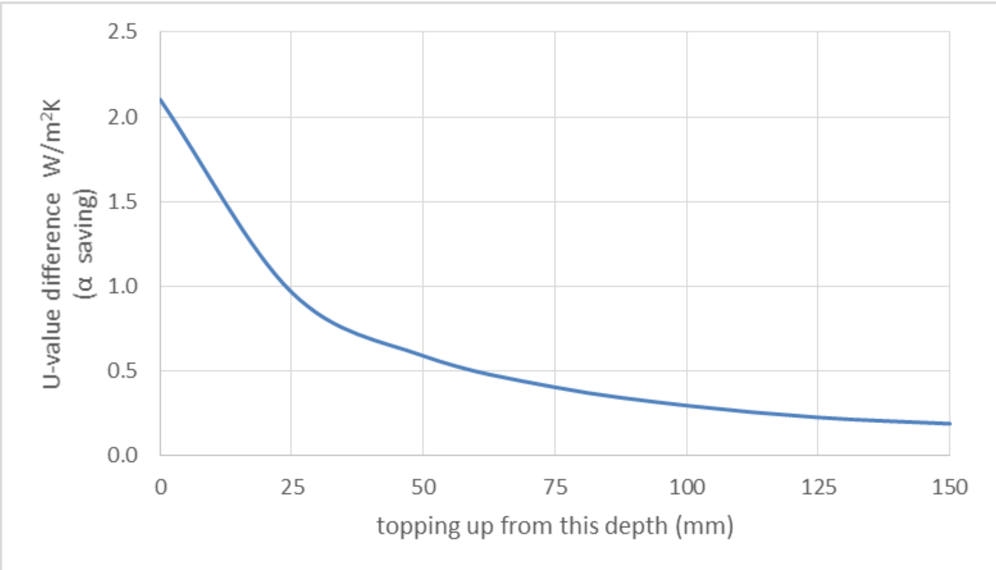

Figure 1: Difference in loft insulation U-value from topping up from different depths.

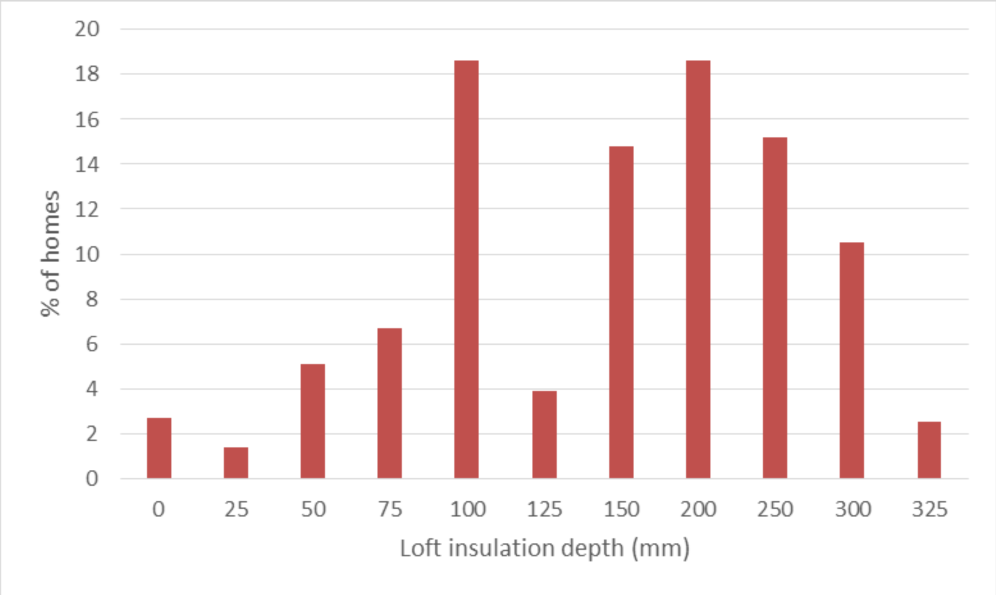

Figure 2: Distribution of loft insulation depths within England.

On the basis of this data, a weighted average U-value of depths in the stock of 100mm or less, and of 125mm or more, were chosen as the 'before' cases (EHS data was recorded in 25mm intervals, any depths between were rounded). The post-insulation U-value assumes a thickness of 270mm, which reflects the requirements of Building Regulations. Table 10 shows the U-values used in the calculations.

Table 10: U-values for loft insulation measure variants

	U-value before (W/m^2K)	U-value after (W/m^2K)
100mm or less of existing insulation	0.727	0.185
125mm or more of existing insulation	0.317	0.185

2.5.4 Room-in-roof insulation

For the ECO3 Deemed Scores, a review of 'room in the roof' (RiR) base assumptions has been made. This review has considered the different sizes of RiRs, and the base U-values of RiRs.

The size of a RiR is constrained by the roof sloping on two, three or four sides. In order to calculate the size of each of the elements of a RiR, RdSAP requires the room floor area (as a minimum) to be measured, and a formula is applied based on this to estimate the areas of the other elements. However, measurement of the floor area is not considered suitable for deemed scores in ECO, and EHS and other data does not directly record the floor area of RiRs (only their presence and some information on their type and age). Instead, data on the *type* of RiR, which is collected by the EHS, is used in order to estimate floor area.

Analysis of EHS data identified two different types of RiR:

a) Those with no dormer windows (e.g. 'Velux' type conversions), or with small 'standard' dormer windows
b) Those with large 'Roof Extension' or 'Box Dormers'. Typically these would be at the rear of the property only, but in some cases they would also extend to the front elevation

It is then assumed that RiRs of type a) typically have a floor area of 50% of the floor below. Those of type b) are split into two categories, depending on whether there is a roof extension or box dormer on one or two elevations. RiRs with either of these elements on one elevation are assumed to have a floor area of 75% of the floor area below. RiRs with these on two elevations, are assumed to have a floor area of 95%.

Using these assumptions, we can produce an estimate of the floor area of all RiRs using the EHS data on the distribution of these types of RiR in the stock as shown in Table 11. This produces an average floor area for RiRs of 59% of the area of the floor below.

Table 11: Assumptions used in estimating size of rooms-in-roof.

Dormer type of room-in-roof	Distribution of room-in-roof type in housing stock (EHS data)[1]	Assumed proportion of floor area occupied by room-in-roof
No dormer or standard dormer	68%	50%
Front or back roof extension dormer	24%	75%
Front and back roof extension dormer	7%	95%
All room-in-roofs	100%	**Weighted average = 59%**

This value is used to calculate a RiR floor area for each of the ECO3 archetypes, which can then be used within the RdSAP calculations to produce the areas of each of the RiR heat loss elements (RiR walls & roof).

EHS data on ages can also be used to assign U-values to these elements. The EHS collects data on the age of properties for 'as-built' RiRs, and an estimated age of loft conversions for converted RiRs. These

[1] Note that there is a 1% error due to rounding

two pieces of information are combined to produce the age of a RiR, which can then be matched with the corresponding U-value for each element from the RdSAP table. A weighted average U-value, representative of RiRs of all ages, is then be produced using the EHS data on the distribution of RiRs in each age band. The results of this analysis is shown in Table 12 below.

Table 12: U-values for loft insulation

Age of room in roof	Total number of dwellings	U-value of elements (using RdSAP Table S10)
Pre 1966	1,068,000 35.40%	2.30
1967 - 1975	233,000 7.70%	1.50
1976 - 1982	160,000 5.30%	0.80
1983 - 1990	274,000 9.10%	0.50
1991 - 1995	214,000 7.10%	0.35
1996 - 2002	324,000 10.70%	0.35
2003 - 2006	260,000 8.60%	0.30
2007 - 2012	368,000 12.20%	0.25
Post 2012	112,000 3.70%	0.18
All dwellings with RIR	3,014,000 100.00%[10]	**Weighted average 1.14**

[10] This total percentage allows for a 0.02% error due to rounding.

Based on this analysis, the ECO3 deemed scores for RiR insulation have been produced using the U-values shown in Table 13 below. The 'after' U-values are based on Building Regulations PartL1B Table 3, assuming an insulation depth of 270mm at loft and ceiling (modified to allow for the 'disturbances' as described under 'Loft insulation').

Table 13: U-values for Room in Roof insulation.

	U-value (W/m^{2}K)	
	before	after
Ceiling	1.14	0.185
Walls	1.14	0.3
Residual	0.36	0.36

2.5.5 Flat roof insulation

Savings were calculated using the standard SAP U-value for an uninsulated roof and insulating to Building Regulations Approved Document Part L1B Table 3 requirements. The U-values used for flat roof insulation are shown in Table 14 below.

Table 14: U-values for flat roof insulation.

U-value before (W/m^{2}K)	U-value after (W/m^{2}K)
2.3	0.18

2.5.6 Underfloor insulation

Savings were calculated for insulating a suspended wooded floor using the U-values shown in Table 15 below. The 'before' U-value for each of the dwelling types/sizes was derived from a standard calculation for wooden timber ground floors (derived from the floor area and perimeter of external walls). For the 'after' case the Building Regulations Part L1B Table 3 requirement of 0.25 W/m^{2}K was used.

Table 15: U-values for floor insulation.

U-value before (W/m^{2}K)	U-value after (W/m^{2}K)
Suspended wooden floor U-value calculation (depends on the area and perimeter so is a different value for each dwelling type and size, varying from 0.46 to 0.79 W/m^{2}K for a suspended timber floor)	0.25

2.5.7 Draught-proofing

Savings were calculated using a 'before' case of 0%, and an 'after' case of 100% draught-proofing.

2.5.8 Glazing

Savings from glazing were calculated for upgrading windows to a U-value of 1.6 W/m^{2}K (the standard required in Building Regulations Approved Document Part L1B Table 1), from two base cases:

(a) Single glazed windows

(b) Double glazed windows, typical for the existing stock as defined in 'base cases' (table 2 in section 2.2).

The U-values used in these calculations are shown in Table 16 below.

Table 16: U-values for glazing upgrades

Before	after
Single glazing U-value: 4.8 W/m^{2}K 0% draughtsealing	Double or triple glazing U-value: 1.6 W/m^{2}K 100% draughtsealing
Double glazing U-value: 2.2 W/m^{2}K 100% draughtsealing	Double or triple glazing U-value: 1.6 W/m^{2}K 100% draughtsealing

2.5.9 High performing doors

Savings from high performing doors were calculated for improving the doors from a standard U-value as given in RdSAP for pre-1976 age bands, to that required by the Building Regulations Approved Document Part L during a refurbishment. This can be applied to doors with areas of glazing since the same Part L minimum requirements apply (n.b. the ECO2t measures table distinguishes between doors with less than 60% and greater than 60% glazing, which give the same savings, but with different lifetimes). The U-value assumptions are shown in Table 17 below.

Table 17: U-values for door improvements

U-value before (W/m^{2}K)	U-value after (W/m^{2}K)
3.0	1.8

2.5.10 Park home insulation

Although many sizes of Park Homes may be found, two common types are found which can be described as either "single" or "double" types. Both are typically 12 metres long and either 3 or 6 metres wide. Savings have been calculated for these two sizes as shown below in Table 18:

Table 18: Park Home dimensions

	Size	Floor area (m^2)
Park Homes	single	36
	double	72

For ECO3, the assumptions on the unimproved position of Park Homes were reviewed and revised, with consequential changes to the pre-installation position and the achieved post-insulation position. Developing 'before' U-values for park home insulation measures requires a different methodology than for other measures, as there is limited data available to come to a 'typical' park home. Combining data from the relevant British Standard for park homes (BS3632 Residential park homes – Specification), the RdSAP age bands and various studies and investigations of park homes suggest the 'before' U-values outlined in Table 19 are a reasonable approximation of a typical park home.

The 'after' position assumes an upgrade to add a thermal resistance of 0.695, a level which internal BRE work considers to be achievable, and which also brings the elemental U-values of the Park Home up to approximately the level of the BS3632:1995 standard. The floor U-values are dependent on whether the single or double park home is selected.

Table 19: U-values used for Park Home Insulation

	Standard Park Home Insulation	
	U-value before (W/m^2K)	U-value after (W/m^2K)
Roof	0.6	0.42
Wall	1.2	0.65
Floor	0.73 (single)/0.92 (double)	0.52

2.5.11 Broken boiler, first time central heating, boiler upgrade and repair

Savings have been calculated for installations and repairs of boiler systems. These include the replacement of a broken heating system, the installation of a central heating system where there was none before ('first time central heating'), upgrading an inefficient boiler system to one using the same fuel, upgrading an inefficient boiler system to one using a different fuel, and the repair of a broken heating system. The main assumptions used for these calculations are shown in Table 20 below.

Table 20: Boiler measure assumptions

Measure	Before heating system	Before controls	After heating system	After controls
Broken boiler replacement	Electric Room Heaters	N/A	All types	With and without controls
Upgrade of boiler	All boilers	With and without controls	All types	With and without controls
First time CH	all room heaters, storage heater, back boiler (not to radiators)	With controls (as applicable)	All types	Without controls
Broken boiler repair	Electric Room Heaters	N/A	Gas, LPG, Electric, Biomass, GSHP, ASHP.	With and without controls

The efficiencies of the 'before' and 'after' heating systems, the assumed controls and the hot water source for boiler measures are shown in Table 21 below.

Table 21: Replacement heating system assumptions

before

	Controls:	Hot water from:	efficiency
Gas central heating	timer, roomstat, TRVs	boiler	72%
Electric storage heating	automatic	dual immersion	100%
Oil central heating	timer, roomstat, TRVs	boiler	81%
LPG central heating	timer, roomstat, TRVs	boiler	72%
Solid fossil central heating	timer, roomstat, TRVs	boiler	60%
Electric boiler central heating	timer, roomstat, TRVs	boiler	100%
Electric room heating	thermostat	immersion	100%
Gas room heating	thermostat	immersion	60%
Solid fossil room heating	none	immersion	50%
Gas back boiler	appliance thermostat	back boiler	50%
Gas back boiler and radiators	appliance thermostat	back boiler	66/56%*

*winter/summer efficiency

after

	Controls (where installed):		
Gas central heating	timer, roomstat, TRVs	boiler	90.3%
LPG central heating	timer, roomstat, TRVs	boiler	90.3%
Biomass central heating	timer, roomstat, TRVs	boiler	65%
Heat pump central heating	timer, bypass, TRVs	system	see below
Electric boiler central heating	timer, roomstat, TRVs	boiler	100%

For boiler upgrades, the 'before' efficiency of gas and LPG boilers used for the ECO3 scores have been reviewed and revised compared to ECO2t. The efficiencies of other boilers remain unchanged. The new gas and LPG boiler scores are based on the mean efficiency of all non-condensing boilers from the EHS (72%). The 'after' efficiency of 90.3% for these boilers is the sum of the average SEDBUK/PCDB efficiency for new boilers of 88% plus an additional 2.3%[11]. This represents the fact that all boilers must have an efficiency of 92% by the ErP metric[12] as well as an increase in efficiency from the additional energy efficiency measure, which are required to be installed alongside new combination boilers as part of the Boiler Plus[13] requirements announced in December 2017. We have assumed that the typical energy efficiency measure to be selected would be a weather or load compensator.

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[11] Data from HHIC indicates that ~78% of all new boilers are combination boilers. The 2.3% uplift is calculated as the uplift for a load / weather compensator in SAP 2012 (3%) multiplied by 0.78.

[12] SEDBUK values are used in SAP, and this SEDBUK value is equivalent to the 92% ErP value outlined in the Boiler Plus regulations.

[13] https://www.gov.uk/government/consultations/heat-in-buildings-the-future-of-heat

Table 22: Sources of assumed efficiencies used for 'after' case i.e. new central heating systems.

Gas and LPG Central Heating	PCDB data and uplift for assumed installation of load / weather compensator for combis
Biomass central heating	from SAP for HETAS approved appliances
Heat pumps	from recent field trials (see Table 21)

The heat pump efficiencies (median SPF_{H3} values) used in the calculations are shown in Table 23 below. These are derived from recent field trial data[14].

Table 23: Median SPF_{H3} values used for heat pumps.

	Space heating	Water heating
Air source	256%	229%
Ground source	289%	269%

2.5.12 Broken, repaired and upgrades of electric storage heaters

Savings for electric storage heater (ESH) upgrades and repairs were also calculated. Broken and repaired ESHs used a 'before' case of no heating system, represented by electric room heating. There are two 'after' cases, fan storage heaters with automatic controls and high heat retention storage heaters, with their associated controls (SAP2012, 9.2.8).

A responsiveness of 0.2 was assumed for existing storage heaters. This is based on the weighted average responsiveness of the different types of storage heaters as observed by the EHS, which was calculated for the housing stock as 0.219. The value of 0.2 is the closest figure available in SAP.

Assumptions for storage heaters are shown in Tables 24 and 25 below.

Table 24: General electric storage heater (ESH) measure assumptions

Measure	Before heating system	Before controls	After heating system	After controls
Broken ESH	Electric Room Heaters	N/A	Electric Storage Heaters	With controls
ESH upgrades	ESH responsiveness of 0.2	With controls	All types	With controls
ESH repair	Electric Room Heaters	N/A	Electric Storage Heaters	With controls

[14] www.gov.uk/government/publications/detailed-analysis-of-data-from-heat-pumps-installed-via-the-renewable-heat-premium-payment-scheme

Table 25: Electric storage heater upgrade assumptions

<table>
<tr><td>before</td><td>Efficiencies and other parameters are as in Table 2, except back boilers; these are from SAP
<table>
<tr><th></th><th>Controls:</th><th>Hot water from:</th><th>Efficiency:</th></tr>
<tr><td>Electric storage heating</td><td>Automatic</td><td>dual immersion</td><td>100%</td></tr>
<tr><td>Oil central heating</td><td>timer, roomstat, TRVs</td><td>boiler</td><td>81%</td></tr>
<tr><td>LPG central heating</td><td>timer, roomstat, TRVs</td><td>boiler</td><td>72%</td></tr>
<tr><td>Solid fossil central heating</td><td>timer, roomstat, TRVs</td><td>boiler</td><td>60%</td></tr>
<tr><td>Electric boiler central heating</td><td>timer, roomstat, TRVs</td><td>boiler</td><td>100%</td></tr>
<tr><td>Electric room heating</td><td>Thermostat</td><td>immersion</td><td>100%</td></tr>
<tr><td>Gas room heating</td><td>Thermostat</td><td>immersion</td><td>60%</td></tr>
<tr><td>Solid fossil room heating</td><td>None</td><td>immersion</td><td>50%</td></tr>
<tr><td>Gas back boiler</td><td>appliance thermostat</td><td>back boiler</td><td>50%</td></tr>
<tr><td>Gas back boiler and radiators</td><td>appliance thermostat</td><td>back boiler</td><td>66/56%*</td></tr>
</table>
*winter/summer efficiency</td></tr>
<tr><td>after</td><td>Electric storage heating, dual immersion
(a) fan storage with automatic controls
(b) high heat retention storage with incorporated controls</td></tr>
</table>

2.5.13 Heating controls

The controls that are included in this measure (see Table 26) are considered normal good practice when installing a central heating system. The savings calculated therefore assume that all heating controls stated in Table 26 are present. Heating control savings are calculated on the basis of the boiler efficiencies as shown for each fuel.

Table 26: Heating control assumptions.

<table>
<tr><td>For:</td><td>
<table>
<tr><th></th><th>Boiler efficiency (in post-position):</th><th>Hot water from:</th></tr>
<tr><td>Gas central heating</td><td>90.3%</td><td>boiler</td></tr>
<tr><td>Oil central heating</td><td>81%</td><td>boiler</td></tr>
<tr><td>LPG central heating</td><td>90.3%</td><td>boiler</td></tr>
<tr><td>Solid fossil central heating</td><td>81%</td><td>boiler</td></tr>
<tr><td>Electric central heating system</td><td>100%</td><td>boiler</td></tr>
</table>
</td></tr>
<tr><td>before</td><td>No heating controls (relevant SAP efficiency penalties as outlined in SAP Tables 4c and 4e for lack of thermostatic controls, and absence of interlock will apply)</td></tr>
<tr><td>after</td><td>Timer, roomstat & TRVs</td></tr>
</table>

2.5.14 Photovoltaics

Savings were calculated for the configuration defined in SAP Appendix T 'Improvement measures for Energy Performance Certificates'. This identifies a solar panel as 2.5kWp, and located on a south facing roof on an incline of 30°, with modest overshading. Scores may be calculated by adjusting these values using the kWp of the individual installation.

Appendix A Changes to the methodology in ECO3

A number of changes to the methodology used for the ECO2t scores have been made for the ECO3 scores. These include the following:

- No carbon scores have been produced for ECO3.
- The wall U-values as published in RdSAP 9.93 have been used in place of those published in RdSAP 9.92. This has impacted all property archetypes, and therefore all measure types. It has also impacted on before and after position for solid wall insulation.
- An average 'Percentage of Property Treated' (POPT) has been applied within the deemed scores for all measure types, except for heating controls and those for which sufficient data was unavailable.
- Fuel prices have been updated to June 2017 prices[15]. This has impacted all pre main heating sources, and therefore all measure types.
- Room in roof insulation assumptions have been reviewed. As a result the size of the room-in-roof, and the starting U-values have been revised.
- The 'before' position for mains gas and LPG boiler measures has been revised from 81% efficiency to 72%. This efficiency represents the average efficiency of a non-condensing boiler.
- The 'after' position for mains gas and LPG boiler measures has been revised from 88% to 90.3% to reflect the effect of the Boiler Plus requirements.
- Deemed scores have not been developed for the repair or installation of oil boilers.

[15] PCDF fuel table 191 (data for 15/Jun/17)

Appendix B Proxy heating systems for rare heating types

The proxy heating systems shown in Table 4 in the main document above have been obtained with reference to the data table B1 below, which includes data for the more common systems.

Table B1: Details of the more common systems, which are to be used as proxies.

		PCDF prices (Jun.2017)		
Fuel	**Responsiveness**	**p/(kWh delivered energy)**	**efficiency**	**p/(kWh useful energy)**
Gas CH	1	4.10	81%	5.06
Bulk LPG CH	1	6.67	81%	8.23
Gas RH	1	4.10	60%	6.83
Oil CH	1	3.89	81%	4.80
Elec RH	1	15.70	100%	15.70
Elec boiler CH	1	15.70	100%	15.70
Elec storage	0.2	9.31	100%	9.31
Solid fossil CH	0.5	4.49	60%	7.48
Solid fossil RH	0.5	4.49	50%	8.98

Proxies are generally developed by matching to the closest p/kWh useful energy system with the same responsiveness from the systems shown in the table B1.

For example, an air source heat pump system has an assumed delivered energy cost of 15.7 p/kWh. Taking into account the efficiency of this system (256%) the total cost of useful energy is 6.13 p/kWh. The closest system of the same responsiveness (1.0) to this useful energy cost is a gas room heater system (which has a useful energy cost of is 5.06 p/kWh). A gas room heater system is, therefore, chosen as the proxy for an air source heat pump system.

The proxies and calculations for rare heating systems shown in Table B2 below.

Table B2: Method for selecting proxies for rare heating systems.

		PCDF prices (Jun.2017)			
Fuel	**Responsive-ness**	**p/(kWh delivered energy)**	**efficiency**	**p/(kWh useful energy)**	**Proxy chosen**
Air/water heat pump central heating	1	15.7	256%	6.13	Gas RH
Air-oil hybrid heat pump	1	15.7	256%	6.13	Gas RH
Biomass district heating system	District heating is always Gas CH				Gas CH
Biomass/wood central heating	0.5	3.46	60%	5.77	Solid fossil CH
Biomass/wood room heating	0.5	3.46	50%	6.92	Solid fossil RH
Bottled LPG back boiler to radiators	1	10.54	66%	15.97	Elec boiler CH
Bottled LPG central heating	1	10.54	81%	13.01	Elec boiler CH
Bottled LPG fire with back boiler	1	10.54	50%	21.08	Elec RH
Bottled LPG range cooker boiler	1	10.54	61%	17.28	Elec RH
Bottled LPG room heaters	1	10.54	60%	17.57	Elec RH
Electric ceiling heaters	0.75	15.70	100%	15.70	Elec RH
Electric underfloor heaters	0.25	15.7	100%	15.70	Elec Storage Heaters
Electric warm air system	Warm air systems always use corresponding CH proxy				Elec boiler CH
Gas back boiler to radiators	1	4.1	66%	6.21	Gas RH
Gas district heating system	District heating is always Gas CH				Gas CH

Gas fire with back boiler	1	4.1	50%	8.20	Bulk LPG CH
Gas range cooker boiler	1	4.1	61%	6.72	Gas RH
Gas warm air system	Warm air systems always use corresponding CH proxy				Gas CH
GSHP central heating	1	15.7	229%	6.86	Gas RH
GSHP district heating system	District heating is always Gas CH				Gas CH
LPG back boiler to radiators	1	6.67	66%	10.11	Bulk LPG CH
LPG boiler - Special Condition 18	1	4.1	81%	5.06	Gas CH
LPG district heating system	District heating is always Gas CH				Gas CH
LPG fire with back boiler	1	6.67	50%	13.34	Elec RH
LPG range cooker boiler	1	6.67	61%	10.93	Bulk LPG CH
LPG room heaters	1	6.67	58%	11.50	Bulk LPG CH
LPG warm air system	Warm air systems always use corresponding CH proxy				Bulk LPG CH
No heating present	Electric room heaters assumed				Elec RH
Oil district heating system	District heating is always Gas CH				Gas CH
Oil range cooker boiler	1	3.89	71%	5.48	Gas CH
Oil room heaters	1	3.89	55%	7.07	Gas RH
Oil warm air system	Warm air systems always use corresponding CH proxy				Oil CH
Solid fossil fuel back boiler to radiators	0.5	4.49	63%	7.13	Solid fossil CH
Solid fossil fuel fire with back boiler	0.5	4.49	50%	8.98	Solid fossil RH