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Evaluating the Robustness of a Domestic EPC to investigate improvements to UK Dwellings

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Abstract

This project aims to evaluate the effectiveness of a domestic Energy Performance Certificate (EPC). A tool was created to run the algorithms behind the calculations for the report. The tool was specifically tailored to the climate and geographical location of the West of Scotland. In order to verify the tool, existing dwellings complete with recent EPCs were simulated. The results from an official EPC were compared against the outputs results from the tool, with the degree of similarity being used to verify the accuracy. Alterations were made to the script, simulating improvements to the dwellings building fabric, heating system and lighting requirements. The generation from a PV array was simulated for each dwelling in order to further reduce CO_2 emissions, energy consumption and fuel cost.

Acknowledgements

I would firstly like to thank my supervisor, Dr Cameron Johnstone, helping me select this project and narrow down the content so that the project flows in a concise and coherent manner. I appreciate his input, advising me of different means of technical content which ultimately produced a more well-rounded project.

I would also like to thank the course supervisor, Dr Paul Tuohy, for his help and guidance throughout. Especially for his participation in supervising a previous group project I was involved in, which focused on the village of Kinlochleven.

Finally, I would like to thank all the members of staff at the university, which I have had the pleasure of working and learning from over the duration of the year.

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1. Introduction

1.1 Background

There is now a mutual agreement between countries, that stems from the quantity of scientific research linking the correlation of releasing greenhouse gases (GHGs) such as: Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur Hexafluoride, to the warming of our planet (SF6) (United Nations Climate Change, 2019a). International binding agreements linked to the United Nations Framework Convention on Climate Change (UNFCCC) commits parties to reduce their GHG Emissions in the years to come (United Nations Climate Change, 2019b). Established in 1997 and enforced in 2005, the Kyoto Protocol was created to minimise such emissions (United Nations Climate Change, 2019b). Another agreement within the UNFCCC signed in 2016 is the Paris Agreement. The central aim of this agreement is to reduce the threat of climate change by keeping temperatures well below 2°C above pre-industrial levels and to limit even further to 1.5°C (United Nations Climate Change, 2018). The UK governments own climate change bill contains a legally binding document to target reductions of CO_2 by at least 80% on 1990 levels by the year 2050 (Moore, 2007). This equates to UK net CO_2 emissions of 118.8 Mt by the year 2050, though the general consensus is that this number is still regarded as inadequate, even though from 1990-2016 the net concentration of CO_2 fell by 36% (Figure 1.1). To prevent irreversible climate changes, scientific research states that atmospheric GHG concentrations should be stabilised to an upper limit of 450 parts per million (PPM) (Moore, 2007).

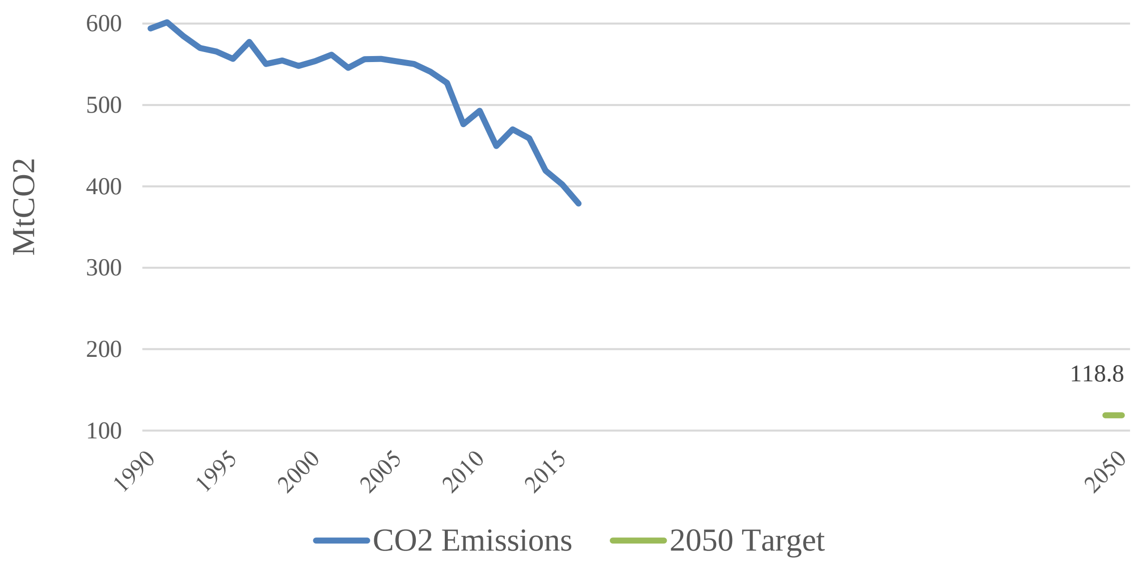


Figure 1.1 Net CO_2 Emissions (BEIS, 2015)

The global population is rapidly growing, expanding more than six-fold from the years 1800-2000, to its current peak of over 7.6 billion (Goldewijk et al, 2010). Coinciding with this population boom is the world's energy consumption hence the increase of pollutants such as CO_2. Sectors significantly increasing these two respective values include: transport, industry and building stock. In the UK building stock is responsible for 46% of the total CO_2 emissions while more precisely 27% comes from domestic properties (Figure 1.2) (Moore, 2007). The source of these emissions is broken down further in Figure 1.3.

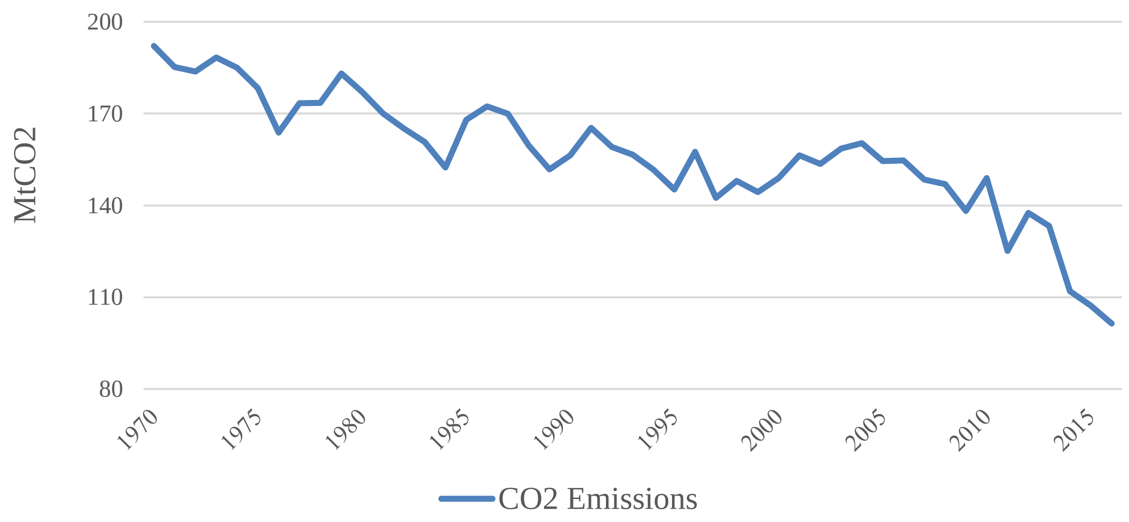


Figure 1.2 Domestic CO_2 Emissions (BEIS, 21015)

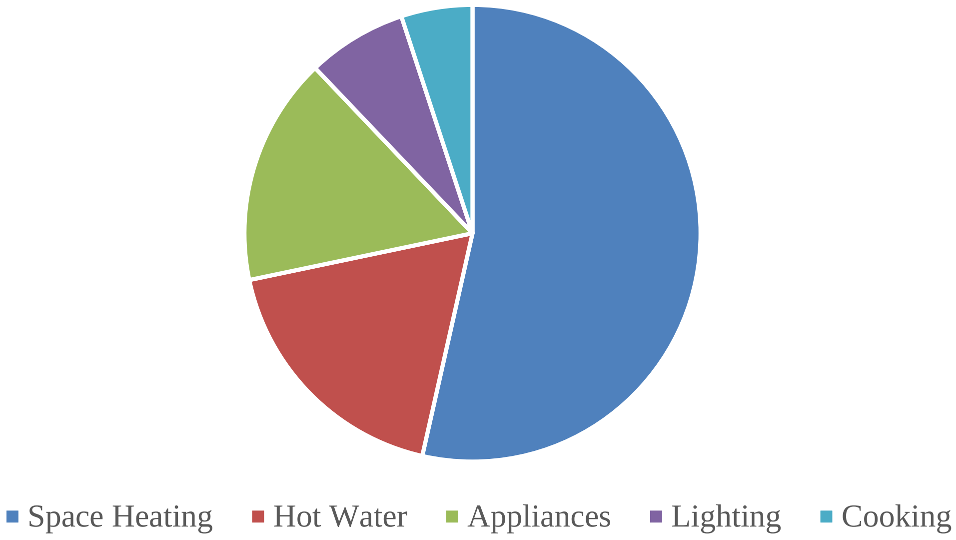


Figure 1.3 Source of CO_2 Emissions by End Use (Moore, 2007)

The source of the energy generation also plays a crucial role in emission levels. As can be viewed from Figure 1.4 not only has the quantity of Tonnes of Oil Equivalent (toe) decreased in recent years but the constituent make-up of the generation mix is generally moving away from fossil fuels such as: coal and oil, incorporating more renewables including: wind, solar and bioenergy (BEIS, 2013). The dispatchable nature of gas as a means of electricity generation means that it can be brought on/offline quickly, filling the deficits in any other generation means. This corresponds to the quantity of gas used for electricity generation purposes staying more or less constant over recent years (BEIS, 2013). In 2018 the UK's dependency on fossil fuels was at an all-time low of 79% (BEIS, 2019). Improvements are constantly being made in energy storage technologies that are essential for a low carbon network. Such technologies allow for the decoupling of energy supply and demand such that more renewable, non-dispatchable, less polluting energy sources can be stored and then released at a time of deficit. Research and development are underway with the primary goals of realising technology costs and improving the performance/efficiencies in order for these systems to be more viable, while also being cost competitive (IEA, 2014).

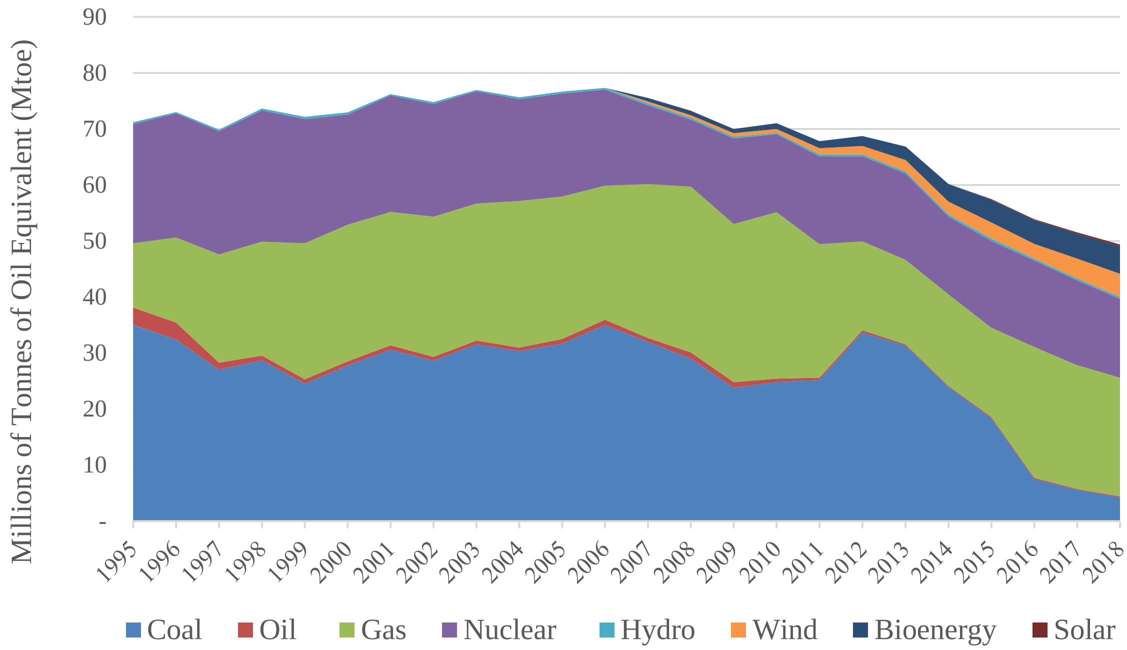


Figure 1.4 Fuel used in Electricity Generation Mix (BEIS, 2013)

In 2017 there were more than 27 million domestic households in the UK (Office for National Statistics, 2016). Of these 55% were built pre 1960, 33% between 1961-1990 and 12% after 1991 (Europe's Buildings Under the Microscope). The UK has the highest proportion of older dwellings in the European Union (EU) thus lies among the least energy efficient dwellings in the EU (Europe's Buildings Under the Microscope). It is estimated that 85% of all current UK domestic homes will still be standing come the year 2050, pushing the average dwelling age up (Banks, 2010). Existing building stock must therefore be retrofitted in order to achieve more energy efficient, less CO_2 intensive dwellings.

Reducing a building's energy performance is viewed as one of the most logical ways to lower the overall energy demand of the UK. New buildings are pushing the boundaries of net zero carbon emissions and net zero energy buildings. Existing buildings are not far behind when enough improvements have been incorporated into the dwelling. Improving the fabric of a building's envelope offers various advantages for the consumer such as: reduced energy costs, improved thermal comfort for occupants, lower capital expenditure, increased property value, and improved aesthetics (Carbon Trust, 2018).

1.2 Justification of Research

The objective of this project is to analyse how different measures of retrofitting a dwelling effect the overall energy consumption and equivalent CO_2 emissions associated with these changes. In the UK the National Calculation Methodology (NCM) for rating a dwelling's energy efficiency is SAP 2012 (BRE Group, 2012). A Domestic Energy Assessor (DEA) runs crucial pieces of a dwelling's make-up through SAP software to produce a document outlining the energy efficiency and environmental impact of a property, known as an: Energy Performance Certificate (EPC) (Building Energy, 2018). A tool was created to run the governing mathematics of the Standard Assessment Procedure (SAP) software, to produce such a report. Various parameters of the building can be altered to imitate the improvements. Energy generation technologies can also be modelled using the tool which illustrate the extremes where a building is a net exporter of energy. For consistency of results and to help minimise errors, the dwellings selected have recently had an EPC produced by a qualified DEA. In working with properties of this type, the consistency of an SAP can also be examined, conducting the same report on the same dwelling to attain a percentage error in results due to variation of examiner. Reducing a dwellings energy consumption is one of the most sensible approaches to lowering CO_2 emissions and more research is required in this field to help meet the targets set for 2050.

1.3 Aims and Objective

The aim of this project is to push the energy efficiency of domestic dwellings to the maximum. This is to be achieved by simulating various improvements in a buildings construction and heating system. The effects of renewable generation will also be simulated in the form of a photovoltaic (PV) array on a dwellings roof. Once the simulations are complete, the results can be interpreted and classified in terms of the overall energy efficiency of the dwelling, the equivalent CO_2 produced, the fuel type used and the financial cost and savings which coincide with the retrofit improvements. Any shortcomings can then be identified, and suggested improvements made which would lead onto further work.

1.4 Method

Background Research	- Research recent energy and building efficiency targets - As well as CO_2 emission levels from UK dwellings
Justification	- Targets set to lower CO_2 emissions by the year 2050 - Reduced energy demands equate to lower bills for consumers
Aims and Objectives	- To create an easy to use tool that's allows a building's performance to be more closely analysed - To validate how precise the current software is - To investigate the effects of electrifying the heating system - Then to suggest any improvements to the current system
Literature Review	- To evaluate the SAP 2012 data sheet - To then compare this against the Reduced Data SAP (RdSAP) - Research different means of retrofitting a building
Tool Creation	- Validate the tool against previous EPCs conducted for the same dwelling
Simulation	- Model the retrofit of various alterations to the building fabric, and heating system
Results Analysis	- Comment on the validity of the results - Suggest improvements to the current method
Conclusions	- Comment on accuracy of the SAP and EPC as a whole - Suggest further work to be undertaken which coincides with the project

2. Literature Review

2.1 Introduction

This chapter presents a description of an EPC and goes into more detail about the information it contains. More depth and insight are given into the NCMs used to govern an EPC report, explaining the differences between the two worksheets. Various averages are given for Scottish housing stock specifically, relating to energy efficiency and the level of CO_2 emitted. Different means of retrofitting a dwelling are reviewed for each respective change in relation to cost, energy efficiency and reduction in CO_2 levels. Renewable generation technologies are included, giving a breakdown of the predicted yield associated within the Scottish climate.

2.2 Domestic Energy Performance Certificate (EPC)

2.2.1 Background

Approved on December 2002 and brought into force on January 2003, the EU produced the Buildings Energy Performance Directive (EPBD) (European Parliament, 2002). The Directive was created in order to comply with the goals of the Kyoto Protocol relating to increasing energy efficiencies and was split into 4 main aspects.

1) Establishment of a calculation method
2) Minimum energy performance requirements
3) Creation of an EPC
4) Inspection of boilers and air-conditioning units

The main requirement was to produce EPCs for residential and non-residential buildings. There is no set price to attain an EPC for a property though usually lies somewhere between £60-£80. The cost for the report can be negotiated however since 2008 in the UK it has been legally contractional for an EPC to be produced whenever a building is constructed, rented or sold, remaining valid for ten years (BEIS, 2007).

2.2.2 Contents

An EPC is a document which illustrates the energy performance in terms of an Energy Efficiency Rating (EER) and the Environmental Impact (EI) of a building based on the standardised way the building is used. These ratings are based on a scale A-G, with A being the most efficient as shown in Figure 2.1. A full example of an EPC is available in APPENDIX B.

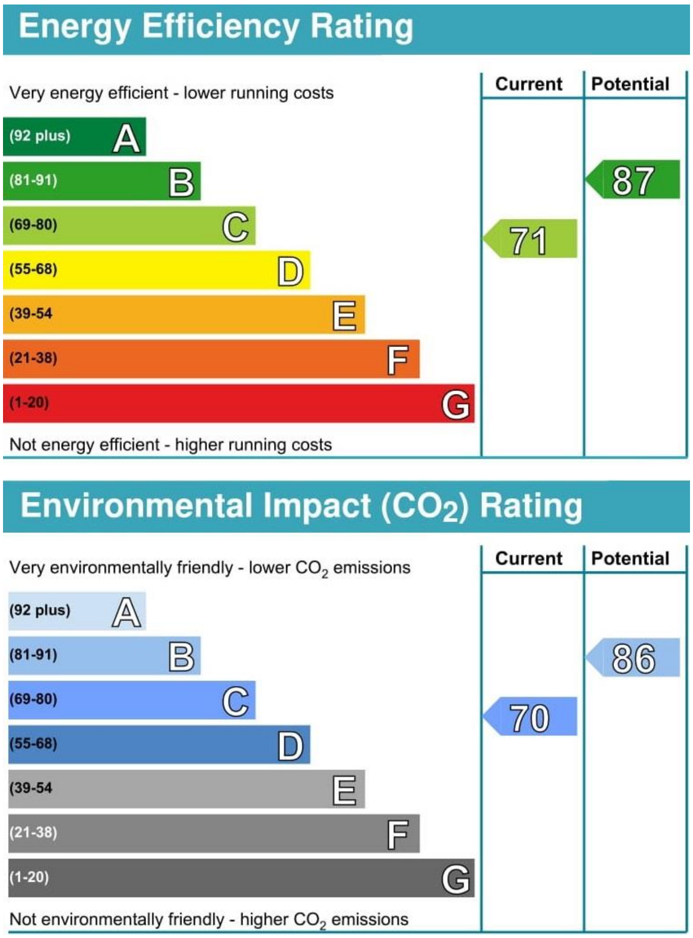


Figure 2.1 Example of EER and EI rating (APPENDIX B)

The average EER and EI ratings are also given, allowing the occupant to compare against the country. The respective ratings are based on the energy costs and CO_2 emissions associated with space heating/cooling, domestic hot water, ventilation and lighting, less any savings attained from energy generation means (NCM, 2019). The higher the rating the less energy the building consumes or in the case of EI the less CO_2 produced. Adjacent to the EER and EI ratings are the predicted ratings. These account for the installation of all the changes from the recommendation report being incorporated into the dwelling. Numerically both ratings can be expressed on a scale from 1-100 which in turn correspond to an alphabetical ratings value. Ratings can exceed 100 when a building is regarded as a net exporter of energy (Table 2.1) (BRE Group, 2012).

Table 2.1 EPC Rating Scheme (NCM, 2019)

A	> 92
B	81 - 91
C	69 - 80
D	55 - 68
E	39 - 54
F	21 - 38
G	1 - 20

The recommendation report provides information relating to how various improvements would alter a building's efficiency and an indication of the cost of such improvements. There is also predicted ratings after each respective improvement to clarify the most beneficial, both in terms of efficiency and cost for the occupant This means that homeowners and occupiers can compare the energy efficiencies and EI ratings of different dwellings, like the means of comparing the energy efficiencies of electrical appliances.

The Total Floor Area (TFA) of the dwelling is listed at the top of the report along with the primary energy indicator. This shows the predicted energy usage of the dwelling as a function of area per year. The total estimated levels of CO_2 is also provided as a function of area per year and in tonnes equivalent. The average emission levels is provided for the country, giving a baseline for comparison.

The summary of energy performance of individual elements of the dwelling such as: walls, roof, floor, windows, heating system(s) and lighting is provided. This is ranked in the form of a star-based system where 1 corresponds to very poor and 5 to very good levels of energy efficiency. This is intended to allow the occupant to easily visualise the weakest areas of performance more easily.

2.3 National Calculation Methods (NCMs)

2.3.1 Background

The Building Research Establishment (BRE) are contracted to maintain and develop NCMs for energy rating dwellings (SAP and RdSAP) on behalf of the UK's Department for Business, Energy & Industrial Strategy (BEIS) (BRE Group, 2012).

2.3.2 Standard Assessment Procedure (SAP)

The SAP is the UK government's approved method for assessing energy efficiencies of dwellings (Figure 2.2). A full example of the SAP Worksheet is available in APPENDIX C. SAP was first published in 1993, but has since been updated regularly, with new versions published in 1998, 2001, 2005, 2009 and 2012 (BRE Group, 2012). Detailed plans and drawings for new domestic dwellings are used in conjunction with the SAP to evaluate a buildings energy consumption and CO_2 emissions. The calculation is based on the energy balance taking into account a range of factors that contribute to energy efficiency (NCM, 2019):

- materials used for construction of the dwelling
- thermal insulation of the building fabric
- air leakage ventilation characteristics of the dwelling, and ventilation equipment
- efficiency and control of the heating system(s)
- solar gains through openings of the dwelling
- the fuel used to provide space and water heating, ventilation and lighting
- energy for space cooling (if applicable)
- renewable energy technologies

7. Mean internal temperature (heating season)

Temperature during heating periods in the living area from Table 9, T_{h1} (°C) | 21 | (85)

Utilisation factor for gains for living area, $\eta_{1,m}$ (see Table 9a)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
$(86)_m$ =	$(86)_1$	$(86)_2$	$(86)_3$	$(86)_4$	$(86)_5$	$(86)_6$	$(86)_7$	$(86)_8$	$(86)_9$	$(86)_{10}$	$(86)_{11}$	$(86)_{12}$	(86)
Mean internal temperature in living area T_1 *(follow steps 3 to 7 in Table 9c)*													
$(87)_m$ =	$(87)_1$	$(87)_2$	$(87)_3$	$(87)_4$	$(87)_5$	$(87)_6$	$(87)_7$	$(87)_8$	$(87)_9$	$(87)_{10}$	$(87)_{11}$	$(87)_{12}$	(87)
Temperature during heating periods in rest of dwelling from Table 9, T_{h2} (°C)													
$(88)_m$ =	$(88)_1$	$(88)_2$	$(88)_3$	$(88)_4$	$(88)_5$	$(88)_6$	$(88)_7$	$(88)_8$	$(88)_9$	$(88)_{10}$	$(88)_{11}$	$(88)_{12}$	(88)
Utilisation factor for gains for rest of dwelling, $\eta_{2,m}$ (see Table 9a)													
$(89)_m$ =	$(89)_1$	$(89)_2$	$(89)_3$	$(89)_4$	$(89)_5$	$(89)_6$	$(89)_7$	$(89)_8$	$(89)_9$	$(89)_{10}$	$(89)_{11}$	$(89)_{12}$	(89)
Mean internal temperature in the rest of dwelling T_2 *(follow steps 8 to 9 in Table 9c, if two main heating systems see further notes in Table 9c)*													
$(90)_m$ =	$(90)_1$	$(90)_2$	$(90)_3$	$(90)_4$	$(90)_5$	$(90)_6$	$(90)_7$	$(90)_8$	$(90)_9$	$(90)_{10}$	$(90)_{11}$	$(90)_{12}$	(90)
Living area fraction									f_{LA} = Living area ÷ (4) =				(91)
Mean internal temperature (for the whole dwelling) = $f_{LA} \times T_1 + (1 - f_{LA}) \times T_2$													
$(92)_m$ =	$(92)_1$	$(92)_2$	$(92)_3$	$(92)_4$	$(92)_5$	$(92)_6$	$(92)_7$	$(92)_8$	$(92)_9$	$(82)_{10}$	$(92)_{11}$	$(92)_{12}$	(92)
Apply adjustment to the mean internal temperature from Table 4e, where appropriate													
$(93)_m$ =	$(93)_1$	$(93)_2$	$(93)_3$	$(93)_4$	$(93)_5$	$(93)_6$	$(93)_7$	$(93)_8$	$(93)_9$	$(93)_{10}$	$(93)_{11}$	$(93)_{12}$	(93)

Figure 2.2 SAP Worksheet Example (Version 9.92) (BRE Group, 2012)

The calculation is independent of factors relating to the individual characteristics of the household occupying the dwelling when the rating is calculated (NCM, 2019):

- household size and composition
- ownership and efficiency of specific domestic electrical appliances
- individual heating patterns and temperatures

This allows dwellings to be compared on a like-for-like comparison of performance (BRE Group, 2012). There have been various versions of the SAP over the years leading to improvements in the most common version, released in 2012 in which (NCM, 2019):

- climate data has been extended to allow calculations using regional weather
- height above sea-level is incorporated into external temperature data
- CO_2 emission factors have been extensively revised
- fuel price and primary energy factors have been revised

2.3.3 Reduced Data Standard Assessment Procedure (RdSAP)

RdSAP was developed by the government for use in existing dwellings based on a site survey of the property, when a complete data set for a SAP calculation is not available (Table 2.2). A full list of the information required to be collected by a DEA is available in APPENDIX D.

The SAP can require greater than 200 input parameters and proves too time consuming, complex and expensive when the detailed plans and drawings for a property are not accessible. A full SAP report requires knowledge of construction materials that may not be easily attained visually by an accessor on an existing building. A RdSAP report is a non-intrusive survey, meaning that the fabric of the building must not be disturbed in the process of the report (Kelly et al, 2012).

Table 2.2 Example of Data to be Collected for RdSAP (BRE Group, 2012)

Item	Data	Comment
Floor construction	One of: - unknown - solid - suspended timber - suspended, not timber	For lowest floor of the building part. Not if another dwelling or other premises below.
Floor insulation	One of: - unknown - as built - retro-fitted	Not if another dwelling or other premises below. There must be evidence for retro-fit insulation.
Floor insulation thickness	One of: - unknown - 50 mm - 100 mm - 150 mm or more	Only if floor insulation is retro-fitted. Applies to ground floors and exposed upper floors.
Floor U-value	Value in W/m^2K	'Insulation Thickness' and 'U-value' are mutually exclusive alternatives.

The calculation starting from reduced data is done in two stages. First the reduced data set is expanded into a full data set (according to specific formulas and appendices), and then the SAP calculation is undertaken using the expanded data set (NCM, 2019). The actual SAP calculation is therefore identical and contains the same quantity of information, whether derived via a full or reduced set of data. The key pieces of information expanded to form the full data set include (NCM, 2019):

- type and age of dwelling
- construction material(s)
- dimensions of the dwelling
- heating system(s)
- insulation levels
- window frame and glazing types
- type of lighting

2.3.4 Steps to the SAP/RdSAP Worksheet

1. Overall Dwelling Dimensions
   Calculates the TFA and the volume of the dwelling.

2. Ventilation Rate
   Calculates the rate at which outside air is entering/leaving the dwelling.

3. Heat Losses and Heat Loss Parameter (HLP)
   Calculates the dwellings specific heat loss.

4. Water Heating Energy Requirement
   Calculates the dwellings heat gains associated with hot water heating.

5. Internal Gains
   Calculates the total internal gains of the dwelling by summing individual gains from: occupants, lights, appliances, cooking and fans, less any evaporation losses.

6. Solar Gains
   Calculates the solar gains associated with each of the dwelling's respective windows and doors.

7. Mean Internal Temperature (Heating Season)
   Calculates the mean internal temperature for the living area and the rest of the dwelling by incorporating all the gains present.

8. Space Heating Requirement
   Calculates the heating requirement to provide satisfactory thermal comfort level for the dwelling's occupants, utilising the mean internal temperate of the dwelling.

8c. Space Cooling Requirement
   Calculates the cooling requirement to provide satisfactory thermal comfort levels for the dwelling's occupants if required.

9a. Energy Requirements – Individual Heating Systems

Incorporates the relative efficiencies of any heating/cooling/hot water systems to calculate the dwelling's associated fuel consumption, used by each individual element

10a. Fuel Costs – Individual Heating System

Summaries the dwelling's fuel costs per annum by scaling the fuel used by individual elements to the fuel cost associated. This is then summed to create the total energy cost.

11a. SAP Rating

Calculates the dwellings SAP rating or the EPCs EER.

12a. CO_2 Emissions – Individual Heating Systems.

Incorporates an emission factor to scale the energy required to the equivalent quantity of CO_2 produced by each individual element within the dwelling. Then the dwellings EI rating is calculated.

13a. Primary Energy Indicator

Incorporates a primary energy factor to combine the energy required by each individual element within the dwelling. Then the dwellings PEI is calculated.

2.4 Scottish Dwellings

2.4.1 Energy Efficiency Ratings (EERs)

In 2016 the mean EER of the Scottish housing stock, under SAP 2012 was 63.7 and the median was 67, indicating that over half of the housing stock has an EER rating of 66 (EPC band D) or better (Scottish Government, 2017). The sample for the survey was over 2.45 million dwellings and Figure 2.3 shows the wider distribution of results.

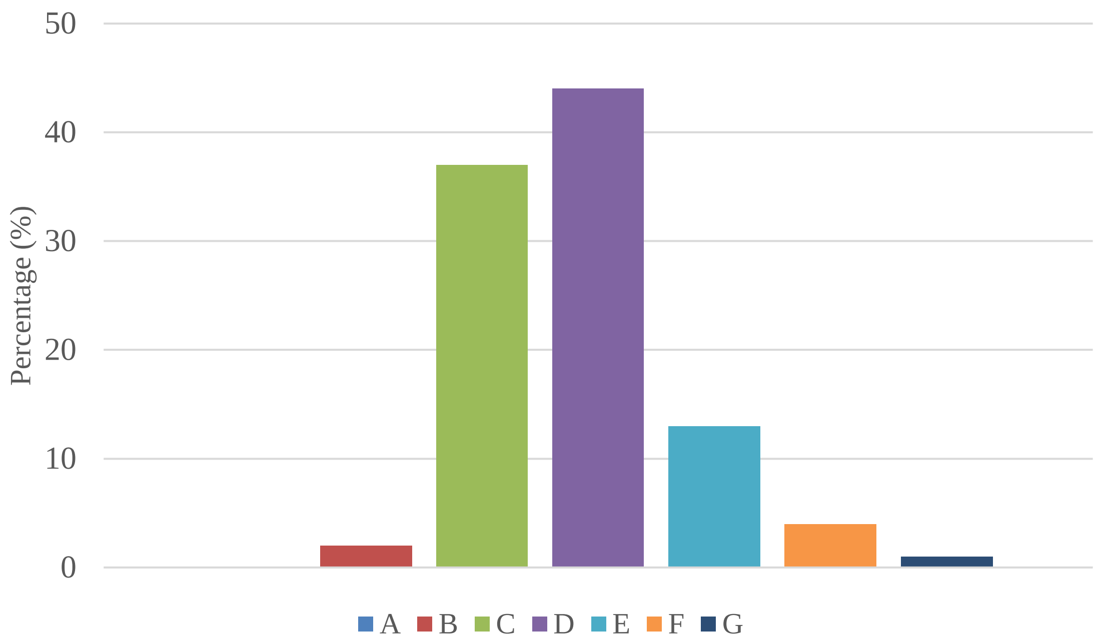


Figure 2.3 Distribution of EER in Scottish Housing (Scottish Government, 2017)

The average EER has been gradually increasing since 2010 correlating to higher levels of dwelling energy efficiencies and lower fuel bills for the occupants. Table 2.3 shows this trend in median values.

Table 2.3 Median EER relative to EPC Bands (Scottish Government, 2017)

	2016	2015	2014	2013	2012	2011	2010
EER	67	67	67	66	64	63	62
Dwellings (000s)	2452	2434	2420	2402	2386	2372	2368

This is a positive but necessary response, coherent to the 2050 targets set by the government. The values are heading in the right direction though perhaps not at a sufficient speed. Similarly, in 2016 the percentage of households regarded as being in fuel poverty (23%) fell to the lowest value in over a decade, though more worryingly still equating to roughly a quarter of all households (Scottish Government, 2017).

2.4.2 Carbon Emissions (EI)

In 2016 the mean EI rating of the Scottish housing stock, under SAP 2012 was 59 and the median was 62, indicating that over half of the housing stock has an EI rating of 61 (EPC band D) or better (Scottish Government, 2017). The sample for the survey was also over 2.45 million dwellings and Figure 2.4 shows the wider distribution of results.

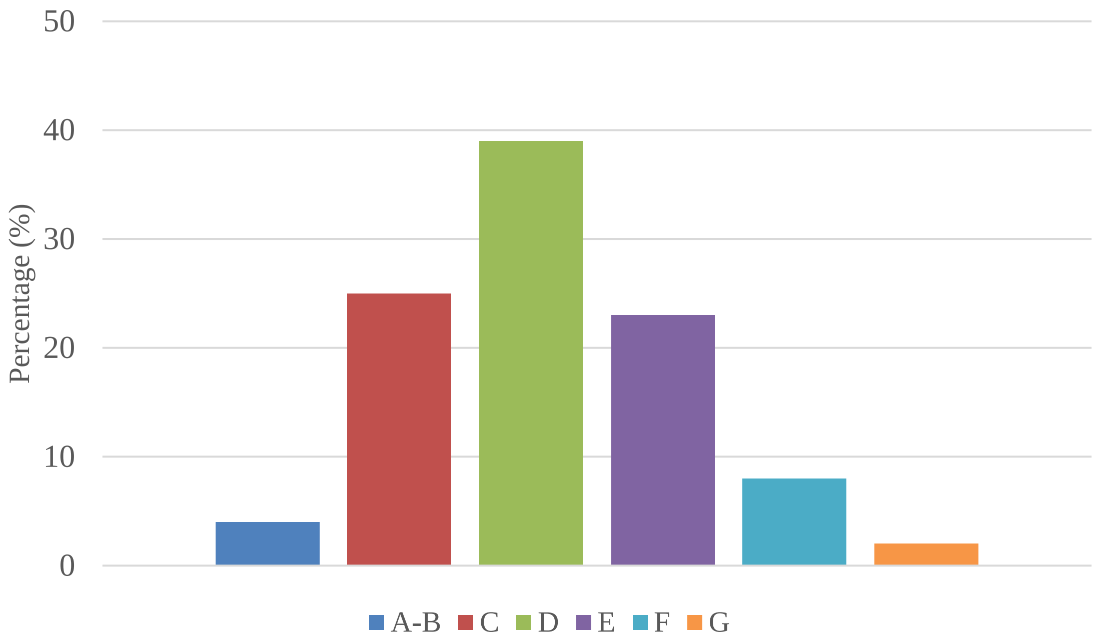


Figure 2.4 Distribution of EI Ratings - Scottish Housing Stock (Scottish Government, 2017)

The average EI rating has been gradually increasing since 2010, excluding the 2015 outlier and 2014 when no data was recorded (Scottish Government, 2017). This indicates that environmental effects have been falling over the sample. This correlates to higher levels of dwelling energy efficiencies, burning less fuel and hence producing lower levels of CO_2 as a consequence. Table 2.4 shows this trend in median values.

Table 2.4 Median EI Rating Relative to EPC Bands (Scottish Government, 2017)

	2016	2015	2013	2012	2011	2010
EI	62	61	63	60	59	58
Dwellings (000s)	2452	2434	2402	2383	2349	2330

2.5 Methods of Retrofit

2.5.1 The Thermal Envelope

The thermal envelope is the name given to collectively describe the roof, walls, windows, doors and floor of a building (The Greenage, 2014b). Any heat that is lost to the surroundings will have passed through one of these elements. Hence installing or upgrading insulation levels in the roof, walls or floors of a dwelling is one of the most appropriate ways to improve energy efficiency.

2.5.1a Roof/Loft Insulation

It is estimated that 25% of heat is lost through a roof in an uninsulated home (The Energy Saving Trust, 2019b). Therefore, installing roof insulation is one of the easiest ways to increase a dwellings energy efficiency while also lowering the occupant's energy bills (Scottish Government, 2017).

Table 2.5 Annual Savings for Roof Insulation from 0 - 270mm

(The Energy Saving Trust, 2019b)

	Detached House	Semi-Detached	Mid-Terrace	Detached Bungalow
Average Installation Cost (£)	396	300	285	375
Energy Bill Savings (£)	225	135	120	195
CO_2 Savings ($kgCO_2$/year)	920	550	490	790

Table 2.6 Annual Savings for Roof Insulation from 120 - 270mm

(The Energy Saving Trust, 2019b)

	Detached House	Semi-Detached	Mid-Terrace	Detached Bungalow
Average Installation Cost (£)	290	240	230	280
Energy Bill Savings (£)	21	12	11	17
CO_2 Savings ($kgCO_2$/year)	80	50	40	70

As can be seen in comparing Tables 2.5 and 2.6, this relationship is not linear and installing roof insulation onto a blank canvas (i.e. no previous insulation) yields much greater results. Moreover, the installation costs would be paid off in energy savings in roughly a 2-year period. Since 2010 an overall improvement in loft insulation has occurred, to the point were in 2017 94% of all applicable dwellings had at least 100mm (Scottish Government, 2017). The same year almost one third of dwellings had a high level of loft insulation (>300mm).

2.5.1b Wall Insulation

About one third of all the heat lost in an uninsulated home escapes through the walls (The Energy Saving Trust, 2019b). Dwellings built after 1990 have wall insulation as standard to keep the heat in, though older dwellings may not have insulation at all (The Energy Saving Trust, 2019b). In general, there are two types of wall insulation: cavity wall insulation (CWI) and then external/internal insulation for solid wall types. Due to the difference in cost both groups will be considered separately.

In Scotland 75% of dwellings have cavity walls (Scottish Government, 2018). The presence of CWI becomes increasingly difficult to identify over time as the injection holes either age or fade, resulting in a possible under estimation by the Scottish House Condition Survey (SCHS) (Scottish Government, 2018).

Table 2.7 Dwelling’s with CWI (Scottish Government, 2018)

	2017	2016	2015	2014	2013	2012
Insulated (000s)	1363	1323	1286	1287	1218	1157
Uninsulated (000s)	457	512	525	518	554	606
% Insulated	75	72	71	71	69	66

From Table 2.7, in 2017 75% of dwellings had been retrofitted with CWI. There is a long-term trend increase in the amount of building’s having insulation injected, both on social and privately-owned houses (Scottish Government, 2017).

Table 2.8 Annual Savings from Injecting CWI (The Energy Saving Trust, 2019b)

	Detached House	Semi-Detached	Mid-Terrace	Detached Bungalow	Flat
Average Installation Cost (£)	725	475	320	430	330
Energy Bill Savings (£)	255	150	95	105	70
CO_2 Savings (kgCO_2/year)	1040	620	380	420	290

From Table 2.8 it can be seen that some dwelling types pay off the initial investment quicker than others. A detached house can claim back the installation costs more quickly, roughly taking 3 years to pay off. The rest of the dwelling types take between 4-5 years of energy bill reductions to claim back the initial expenditure. Though after this time period the occupant is subject to a much lower energy bill, constituting to lower levels of CO_2 emissions being released.

The remaining 25% of houses are constructions from solid brick or other wall types.

Table 2.9 Dwelling's with Insulation for Solid or Other Wall Types (Scottish Government, 2018)

	2017	2016	2015	2014	2013	2012
Insulated (000s)	115	94	71	85	71	66
Uninsulated (000s)	529	524	552	528	559	557
% Insulated	18	15	11	14	11	11

Table 2.9 shows the disparity in solid or other walled dwelling types being retrofitted with insulation. This is largely due to the higher costs associated with insulating such properties (Scottish Government, 2017). However, in the social sector in 2017 44% of these types of walled dwellings where retrofitted. Government grants made this energy reduction method feasible (Scottish Government, 2018).

2.5.1c Floor Insulation

It Is estimated that around 10% of heat is lost through an uninsulated floor (The Greenage, 2014b). Floor insulation typically costs anywhere between £520-£1300 depending on the circumstances of whether the floor is solid or a suspended timber frame (The Energy Saving Trust, 2019b). If the floor is solid concrete, then it must be insulated when the flooring is being replaced in order to comply with building regulations. The positioning of the insulation, either above or below the concrete, also influences how the heat is retained. In the case of a suspended floor, the boards can be lifted, and insulation laid down beneath (The Greenage, 2014b).

Despite being more difficult to install, floor insulation still has a great effect on an occupant's ability to reduce the energy requirements of a dwelling, while also reducing the equivalent levels of CO_2 produced (Figure 2.5). The average dwelling type after being retrofitted with floor insulation would save approximately 245 $kgCO_2$/year (The Energy Saving Trust, 2019b).

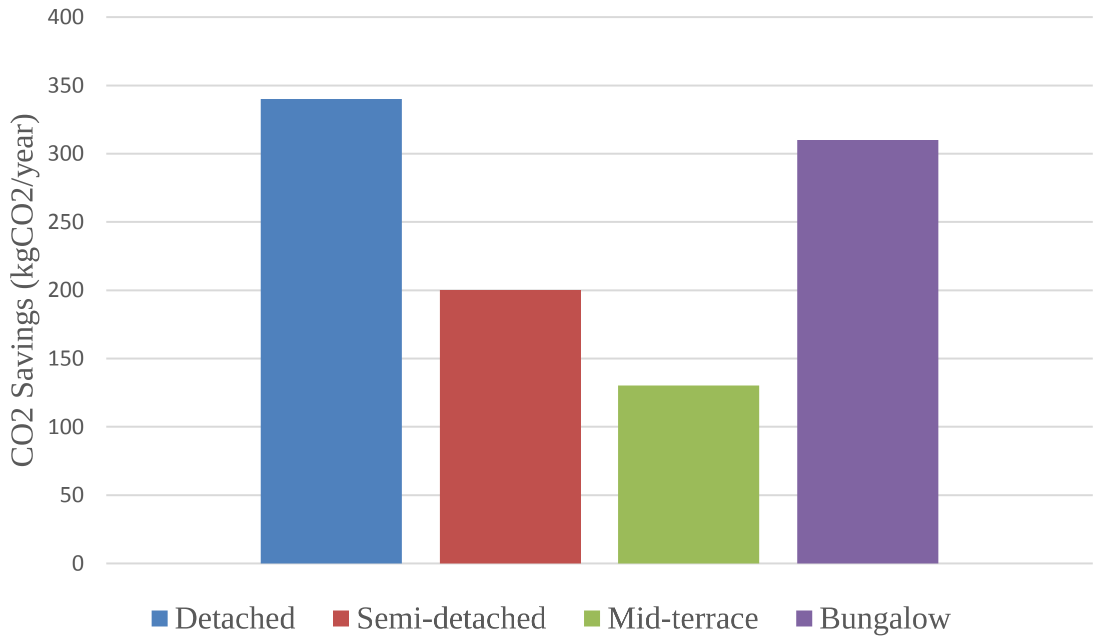


Figure 2.5 Savings in CO_2 for Floor Insulation Installation (The Energy Saving Trust, 2019b)

2.5.1d Windows

A typical house loses about 10% of its heat through windows (Green Spec, 2019). There are several different types of window such as: single glazing, double glazing, triple glazing and then there are also various coatings which can be applied to the glass in order to minimise heat loss (The Energy Saving Trust, 2017a). The largest savings in energy and equivalent CO_2 emissions are from a single glazing unit being retrofitted (Figure 2.6). Similar to an EER, windows are often rated on a letter-based system from A-G. Other common methods to rate the quality of heat retention of a window is by its u-value (level of thermal transmittance) or g-value (level of solar gain) (Green Spec, 2019).

The most significant development in glazing has been that of low-emissivity (Low-e) glass. By coating the face of the inner pane of glass with metal, short wave radiation from the sun can enter the building, while long wave radiation in the form of heat from the inside is reflected back into the room (Green Spec, 2019). This therefore always increases the g-value of the window and hence the inside air temperature. Gas filled units are often used in conjunction with this technology, were a low conductivity gas such as argon is used to fill the gaps between panes windows (Green Spec, 2019).

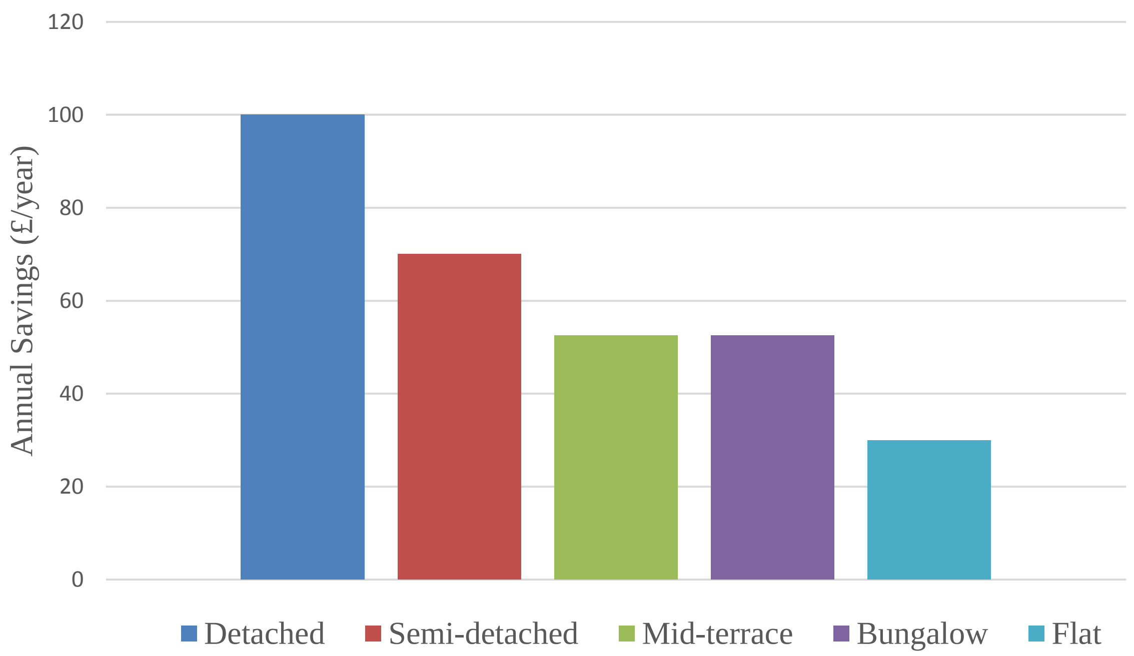


Figure 2.6 Single Glazing to Double Glazing (C) Windows (The Energy Saving Trust, 2017a)

2.5.2 Methods of Renewable Generation

There are various technologies available to generate a domestic heat and/or electricity supply. The most common of which include PV panels, small scale wind turbines, solar thermal heating systems and a variety of heat pumps including: Air-Source Heat Pumps (ASHPs), Ground-Source Heat Pumps (GSHPs) and Water-Source Heat Pumps (WSHPs). Renewable sources of technology for generating heat or electricity provide a lower unit price of electricity to the consumer, while also producing a lower equivalent of CO_2.

2.5.2a PV Panels

There are 2 common types of PV system. The grid-connected system and the stand-alone system. As the name suggest the grid-connected system is connected to the national grid, meaning that at times of a generation deficit (i.e. at night), electricity can be drawn from the grid (Green Match, 2019). The stand-alone system works more efficiently in rural areas when a grid connection mat not always be accessible (Green Match, 2019). In this system batteries are used to store electricity during times of generation surplus, then utilised at times when there is no generation (The Energy Saving Trust, 2017b).

The PV cells are made from a semiconducting material (typically silicon) which produce an electric field in the presence of sunlight (Green Match, 2019). The more direct and intense the sunlight, the more electricity generated. Though these systems still generate energy on a cloudy day by collecting diffuse light.

Figure 2.7 Typical PV System (The Energy Saving Trust, 2017b)

There are many factors which contribute to a PV panels output including; the geographical location, the orientation of the panel and the capacity of the system. A typical PV panel has an efficiency of about 10% (MacKay, 2008). A 4-kilowatt peak (kWp) system in Scotland can typically generate about 3400kWh of electricity a year, saving about 1.3 tonnes of CO_2 (The Energy Saving Trust, 2017b). The costs for this system would roughly work out as £6200.

2.5.2b Solar Thermal

There are 2 common solar water heating panels: flat plate collectors or evacuated tubes. Both collect radiation in the form of heat from the sun and use this to heat up water which is stored in a hot water cylinder (The Energy Saving Trust, 2017b). There is a mixture of water and anti-freeze that flows through the system to stop the water freezing in the winter months. The hot water in the tank regularly has to be heated to kill off any bacteria.

Figure 2.8 Typical Flat Plate Solar Thermal Collector (Renew Green Energy, 2019)

The cost of installing a typical solar thermal system is between £4000-£5000. These systems can provide almost all of the domestic hot water needs in the summer (The Energy Saving Trust, 2017b). This system could provide CO_2 savings of between 220 – 520kg, depending on the existing hot water generation type (The Energy Saving Trust, 2017b).

Similar to PV systems, many of the factors which contribute to the solar thermal systems output efficiency match that of the electricity generating counterpart. Geographical location and orientation being crucial to performance results. The collectors can also be installed on the ground if the roof isn’t suitable, as long as there is a direct path of unshaded sunlight (Renew Green Energy, 2019).

2.5.2c Wind Turbines

Small-scale wind turbines are another highly beneficial means of generating electricity by a renewable means. Wind turbines use strategically placed blades to catch the wind. When the wind blows, these blades are forced to rotate, in turn driving a turbine which is used to generate electricity (The Energy Saving Trust, 2017a). Generally speaking, the stronger the wind present, the more electricity generated.

There are two general types of domestic wind turbine. Pole-mounted turbines which are free standing and erected in an exposed position suitable for maximising generation and building-mounted turbines which have a smaller system capacity, directly attached to the façade of a building (The Energy Saving Trust, 2017b). Building-mounted turbines tend to be less efficient than pole-mounted turbines.

Figure 2.9 Typical Pole-Mounted Domestic Wind Turbine (Sense Renewables, 2019)

Small scale wind turbines are generally more expensive than other means of renewable generation though tend to generate more electricity. A typical 6kW pole- mounted system costs between £21000 and £30000, and yields a generation potential of 9000kWh, saving around 3.4 tonnes of CO_2 emssions per year (The Energy Saving Trust, 2017b).

2.5.2d Heat Pumps

The most common type of heat pump is the ASHP, which transfers heat between your house and the outside air (Energy.gov, 2018). These systems transfer heat from outside to the inside of a home, in the same way that a fridge extracts heat from its inside and expels it into the room. An ASHP can even extract heat from outside when the external air temperature is as low as -15°C (The Energy Saving Trust, 2019a).

There are two types of ASHP: an air-to-water system or an air-to-air system. Air-to-water systems distribute heat via a wet central heating system, working much more efficiently at a lower temperature than a standard gas boiler system. This results in them being more suitable for underfloor heating systems or larger radiators, which give out heat at lower temperatures over longer periods of time (The Energy Saving Trust, 2019a). Air-to-air systems typically use fans to circulate warm air around the home and cannot be used to heat water (Centre for Sustainable Energy, 2018).

A typical ASHP system costs around £6000 - £8000 including installation and is then subject to electricty costs (The Energy Saving Trust, 2019a).

Figure 2.10 Typical ASHP (Centre for Sustainable Energy, 2018)

Other common sources of heat pump are GSHPs or WSHPs. Although they cost more to install, GSHPs and WSHPs have low operating costs because they take advantage of relatively constant ground or water temperatures (Energy.gov, 2018).

The efficiency of a heat pump is denoted by its Coefficient of Performance (CoP). The Cop is the ratio of heat provided by the heat pump to the electricity consumed (MacKay, 2008). A GSHP or a WSHP will have a higher Cop than an ASHP as the seasonal change in temperature is more consistent (The Greenage, 2014).

2.5.3 Lighting

Low-energy light bulbs are a simple yet effective way to reduce energy consumption and CO_2 emissions in a domestic dwelling. On average lighting accounts for around 8% of a household's energy bill in the UK (The Greenage, 2016a).

Traditional incandescent bulbs work by passing electricity through a filament in order to produce light. These are incredibly inefficient however as of all the electricity that goes through the filament, only approximately 10% produces light and then rest is wasted as heat (The Greenage, 2016a). Low-energy (low-E) lights such as light emitting diodes (LEDs) convert a much higher percentage of electrical energy into light, therefore require less energy to operate. LEDs require about 10% of the electricity used by an incandescent, while still producing the same amount of light (The Greenage, 2016a).

A traditional 60W incandescent bulb lasts for around 1000 hours while a 12W LED bulb lasts for around 25000 hours (The Greenage, 2016a). Although LEDs are slightly more expensive, the pros out way the cons, as they last much longer and consume a significant amount of energy less.

3. Modelling and Simulation

3.1 Overview

In order to produce an EPC report, a tool was created to simulate the governing mathematics behind the SAP 2012 worksheet. The tool would be validated against an EPC for the same dwelling, produced by an official DEA. A close correlation in results would suggest that the tool is functioning effectively. Initially the tool was fixed for certain input parameters though later altered for the modelling of a means of energy generation and alternative heating system.

3.2 Tool Creation

Each line of code from the SAP 2012 worksheet was reproduced using Microsoft Excel to create a user-friendly tool. The geographical location for the tool was fixed to the West of Scotland since all the dwelling's considered are in this area. Table 3.1 shows the data used to simulate the climate; all weather data being averaged over the previous 3 years (BRE Group, 2012). All the dwellings surveyed had gas combi heating systems, with no means of hot water storage and no means of renewable energy generation technologies present. The dwellings are all existing builds therefore the RdSAP 2012 method was implemented according to APPENDIX D.

Table 3.1 Weather Data Specific to the West of Scotland (BRE Group, 2012)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)	4.0	4.4	5.6	7.9	10.4	13.0	14.5	14.4	12.5	9.3	6.5	3.8
Wind Speed (m/s)	6.2	6.2	5.9	5.2	4.9	4.7	4.3	4.3	4.9	5.4	5.7	5.4
Solar Radiation (W/m^2)	19	46	88	148	196	193	185	150	101	55	25	15
Solar Declination (All Regions) (°)	-20.7	-12.8	-1.8	9.8	18.8	23.1	21.2	13.7	2.9	-8.7	-18.4	-23.0
Mean Height Above Sea Level (m)						113						
Representative Latitude (°N)						55.9						

3.2.1 Sheet 1 – Overall Dwelling Dimensions

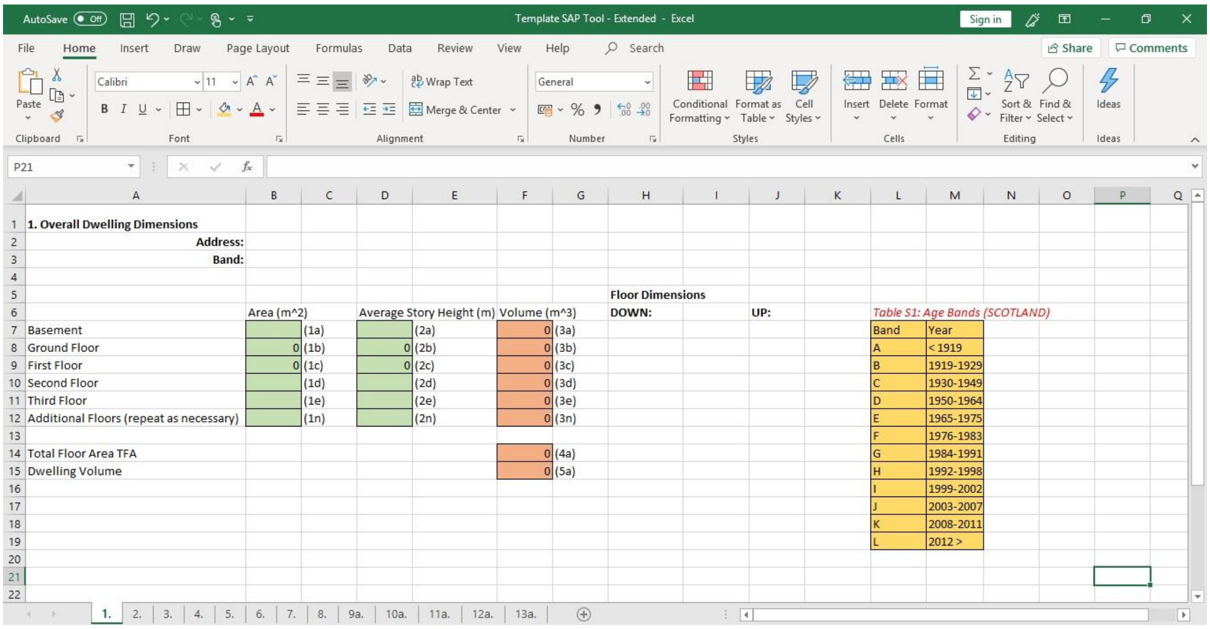


Figure 3.1 SAP Tool – Sheet 1

Dimensions refer to the inner surfaces of the elements bounding the dwelling; therefore, floor areas are calculated based on the measurement of the inner surface between any external or party walls, excluding any internal partition walls (BRE Group, 2012). In general, additional cupboard space is included in the floor area. The storey height is the total height between the ceiling surface of a given storey and the ceiling surface of the storey below, therefore an additional 250mm is added onto the internal height measurement to calculate the total storey height of any storey that isn't the ground floor (BRE Group, 2012). Summing the floor areas of multiple storeys yields the TFA of the dwelling and allows for the volume of the dwelling to be calculated.

The address and postcode of the dwelling can be used to categorise the age band of the dwelling (APPENDIX A).

3.2.2 Sheet 2 – Ventilation Rate

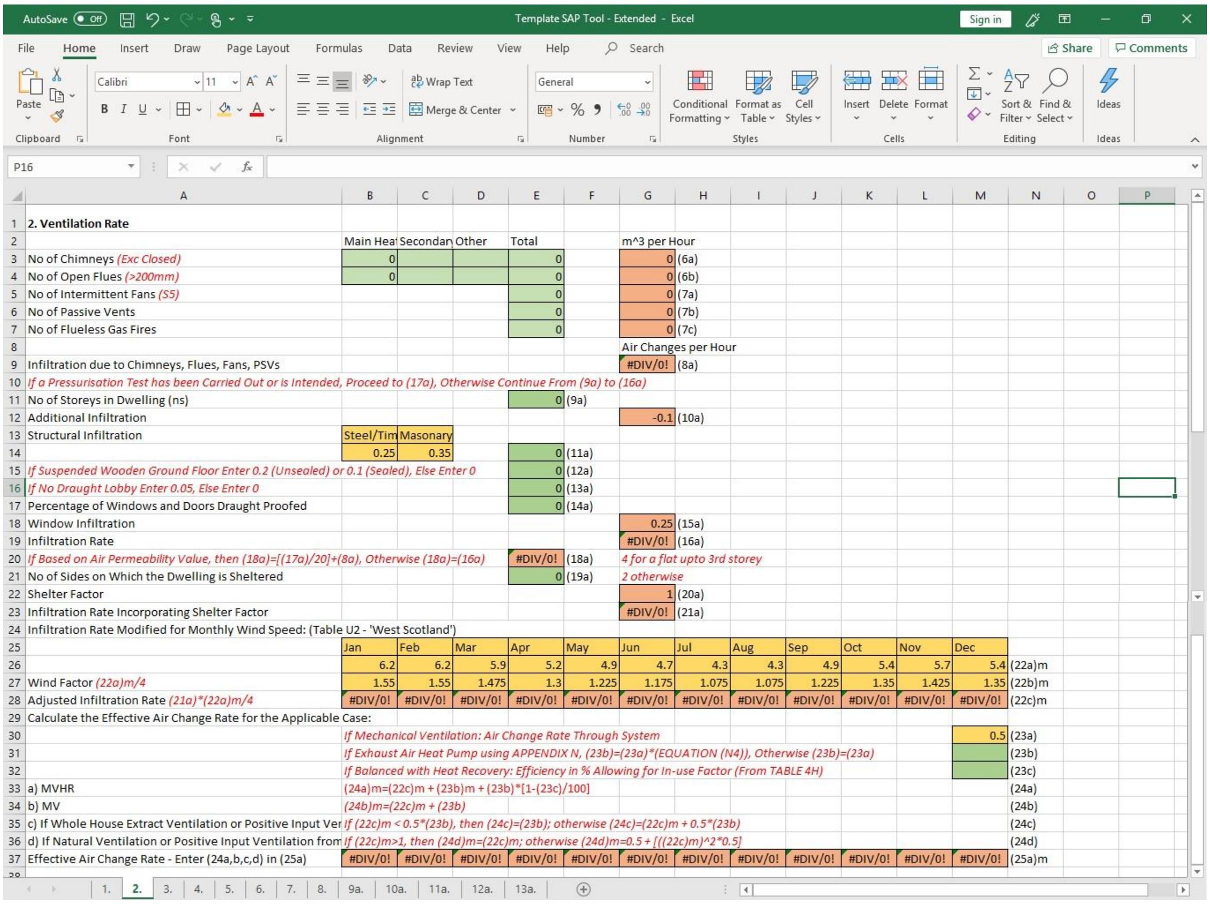


Figure 3.2 SAP Tool – Sheet 2

The ventilation air change rate is the rate at which outside air enters or leaves the building (BRE Group, 2012). The RdSAP for calculating the infiltration rate relies on information relating to the number of stories, the construction material, whether the ground floor has been suspended, whether there is a draught lobby and whether the windows and doors have been draught proofed. Additional to this, ventilation rates depend upon the quantity of chimneys, open flues, intermittent fans, passive vents and flueless gas fires as given in APPENDIX A. These variables are then combined with the average wind speed values from Table 3.1 to finalise the adjusted air change rate for the building.

The effective air change rate can then be calculated by an algorithm for the applicable case, relating to the ventilation system present and whether or there is a heat recovery system in place.

3.2.3 Sheet 3 – Heat Losses and HLP

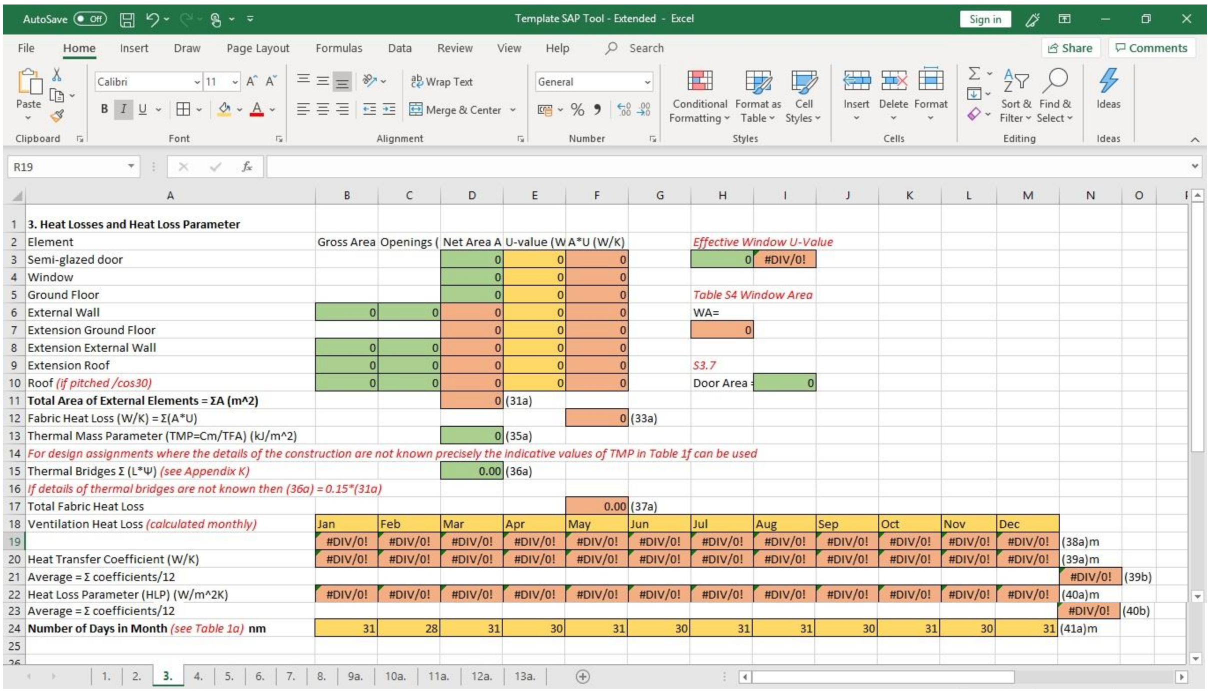


Figure 3.3 SAP Tool – Sheet 3

Heat transmission is based on the area of building elements on the exterior of the dwelling. As from the RdSAP, the area of an external door is taken to be 1.85m^2 and the area of all the windows in the building is formulated using Table 3.2 for a typical amount of glazing (BRE Group, 2012). All the other areas are obtained through measurement, some of which have been calculated in Section 3.2.1.

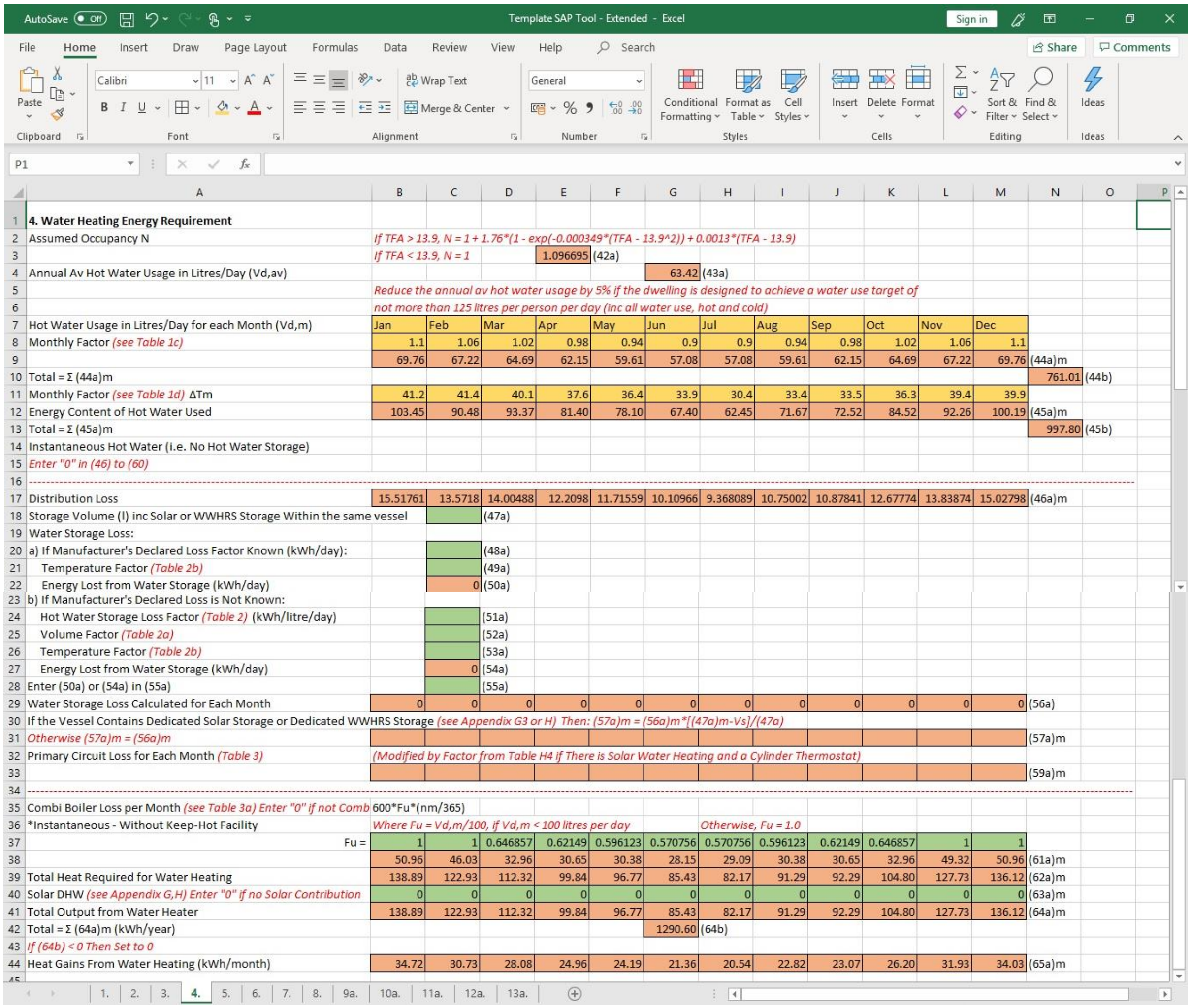
Table 3.2 Window Area (WA) (BRE Group, 2012)

Age Band	House or Bungalow	Flat or Maisonette
A,B,C	WA = 0.1220 TFA + 6.875	WA = 0.0801 TFA + 5.580
D	WA = 0.1294 TFA + 5.515	WA = 0.0341 TFA + 8.562
E	WA = 0.1239 TFA + 7.332	WA = 0.0717 TFA + 6.560
F	WA = 0.1252 TFA + 5.520	WA = 0.1199 TFA + 1.975
G	WA = 0.1356 TFA + 5.242	WA = 0.0510 TFA + 4.554
H	WA = 0.0948 TFA + 6.534	WA = 0.0813 TFA + 3.744
I	WA = 0.1382 TFA – 0.027	WA = 0.1148 TFA + 0.392
J,K,L	WA = 0.1435 TFA – 0.403	WA = 0.1148 TFA + 0.392

The total fabric heat loss is calculated by summing all individual building parts. This calculation should allow for different types of element were their U-values differ (BRE Group, 2012). A full list of U-values for windows, doors, external walls, party walls, roofs and floors can be found in APPENDIX A.

For the RdSAP the overall heat capacity of the building is not required and the thermal mass parameter (TMP) is taken as 250KJ/m²K (BRE Group, 2012). The values for thermal bridges are taken as 15% of the total external building elements (BRE Group, 2012). The ventilation heat loss calculated in Section 3.2.2 is summed together with the total fabric heat loss, yielding the monthly heat transfer coefficient and finally the HLP once divided by the TFA.

3.2.4 Sheet 4 – Water Heating Energy Requirement



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**4. Water Heating Energy Requirement**														
2	Assumed Occupancy N	*If TFA > 13.9, N = 1 + 1.76*(1 - exp(-0.000349*(TFA - 13.9^2)) + 0.0013*(TFA - 13.9)*													
3		*If TFA < 13.9, N = 1*			1.096695	(42a)									
4	Annual Av Hot Water Usage in Litres/Day (Vd,av)						63.42	(43a)							
5		*Reduce the annual av hot water usage by 5% if the dwelling is designed to achieve a water use target of*													
6		*not more than 125 litres per person per day (inc all water use, hot and cold)*													
7	Hot Water Usage in Litres/Day for each Month (Vd,m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
8	Monthly Factor *(see Table 1c)*	1.1	1.06	1.02	0.98	0.94	0.9	0.9	0.94	0.98	1.02	1.06	1.1		
9		69.76	67.22	64.69	62.15	59.61	57.08	57.08	59.61	62.15	64.69	67.22	69.76	(44a)m	
10	Total = Σ (44a)m													761.01	(44b)
11	Monthly Factor *(see Table 1d)* ΔTm	41.2	41.4	40.1	37.6	36.4	33.9	30.4	33.4	33.5	36.3	39.4	39.9		
12	Energy Content of Hot Water Used	103.45	90.48	93.37	81.40	78.10	67.40	62.45	71.67	72.52	84.52	92.26	100.19	(45a)m	
13	Total = Σ (45a)m													997.80	(45b)
14	Instantaneous Hot Water (i.e. No Hot Water Storage)														
15	*Enter "0" in (46) to (60)*														
16	--														
17	Distribution Loss	15.51761	13.5718	14.00488	12.2098	11.71559	10.10966	9.368089	10.75002	10.87841	12.67774	13.83874	15.02798	(46a)m	
18	Storage Volume (l) inc Solar or WWHRS Storage Within the same vessel			(47a)											
19	Water Storage Loss:														
20	a) If Manufacturer's Declared Loss Factor Known (kWh/day):			(48a)											
21	Temperature Factor *(Table 2b)*			(49a)											
22	Energy Lost from Water Storage (kWh/day)		0	(50a)											
23	b) If Manufacturer's Declared Loss is Not Known:														
24	Hot Water Storage Loss Factor *(Table 2)* (kWh/litre/day)			(51a)											
25	Volume Factor *(Table 2a)*			(52a)											
26	Temperature Factor *(Table 2b)*			(53a)											
27	Energy Lost from Water Storage (kWh/day)		0	(54a)											
28	Enter (50a) or (54a) in (55a)			(55a)											
29	Water Storage Loss Calculated for Each Month	0	0	0	0	0	0	0	0	0	0	0	0	(56a)	
30	If the Vessel Contains Dedicated Solar Storage or Dedicated WWHRS Storage *(see Appendix G3 or H) Then: (57a)m = (56a)m*[(47a)m-Vs]/(47a)*														
31	*Otherwise (57a)m = (56a)m*													(57a)m	
32	Primary Circuit Loss for Each Month *(Table 3)*	*(Modified by Factor from Table H4 if There is Solar Water Heating and a Cylinder Thermostat)*													
33														(59a)m	
34	--														
35	Combi Boiler Loss per Month *(see Table 3a) Enter "0" if not Comb*	600*Fu*(nm/365)													
36	*Instantaneous - Without Keep-Hot Facility	*Where Fu = Vd,m/100, if Vd,m < 100 litres per day*						*Otherwise, Fu = 1.0*							
37	Fu =	1	1	0.646857	0.62149	0.596123	0.570756	0.570756	0.596123	0.62149	0.646857	1	1		
38		50.96	46.03	32.96	30.65	30.38	28.15	29.09	30.38	30.65	32.96	49.32	50.96	(61a)m	
39	Total Heat Required for Water Heating	138.89	122.93	112.32	99.84	96.77	85.43	82.17	91.29	92.29	104.80	127.73	136.12	(62a)m	
40	Solar DHW *(see Appendix G,H) Enter "0" if no Solar Contribution*	0	0	0	0	0	0	0	0	0	0	0	0	(63a)m	
41	Total Output from Water Heater	138.89	122.93	112.32	99.84	96.77	85.43	82.17	91.29	92.29	104.80	127.73	136.12	(64a)m	
42	Total = Σ (64a)m (kWh/year)						1290.60	(64b)							
43	*If (64b) < 0 Then Set to 0*														
44	Heat Gains From Water Heating (kWh/month)	34.72	30.73	28.08	24.96	24.19	21.36	20.54	22.82	23.07	26.20	31.93	34.03	(65a)m	

Figure 3.4 SAP Tool – Sheet 4

The domestic hot water demand is derived from the TFA and based on the assumed occupancy (N) of the dwelling (BRE Group, 2012):

if TFA > 13.9, N = 1+1.76×[1-exp(-0.000349× {TFA– 13.9}^{2})]+0.0013×(TFA- 13.9)

if TFA $\leq$ 13.9, N = 1

N allows for the calculation of the annual average hot water usage (l/day) (BRE Group, 2012):

$V_{d,average}$ = (25 × N) + 36

This is transformed into a monthly value $V_{d,m}$, by multiplying by the factor from Table 3.3.

Table 3.3 Monthly Factors for Hot Water Use (BRE Group, 2012)

Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1.10	1.06	1.02	0.98	0.94	0.90	0.90	0.94	0.98	1.02	1.06	1.10

The energy content in the hot water can be calculated (BRE Group, 2012):

E_m = 4.18 × $V_{d,m}$ × n_m × ΔT_m / 3600

where,

n_m is the number of days in each month

ΔT_m (K) is the temperature rise of hot water drawn off (Table 3.4)

Table 3.4 Temperature Rise of Hot Water Drawn Off (K) (BRE Group, 2012)

Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
41.2	41.4	40.1	37.6	36.4	33.9	30.4	33.4	33.5	36.3	39.4	39.9

The combi loss is calculated for each month (BRE Group, 2012):

C_{LOSS} = 600 × f_u × n_m / 365

Where,

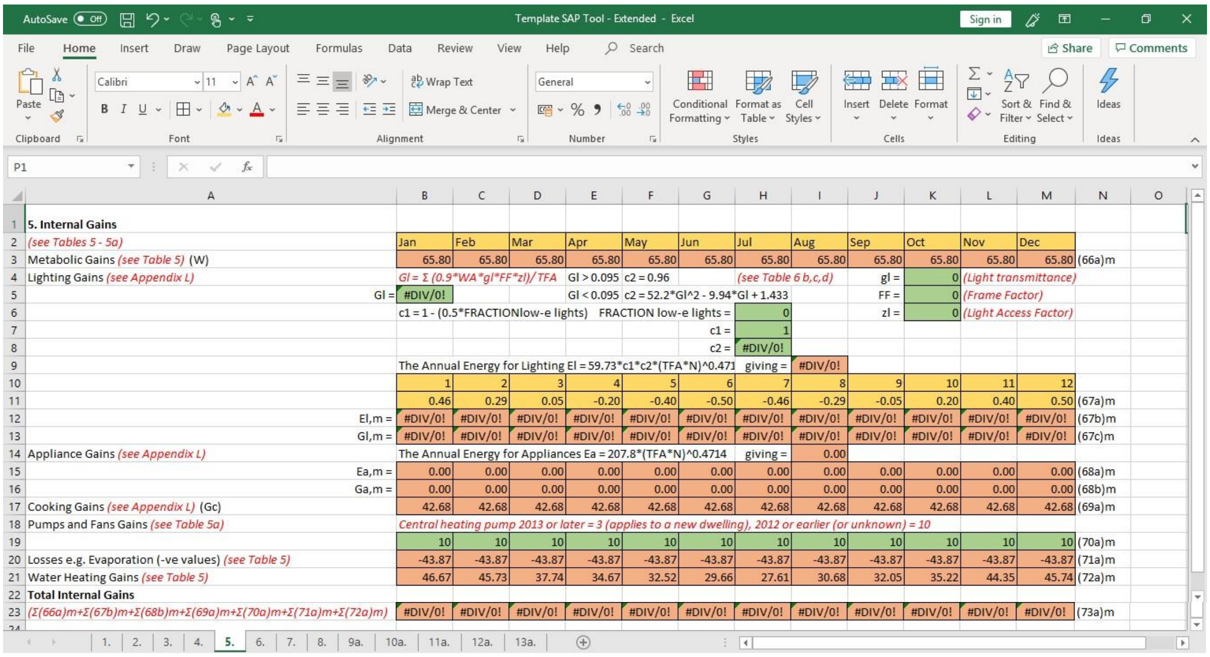
if $V_{d,m}$ < 100 litres per day, then $f_u = V_{d,m}$ / 100

otherwise f_u = 1

The heat gains from water heating (G_W) can be calculated (BRE Group, 2012):

$G_W = 0.25 \times (0.85 \times E_m + C_{LOSS})$

3.2.5 Sheet 5 – Internal Gains



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**5. Internal Gains**													
2	*(see Tables 5 - 5a)*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
3	Metabolic Gains *(see Table 5)* (W)	65.80	65.80	65.80	65.80	65.80	65.80	65.80	65.80	65.80	65.80	65.80	65.80	(66a)m
4	Lighting Gains *(see Appendix L)*	*Gl = Σ (0.9*WA*gl*FF*zl)/ TFA*			Gl > 0.095	c2 = 0.96		*(see Table 6 b,c,d)*		gl =	0	*(Light transmittance)*		
5	Gl =	#DIV/0!			Gl < 0.095	c2 = 52.2*Gl^2 - 9.94*Gl + 1.433				FF =	0	*(Frame Factor)*		
6		c1 = 1 - (0.5*FRACTIONlow-e lights)				FRACTION low-e lights =		0		zl =	0	*(Light Access Factor)*		
7							c1 =	1						
8							c2 =	#DIV/0!						
9		The Annual Energy for Lighting El = 59.73*c1*c2*(TFA*N)^0.471						giving =	#DIV/0!					
10		1	2	3	4	5	6	7	8	9	10	11	12	
11		0.46	0.29	0.05	-0.20	-0.40	-0.50	-0.46	-0.29	-0.05	0.20	0.40	0.50	(67a)m
12	El,m =	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	(67b)m
13	Gl,m =	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	(67c)m
14	Appliance Gains *(see Appendix L)*	The Annual Energy for Appliances Ea = 207.8*(TFA*N)^0.4714						giving =	0.00					
15	Ea,m =	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(68a)m
16	Ga,m =	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(68b)m
17	Cooking Gains *(see Appendix L)* (Gc)	42.68	42.68	42.68	42.68	42.68	42.68	42.68	42.68	42.68	42.68	42.68	42.68	(69a)m
18	Pumps and Fans Gains *(see Table 5a)*	*Central heating pump 2013 or later = 3 (applies to a new dwelling), 2012 or earlier (or unknown) = 10*												
19		10	10	10	10	10	10	10	10	10	10	10	10	(70a)m
20	Losses e.g. Evaporation (-ve values) *(see Table 5)*	-43.87	-43.87	-43.87	-43.87	-43.87	-43.87	-43.87	-43.87	-43.87	-43.87	-43.87	-43.87	(71a)m
21	Water Heating Gains *(see Table 5)*	46.67	45.73	37.74	34.67	32.52	29.66	27.61	30.68	32.05	35.22	44.35	45.74	(72a)m
22	**Total Internal Gains**													
23	*(Σ(66a)m+Σ(67b)m+Σ(68b)m+Σ(69a)m+Σ(70a)m+Σ(71a)m+Σ(72a)m)*	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	(73a)m

Figure 3.5 SAP Tool – Sheet 5

Metabolic gains (G_M) are calculated for each respective month as (BRE Group, 2012):

$$G_M = 60 \times N$$

Lighting gains depend on a number on factors. Analysis gives a correction factor G_L which depends on the ratio of window area (A_w) to floor area, the glass transmittance (g_L) (APPENDIX A), the frame factor (FF) and the light access factor (Z_L) (BRE Group, 2012):

$$G_L = (\Sigma\, 0.9 \times A_w \times g_L \times FF \times Z_L)/TFA$$

If the window frame is constructed from polyvinyl chloride (PVC), the FF is 0.7 and the average value for Z_L = 0.83. The initial value for the annual lighting used in the dwelling (E_L) is (BRE Group, 2012):

$$E_L = 59.73 \times (TFA \times N)^{0.4714} \times (1 - 0.50 \times \%\text{low-energy lights}) \times C_2$$

$$\text{if } G_L \leq 0.095,\ C_2 = 52.2 \times G_L{}^2 - 9.94 \times G_L + 1.433$$

$$\text{if } G_L > 0.095,\ C_2 = 0.96$$

This is converted to a monthly value in Watts (BRE Group, 2012):

$$E_{L,m} = E_L \times [1 + 0.5 \times \cos(2\pi(m - 0.2)/12)] \times n_m/365$$

The initial value for the annual energy consumption for electrical appliances is:

$$E_A = 207.8 \times (TFA \times N)^{0.4714}$$

This is converted to a monthly value in Watts (BRE Group, 2012):

$$E_{A.m} = E_A \times [1 + 0.157 \times \cos(2\pi(m - 01.78/12)] \times n_m/365$$

The internal gains calculated for each month from cooking (G_C) (BRE Group, 2012):

$$G_C = 35 + 7N$$

Gains from pumps and fans (G_P) for a standard combi boiler are given in Table 3.5

Table 3.5 Central Heating Gains per Month (BRE Group, 2012)

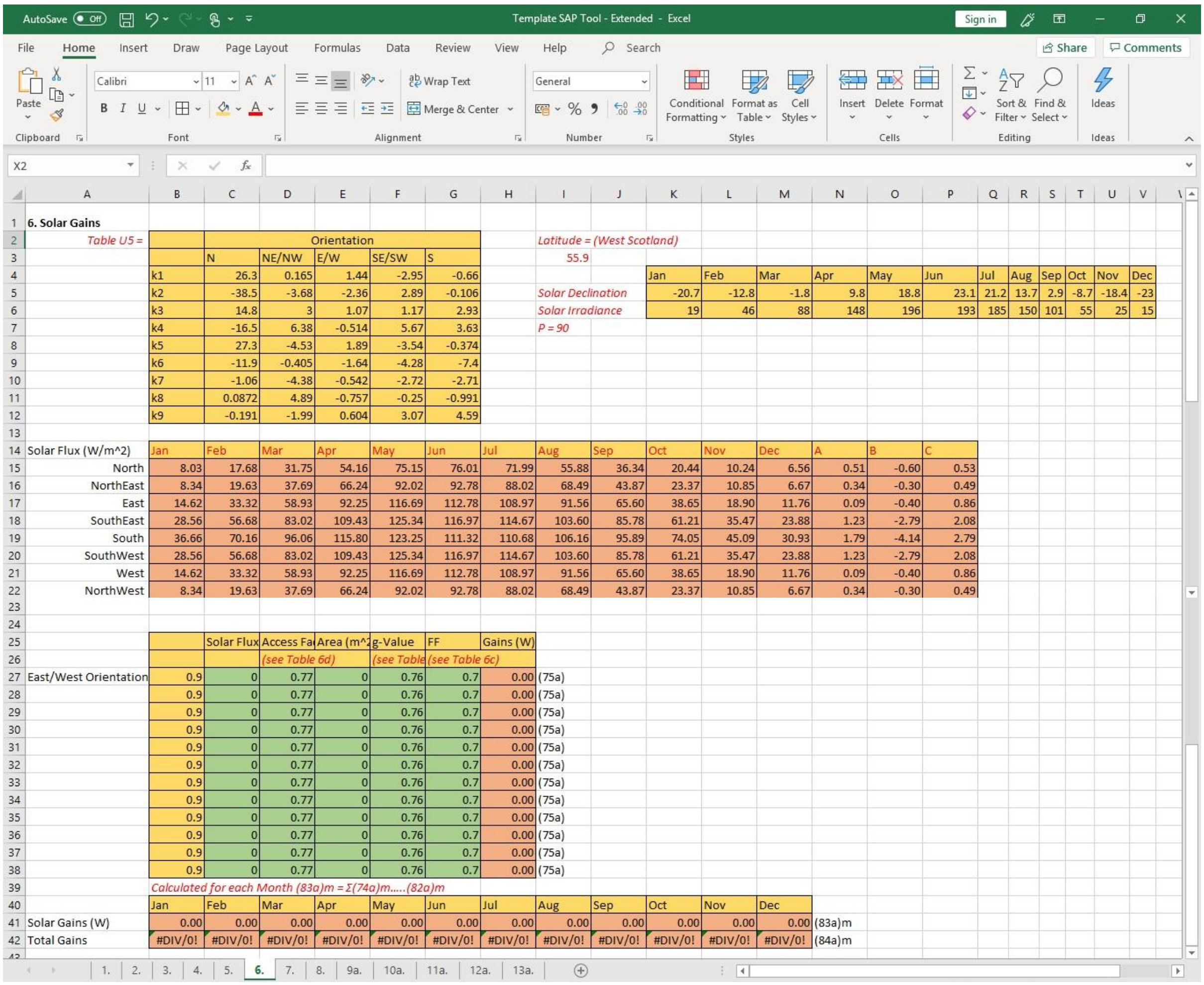
Central Heating Pump	Gains (W)
2013 or later	3
2012 or earlier	10

Various losses (e.g. from evaporation) are calculated as (BRE Group, 2012):

$$G_{LOSS} = -40 \times N$$

Summing all the gains, together with the gains from water heating calculated in Section 3.2.4 (converted from kWh/month into W), yields the total internal gains present in the dwelling.

3.2.6 Sheet 6 – Solar Gains



6. Solar Gains

Table U5 =		Orientation				
		N	NE/NW	E/W	SE/SW	S
	k1	26.3	0.165	1.44	-2.95	-0.66
	k2	-38.5	-3.68	-2.36	2.89	-0.106
	k3	14.8	3	1.07	1.17	2.93
	k4	-16.5	6.38	-0.514	5.67	3.63
	k5	27.3	-4.53	1.89	-3.54	-0.374
	k6	-11.9	-0.405	-1.64	-4.28	-7.4
	k7	-1.06	-4.38	-0.542	-2.72	-2.71
	k8	0.0872	4.89	-0.757	-0.25	-0.991
	k9	-0.191	-1.99	0.604	3.07	4.59

Latitude = (West Scotland)
55.9

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar Declination	-20.7	-12.8	-1.8	9.8	18.8	23.1	21.2	13.7	2.9	-8.7	-18.4	-23
Solar Irradiance	19	46	88	148	196	193	185	150	101	55	25	15

P = 90

Solar Flux (W/m^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	A	B	C
North	8.03	17.68	31.75	54.16	75.15	76.01	71.99	55.88	36.34	20.44	10.24	6.56	0.51	-0.60	0.53
NorthEast	8.34	19.63	37.69	66.24	92.02	92.78	88.02	68.49	43.87	23.37	10.85	6.67	0.34	-0.30	0.49
East	14.62	33.32	58.93	92.25	116.69	112.78	108.97	91.56	65.60	38.65	18.90	11.76	0.09	-0.40	0.86
SouthEast	28.56	56.68	83.02	109.43	125.34	116.97	114.67	103.60	85.78	61.21	35.47	23.88	1.23	-2.79	2.08
South	36.66	70.16	96.06	115.80	123.25	111.32	110.68	106.16	95.89	74.05	45.09	30.93	1.79	-4.14	2.79
SouthWest	28.56	56.68	83.02	109.43	125.34	116.97	114.67	103.60	85.78	61.21	35.47	23.88	1.23	-2.79	2.08
West	14.62	33.32	58.93	92.25	116.69	112.78	108.97	91.56	65.60	38.65	18.90	11.76	0.09	-0.40	0.86
NorthWest	8.34	19.63	37.69	66.24	92.02	92.78	88.02	68.49	43.87	23.37	10.85	6.67	0.34	-0.30	0.49

		Solar Flux	Access Fa	Area (m^2	g-Value	FF	Gains (W)	
			(see Table 6d)		(see Table	(see Table 6c)		
East/West Orientation	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)
	0.9	0	0.77	0	0.76	0.7	0.00	(75a)

Calculated for each Month (83a)m = Σ(74a)m.....(82a)m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Solar Gains (W)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(83a)m
Total Gains	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	(84a)m

Figure 3.6 SAP Tool – Sheet 6

The heat gains through windows and glazed doors is calculated as (BRE Group, 2012):

$$G_L = 0.9 \times A_w \times g_{\perp} \times S \times FF \times Z_L$$

where,

$g_{\perp}$ is the total solar energy transmittance factor of the glazing at normal incidence

S is the solar flux on the applicable surface

The solar flux is dependent upon the position of the window. As from RdSAP all windows are assumed to have an East/West orientation (BRE Group, 2012).

The solar radiation present on the window surface is given from (BRE Group, 2012):

$$S = A \times \cos^2(\phi - \delta) + B \times \cos(\phi - \delta) + C$$

$$A = k_1 \times \sin^3(p/2) + k_2 \times \sin^2(p/2) + k_3 \times \sin(p/2)$$

$$B = k_4 \times \sin^3(p/2) + k_5 \times \sin^2(p/2) + k_6 \times \sin(p/2)$$

$$C = k_7 \times \sin^3(p/2) + k_8 \times \sin^2(p/2) + k_9 \times \sin(p/2) + 1$$

where,

ϕ is the latitude (Table 3.1)

δ is the solar declination (Table 3.1)

p is the tilt (90° for windows or doors)

k_x are constants for the calculation of solar flux on non-horizontal surfaces, for the East/West orientation (APPENDIX A)

3.2.7 Sheet 7 – Mean Internal Temperature

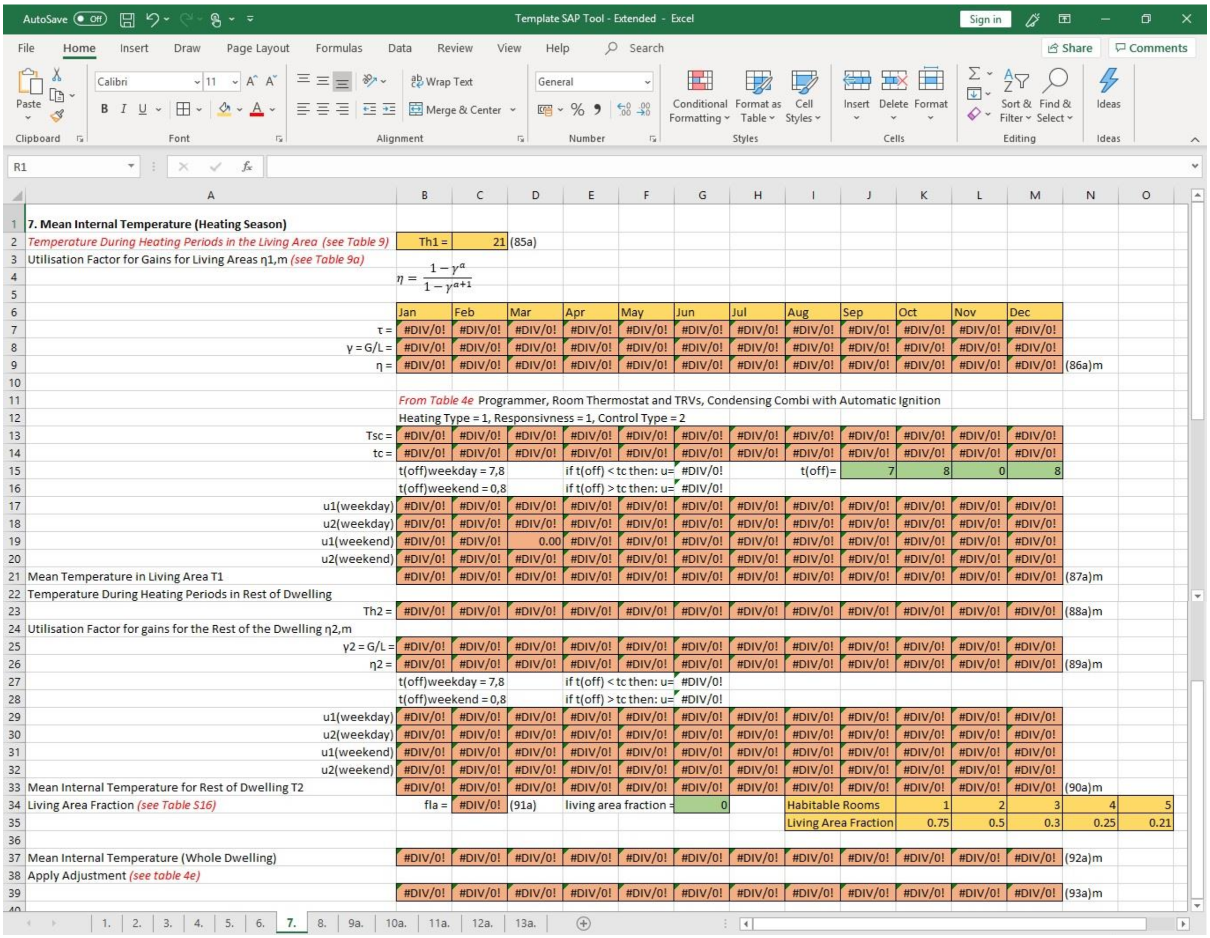


Figure 3.7 SAP Tool – Sheet 7

The temperature during heating periods in the living area (T_{h1}) is set to 21°C (BRE Group, 2012).

The internal temperature without heating (T_{sc}) is given from (BRE Group, 2012):

$$T_{sc} = (1-R)\times(T_{h1} - 2.0) + R\,(T_e + \eta G/H)$$

where,

R is the responsiveness of the heating system (for a standard combi boiler with a programmer, thermostat and thermostatic radiator valves (TRVs), R = 1)

T_e is the monthly average external temperature (Table 3.1)

η the utilisation factor for gains

η is dependent on the ratio of the total gains (G) to heat loss rate (L) (BRE Group, 2012):

$$\gamma = G/L$$

$$\eta = 1 - \gamma^{a}/1 - \gamma^{a+1}$$

where,

$$a = 1 + (TMP/3.6\times HLP)/15$$

The hours of heating for a combi system are between 0700-0900 and 1600-2300 for weekdays and 0700-2300 for weekends. The hours the heating is off is referred to as t_{off} .

The mean internal temperature for the living area is given by:

$$T_1 = (5\{T_h - (u_1 + u_2)\} + 2\{T_h - (u_1 + u_2)\}/7$$

$$t_c = 4 + (TMP/3.6\times HLP)/4$$

if $t_{off} \leq t_c$ then, $u = 0.5t_{off}^{2} \times (T_h - T_{sc})/(24\times t_c)$

if $t_{off} > t_c$ then, $u = (T_h - T_{sc}) \times (t_{off} - 0.5t_c)/24$

To calculate the mean internal temperature for the rest of the dwelling (T_2), the same process is repeated though the internal temperature is changed to the temperature for elsewhere in the dwelling during the heating periods (T_{h2}):

$$T_{h2} = 21 - HLP + HLP^{2}/12$$

The mean internal temperature for the whole dwelling is given by (BRE Group, 2012):

$$T_m = f_{LA} \times T_1 + (1 - f_{LA}) \times T_2$$

where,

f_{LA} is the living area fraction (APPENDIX A) / TFA

3.2.8 Sheet 8 – Space Heating Requirement

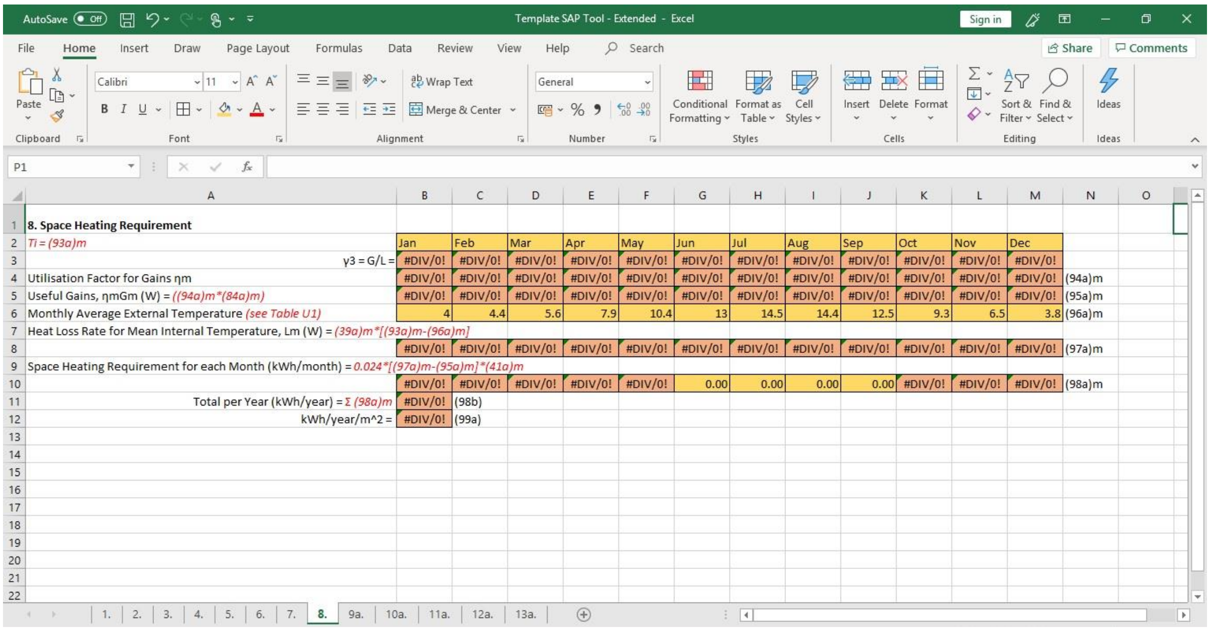


Figure 3.8 SAP Tool – Sheet 8

The same process as in Spreadsheet 7 is followed though the internal temperature is changed once more to the mean internal temperature for the whole dwelling, calculated in the previous step.

Once the new utilisation factor (η_m) is calculated, the useful gains ($\eta_m G_m$) can be obtained, summing the total internal and solar gains and multiplying them by η_m.

This allows the heat loss rate (L_m) for the mean internal temperature to be calculated, multiplying the heat transfer coefficient (Sheet 3) with the difference between the temperature calculated and the external air temperature (Table 3.1).

The space heating requirement for each month is then given by:

$$0.024 \times [L_m - \eta_m G_m] \times n_m \text{ (kWh/month)}$$

Summing over all the months when space heating is required (January-May, August-December) yields the annual space heating requirement (BRE Group, 2012).

3.2.9 Sheet 9a – Energy Requirements

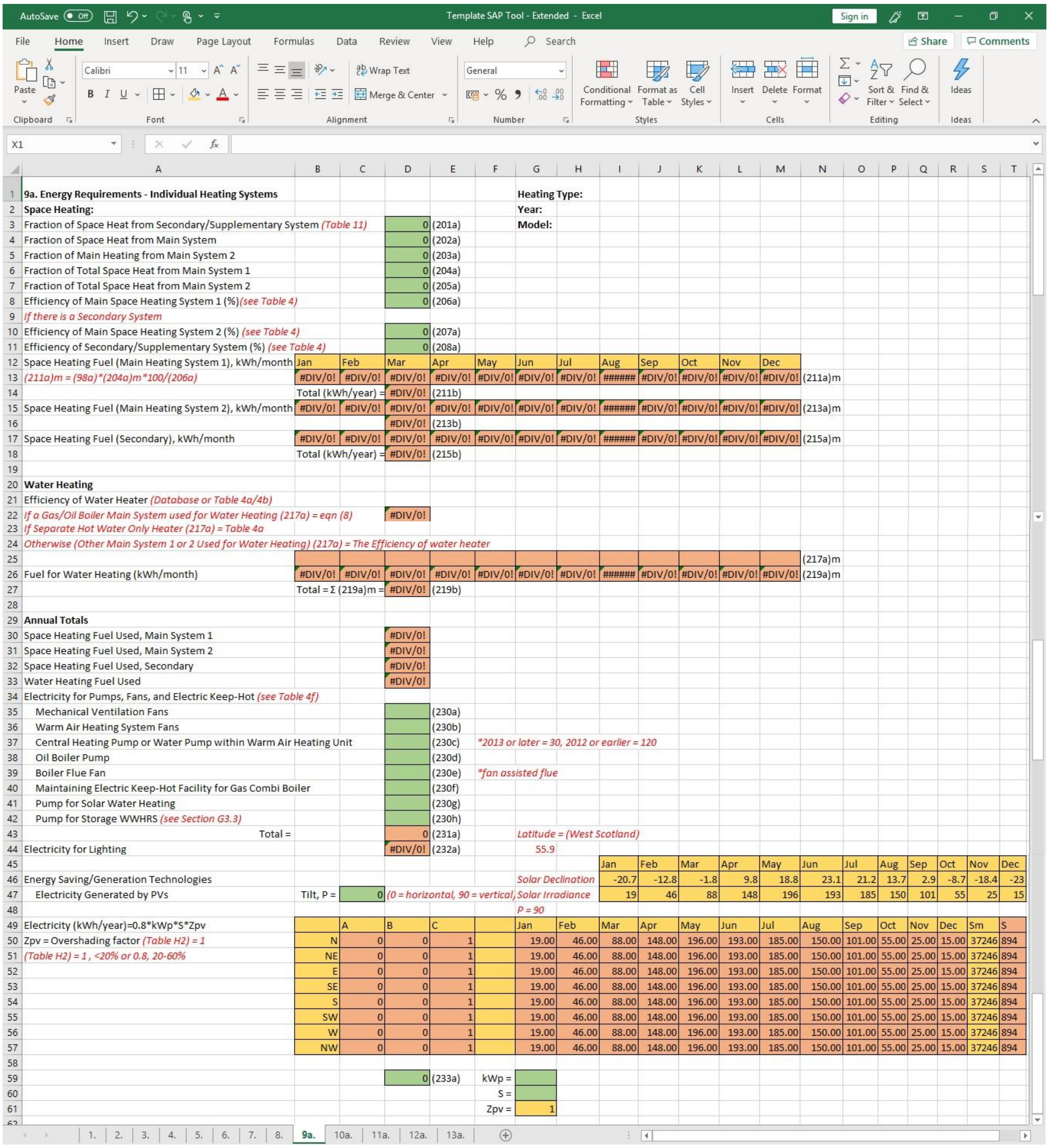


Figure 3.9 SAP Tool – Sheet 9a

The fraction of space heating from the primary or secondary system is identified. If there is no secondary system, then the primary system will be providing 100%. The efficiency of the heating system must be known. A products characteristics database (PCDB) is made available to look-up values that are unknown, provided the make and model of the system are known (NCM, 2019).

Using the efficiency and the fraction provided, the amount of fuel required to produce the required heating is calculated. Similarly, this is repeated for water heating in order to yield the amount of fuel required for water heating as well. There is a summary of all the annual energy totals for all the respective building elements that constitute the total energy consumption of the dwelling, effectively summarising the previous 8 sections.

The quantity of energy yielded through generation technologies (if present), is calculated and deducted off the demand for the dwelling, leaving the net amount of energy that is required.

3.2.10 Sheet 10a – Fuel Costs

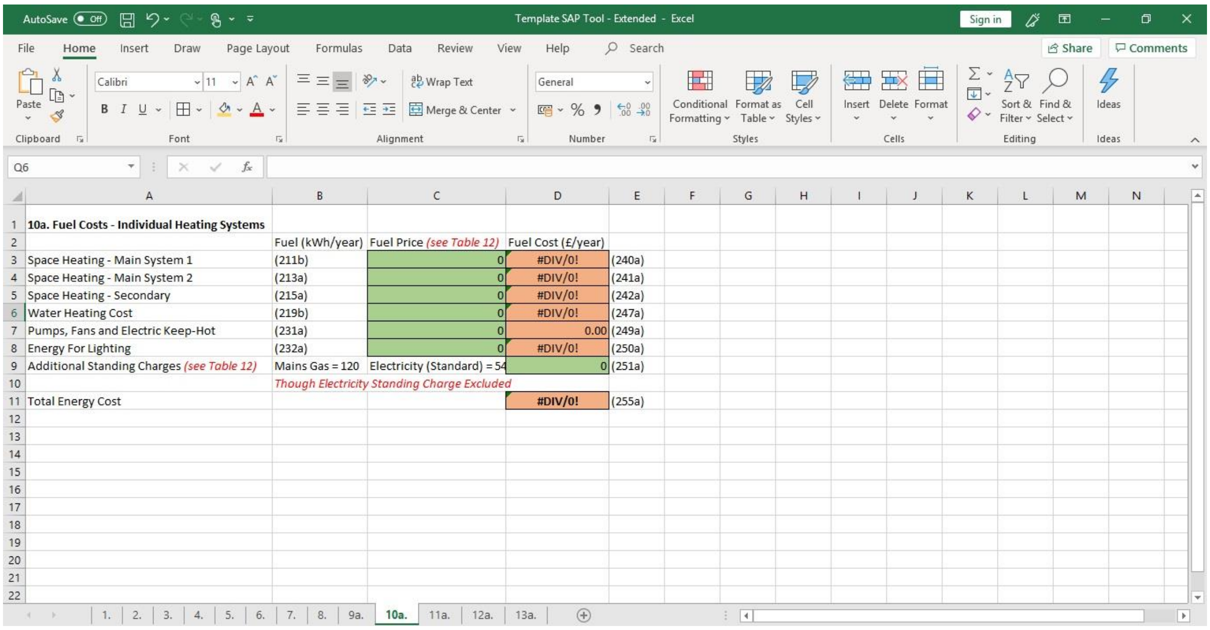


Figure 3.10 SAP Tool – Sheet 10

The fuel cost associated with providing each specific energy cost is calculated. The fuel costs are an average over the previous three years and are listed in APPENDIX A. Mains gas is 3.48 p/kWh and electricity 13.19 p/kWh (BRE Group, 2012). Additional standing charges are also factored in (APPENDIX A). The only charge omitted is the standing charge for electricity (£54) with the rationale being that everyone is connected to the electricity mains, so everyone must pay this amount regardless (Scottish Government, 2015). If there are any generation technologies present, then these are deducted from the totals. The total energy cost is then summed.

3.2.11 Sheet 11a – SAP Rating

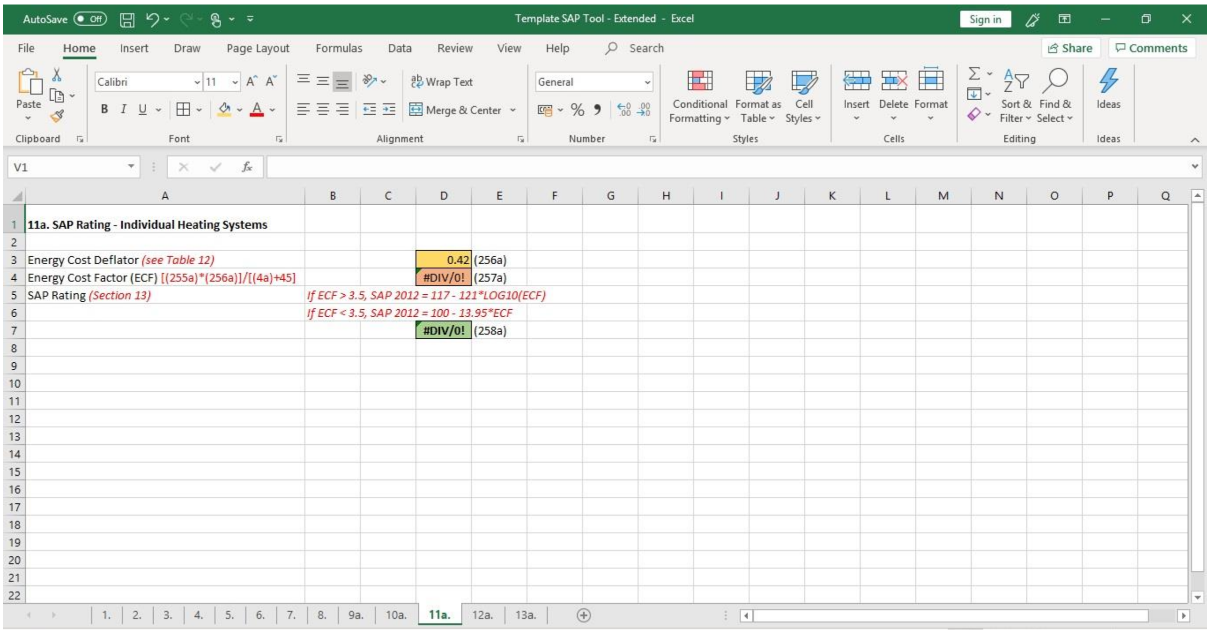


Figure 3.11 SAP Tool – Sheet 11

The SAP rating is calculated. The SAP rating is related to the total energy cost by an energy cost factor (ECF) (BRE Group, 2012):

$$ECF = 0.42 \times \text{total energy cost} / (TFA + 45)$$

if $ECF \geq 3.5$, $SAP\ 2012 = 117 - 121 \times \log_{10}(ECF)$

if $ECF < 3.5$, $SAP\ 2012 = 100 - 13.95 \times ECF$

3.2.12 Sheet 12a – CO_2 Emissions

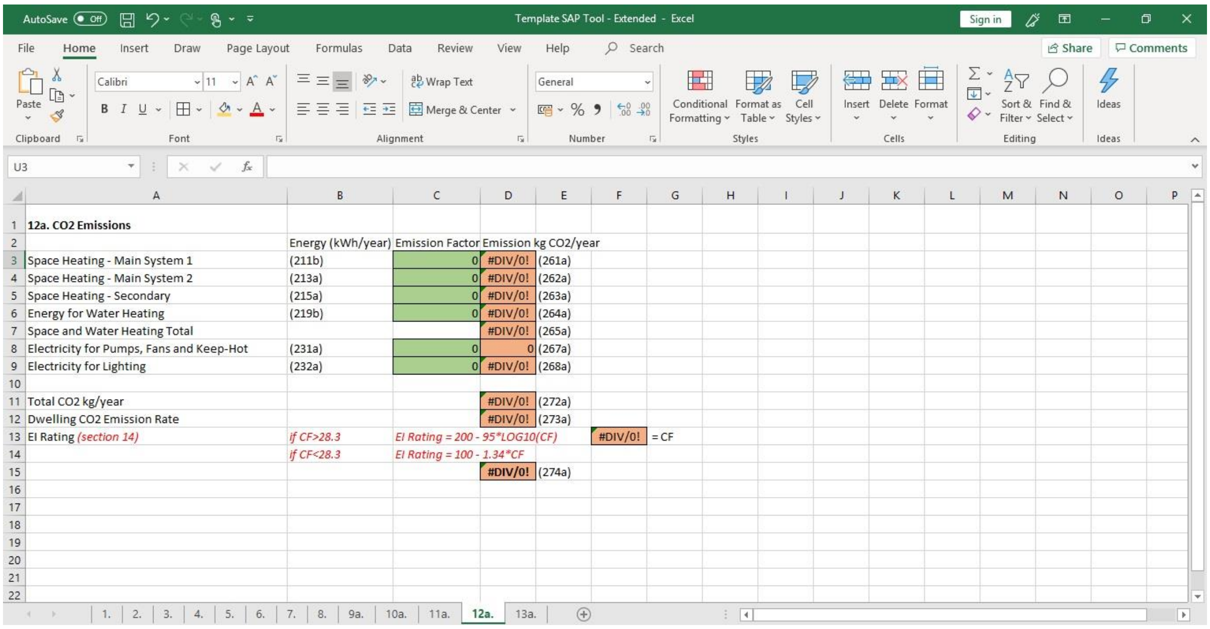


Figure 3.12 SAP Tool – Sheet 12

The annual CO_2 emissions are calculated for each individual energy consuming element of the dwelling, using the emission factor from APPENDIX A. If any generation technologies are present, then these are subtracted from the total amount. The dwellings CO_2 emissions rate is calculated by dividing the total number of emissions by the TFA (BRE Group, 2012).

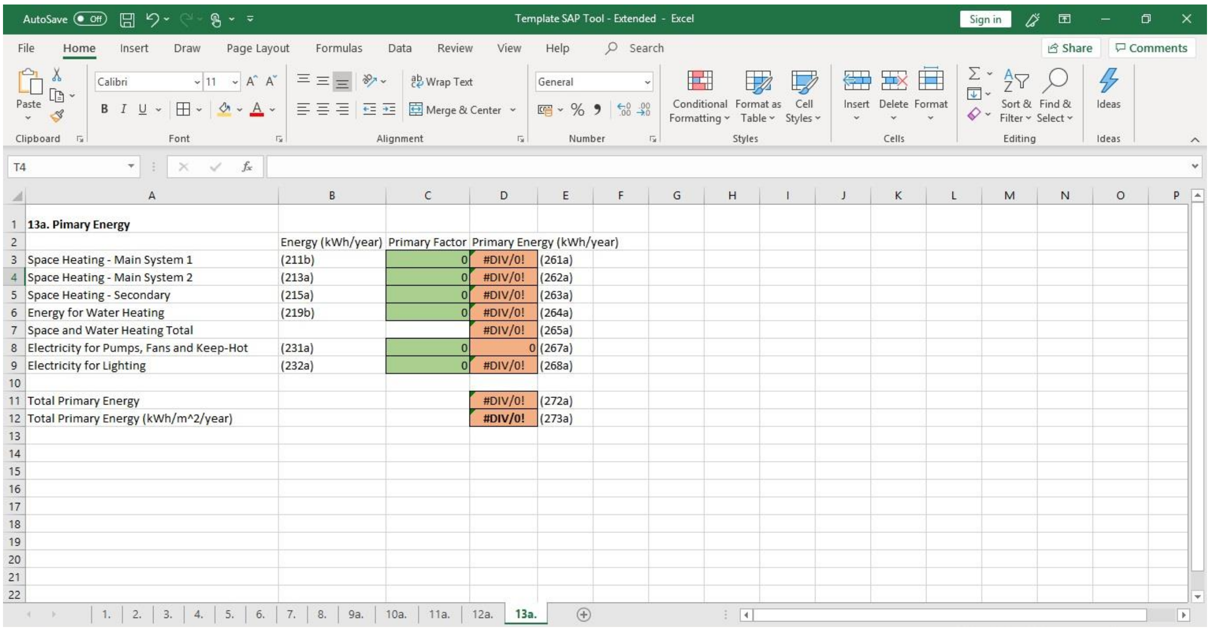
Then the EI rating can be calculated. The EI rating is related to the annual CO_2 emissions by (BRE Group, 2012):

$$CF = (CO_2 \text{ emissions}) / (TFA + 45)$$

if $CF \geq 28.3$, the EI rating = $200 - 95 \times \log_{10}(CF)$

if $CF < 28.3$, the EI rating = $100 - 1.34 \times CF$

3.2.12 Sheet 13a – Primary Energy



	A	B	C	D	E
1	13a. Pimary Energy				
2		Energy (kWh/year)	Primary Factor	Primary Energy (kWh/year)	
3	Space Heating - Main System 1	(211b)	0	#DIV/0!	(261a)
4	Space Heating - Main System 2	(213a)	0	#DIV/0!	(262a)
5	Space Heating - Secondary	(215a)	0	#DIV/0!	(263a)
6	Energy for Water Heating	(219b)	0	#DIV/0!	(264a)
7	Space and Water Heating Total			#DIV/0!	(265a)
8	Electricity for Pumps, Fans and Keep-Hot	(231a)	0	0	(267a)
9	Electricity for Lighting	(232a)	0	#DIV/0!	(268a)
10					
11	Total Primary Energy			#DIV/0!	(272a)
12	Total Primary Energy (kWh/m^2/year)			#DIV/0!	(273a)

Figure 3.13 SAP Tool – Sheet 13

Similar to the primary emissions factor, the primary energy factor is calculated using APPENDIX A. The primary emissions factors are summed, less any generation technologies to yield the total amount of energy consumed by the dwelling. Dividing by the TFA allows the total energy used to be determined.

4. Results Analysis

4.1 Overview

Initially 3 properties were surveyed according to the RdSAP criteria from APPENDIX D and the results loaded into the SAP tool. This allowed a full SAP report to be modelled for each dwelling. The postcodes of the dwellings have been left intact though the specific house number has been redacted for discretion, listed in Table 4.1. The buildings are referred to as: Dwelling 1, 2 and 3 respectively. These buildings were specifically selected as all of them have recently been sold or rented, therefore already have an up to date EPC, used to validate the accuracy of the tool (Energy Saving Trust, 2019).

Table 4.1 Dwelling Location [APPENDIX B]

	Location	Postcode
Dwelling 1	Old Kilpatrick, Glasgow	G60 5EA
Dwelling 2	Duntocher, Clydebank	G81 6HP
Dwelling 3	Clydebank	G81 3QW

Each dwelling was simulated in the SAP tool created to produce the equivalent of an EPC report. For clarity of the construction of the building, the dwelling will be summarised according to:

- The building envelope in terms of construction materials, insulation levels, u-values and the net area for each building part can be summarised.
- The buildings heating system and efficiency.
- The fraction of low-E lighting units present.
- The costs associated with individual energy requirements.
- The final output results of the tool: TFA, energy cost, quantity of CO_2, primary energy and SAP/EI ratings.

4.1.1 Dwelling 1

This dwelling is a 2 storey, end-terrace house, that consists of 4 habitable rooms which are all heated from the main system. There is a small extension to the rear of the building. The floor plan is shown in Figure 4.1. The main building part is categorised as an age band F category and the extension is band J. The building envelope is summarised in Table 4.2.

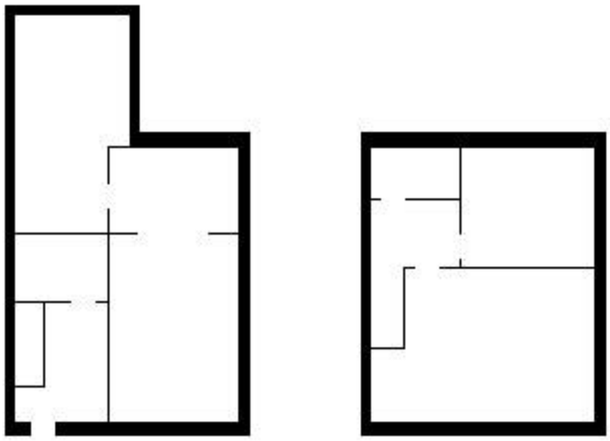


Figure 4.1 Dwelling 1 – Floor Plan

Table 4.2 Dwelling 1 - Building Envelope Summary

Element	Building Part	Description	U-value	Net Area (m^2)
Walls	Main	System built, 50mm external insulation	0.45	82.56
	Party	System built	0	31.74
	Extension	Timber frame as built, internal insulation (assumed)	0.3	18.52
Roof(s)	Main	Pitched slate (access to loft), 150mm insulation (between joists)	0.3	39.26
	Extension	Pitched slate (no access to loft), insulation (assumed)	0.16	10.74
Floor(s)	Main	Suspended timber, no insulation (assumed)	0.77	36.69
	Extension	Suspended timber, insulation (assumed)	0.22	9.3
Windows	All	Fully double glazed, 100% draught proofed	1.85	15.53
Door(s)	All	Semi glazed, 100% draught proofed	3	1.85

The heating system present is the: Viessmann Vitodens 100 WB1A 24 kW (2007), condensing combi boiler (automatic ignition) with an annual efficiency of 89%. The hot water stems from this system and there was no secondary system present. The percentage of low-E lighting units in the house was 0%.

The total equivalent energy required for: space heating, hot water, lighting and electricity for pumps and fans is given in Table 4.3.

Table 4.3 Dwelling 1 - Energy Requirements

Energy Requirements	Fuel Used (kWh/year)
Space heating	9562
Water heating	2247
Electricity for pumps and fans	165
Electricity for lighting	698

The total cost of energy for the dwelling per year is $645. The SAP algorithm calculator produces an SAP rating of 70 which lies in the band C category for EER, which is above the Scottish average of a D. The dwelling produces about 3 tonnes of CO_2 per year, equating to an EI rating of 68. The total primary energy indicator for the dwelling was 213kWh/m^2/year.

4.1.2 Dwelling 2

This dwelling is a single storey, top-floor flat, consisting of 3 habitable rooms all of which are heated. The floor plan is shown in Figure 4.2. The age band for the dwelling is I and the building envelope is summarised in Table 4.4.

The heating system present is the: Worcester Greenstar 24i Junior (2005), condensing combi boiler (automatic ignition) with an annual efficiency of 89%. The hot water comes from the main heating system and there was no secondary system.

The full dwelling has been installed with low-E lighting units, in the form of L.E.D bulbs.

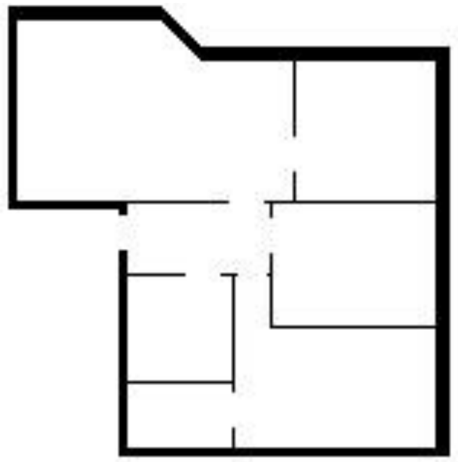


Figure 4.2 Dwelling 2 – Floor Plan

Table 4.4 Dwelling 2 - Building Envelope Summary

Element	Building Part	Description	U-value	Net Area (m^2)
Walls	Main	Timber frame as built, insulation (assumed)	0.45	34.70
	Party	Timber fame as built	0	20.65
	Party (Unheated Corridor)	Timber frame as built	0.38	12.89
Roof(s)	Main	Pitched slate (access to loft), 200mm insulation (between joists)	0.21	70.36
Floor(s)	Main	Another dwelling below	0	60.93
Windows	All	Fully double glazed, 100% draught proofed	1.85	13.67
Door(s)	All	Solid wood, 100% draught proofed, included in the party wall to unheated corridor	n/a	1.85

The total equivalent energy required for: space heating, hot water, lighting and electricity for pumps and fans is given in Table 4.5. Due to this dwelling being regarded as relatively knew in building terms, the heat transfer values are comparably low. As there is another dwelling beneath, the thermal transmittance for the floor is 0. Heat is lost through the floor though heat is also gained from the flat underneath, resulting in no net loss of energy through the floor.

Table 4.5 Dwelling 2 - Energy Requirements

Energy Requirements	Fuel Used (kWh/year)
Space heating	5108
Water heating	1821
Electricity for pumps and fans	165
Electricity for lighting	306

The total energy cost for the dwelling is £423 per year. The SAP algorithm calculator produces an SAP rating of 77, which lies in the upper half of the band C category for EER, well above the Scottish average. The dwelling produces about 1.7 tonnes of CO_2 per year, equating to an EI rating of 78. The total primary energy indicator for the dwelling was 162kWh/m^2/year.

4.1.3 Dwelling 3

This dwelling is a single storey, top-floor flat, which consists of 2 habitable rooms all of which are heated. There is no draught lobby in this flat, so the external door is on the exterior of the building. The floor plan is shown in Figure 4.3. The age band for the dwelling is C and the building envelope summarised in Table 4.6. Due to the age of the building, the thermal transmittance values for heat transfer are relatively high, when compared against the other dwellings.

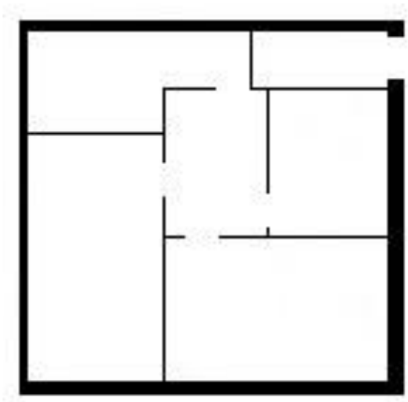


Figure 4.3 Dwelling 3 – Floor Plan

Table 4.6 Dwelling 3 - Building Envelope Summary

Element	Building Part	Description	U-value	Net Area (m^2)
Walls	Main	Cavity wall as built, no insulation (assumed)	1.6	43.20
	Party	System built	0	20.10
Roof(s)	Main	Pitched slate (access to loft), 250 mm insulation (between joists)	0.17	59.21
Floor(s)	Main	Another dwelling below	0	51
Windows	All	Fully double glazed, 100% draught proofed	1.85	9.73
Door(s)	All	Semi-glazed, 100% draught proofed	3	1.85

The heating system present is the: Vokera Compact 24 kW (2002), condensing combi boiler (automatic ignition) with an annual efficiency of 80%. The hot water comes from the main heating system and there is no secondary system. The fraction of low-E lighting in the flat is 0.

The total equivalent energy required for: space heating, hot water, lighting and electricity for pumps and fans is given in Table 4.7.

Table 4.7 Dwelling 3 - Energy Requirements

Energy Requirements	Fuel Used (kWh/year)
Space heating	8133
Water heating	1995
Electricity for pumps and fans	165
Electricity for lighting	480

The total energy cost for the dwelling is £558 per year. The SAP algorithm calculator produces an SAP rating of 66, which lies in the upper half of the band D category for EER. The dwelling produces about 2.5 tonnes of CO_2 per year, equating to an EI rating of 65. The total primary energy indicator for the dwelling equated to 280kWh/m^2/year.

4.2 Comparison to Existing EPCs

Extracting the information from the EPCs conducted by the DEAs (APPENDIX B) shows the results produced, summarised in Table 4.8. This can then be compared against the results which were modelled (Section 4.1) to see if there are any discrepancies. As all the reports were conducted without any alterations to the building fabric or heating system etc, the output results should coincide with each other to a close degree.

Table 4.8 Summary of APPENDIX B

	EER Rating	EI Rating	Fuel Cost (£)	TFA (m^2)	CO_2 Emissions (tonnes/year)	Primary Energy Indicator ($kWh/m^2/year$)
Dwelling 1	71	70	689	81	3	208
Dwelling 2	77	79	502	67	1.8	157
Dwelling 3	67	66	651	53	2.6	282

Table 4.9 Summary of Section 4.1

	EER Rating	EI Rating	Fuel Cost (£)	TFA (m^2)	CO_2 Emissions (tonnes/year)	Primary Energy Indicator ($kWh/m^2/year$)
Dwelling 1	70	68	645	80	3	213
Dwelling 2	77	78	423	61	1.7	162
Dwelling 3	66	65	558	51	2.5	280

As factors such as fuel cost change every 3 years, then with inflation these are expected to increase (BRE Group, 2012). The other factors which should remain consistent such as EER and EI ratings, coincide with the results obtained by the respective DEA that surveyed each dwelling. This gives some form of validation to the tool, providing 3 working examples.

4.3 Recommendation Report

In order to push the recommendation report to the extreme, 4 independent changes where modelled for each dwelling. This allows each change to be evaluated both individually and collectively in terms of EER, EI rating, cost of energy, quantity of CO_2 emissions and the overall primary energy indicator. The alterations simulated were to:

1. Lighting – Changing all lights to low-E bulbs.

2. Glazing/Doors – Changing all windows to triple glazing, low-E, 24mm, argon filled units with an effective u-value of 1.33W/m^2K (Travis Perkins, 2019a). Also changing the door of the dwelling from the solid-wood door to a semi-glazed PVC door, with a u-value of 1.8W/m^2K (Travis Perkins, 2019b).

3. Insulation – Upgrading or installing insulation levels to 200mm in walls and 300mm in the roof.

4. Heat Pump – Installing an ASHP: Mitsubishi Ecodan 8.5kW, PUHW-W85VAA (2018) for space and water heating (Air Heat Pumps, 2019). Annual efficiency for space heating - 250% and water heating - 175 %.

5. PV System – Installing a PV system on the roof of each of the dwellings (system size is dependent on the size of the roof of the dwelling). The systems consist of an array of 500W panels (Solar Bluesun, 2019).

For the case of Dwelling 2, low-E lighting was already installed. The case where 0% of low-E lights was modelled as the reference point for each change in this building. This is just to keep a level of consistency with the other dwellings.

4.3.1 Lighting

Table 4.10 Effects of Lighting Alterations

	Dwelling 1	Dwelling 2	Dwelling 3
Energy for Space Heating (kWh/year)	9562 → 9741	4943 → 5108	8133 → 8263
Energy for Water Heating (kWh/year)	2247 → 2247	1821 → 1821	1995 → 1995
Energy for Pumps and Fans (kWh/year)	165 → 165	165 → 165	165 → 165
Energy for Lighting (kWh/year)	698 → 349	611 → 306	480 → 240
EER Rating	70 → 72	75 → 77	66 → 68
EI Rating	68 → 70	76 → 78	65 → 66
Primary Energy Indicator (kWh/m^2/year)	213 → 203	175 → 162	280 → 268
CO_2 Emissions (tonnes/year)	3 → 2.9	1.9 → 1.7	2.5 → 2.4
Cost of Energy (£)	645 → 605	458 → 423	558 →530
Savings (£)	40	35	28

As can be seen from Table 4.10, the effects of changing all light units in each of the dwellings to 100% low-E lights has relatively severe consequences on the output of the SAP tool. The energy required for space heating increases in each case due to a reduced level of internal gains for lighting. However, this increase is lower than the reduction in the energy required for lighting. The price of gas is substantially lower than that of electricity, therefore there is still a net positive outcome for implementing this change.

Dwelling 1 rises from an EI rating category D to a C with this change.

4.3.2 Glazing/Doors

As can be seen from Table 4.11, the effects of installing semi-glazed doors and triple glazed windows in each of the models has a small yet still beneficial consequence on the output of the SAP tool. In every case the energy required for space heating decreases as the low emissivity coating and argon fill helps to retain heat in the dwelling. The decreased u-value in altering the dwelling's door helps to reduce the energy lost through the building envelope.

Again, this change alone is enough to change the EI rating of Dwelling 1 to a band C.

Table 4.11 Effects of Glazing/Door Alterations

	Dwelling 1	Dwelling 2	Dwelling 3
Energy for Space Heating (kWh/year)	9562 → 9030	4943 → 4718	8133 → 7744
Energy for Water Heating (kWh/year)	2247 → 2246	1821 → 1820	1995 → 1995
Energy for Pumps and Fans (kWh/year)	165 → 165	165 → 165	165 → 165
Energy for Lighting (kWh/year)	698 → 698	611 → 611	480 → 480
EER Rating	70 → 71	75 → 75	66 → 67
EI Rating	68 → 69	76 → 77	65 → 66
Primary Energy Indicator (kWh/m^2/year)	213 → 205	175 → 170	280 → 270
CO_2 Emissions (tonnes/year)	3 → 2.9	1.9 → 1.8	2.5 → 2.4
Cost of Energy (£)	645 → 626	458 → 450	558 → 544
Savings (£)	19	8	14

4.3.3 Insulation

As can be seen from Table 4.12, increasing or installing roof of wall insulation in each of the dwellings can have a massive impact on the output results from the SAP tool. The older buildings (Dwellings 1 and 3) experience the greatest improvements as these dwellings had the least amount of insulation to begin with. The energy for space heating in Dwelling 3 almost halves, decreasing from 8133-4374kWh/year, helping to produce an annual saving of £130 on energy. Around 800 kg less CO_2 emissions are produced per year in Dwelling 3. As Dwelling 2 is a relatively new-build flat so the insulation levels are already to a high standard.

The EI rating for Dwelling 1 is increased from a band D to C. Both the EI and EER for Dwelling 3 are increased from band D to comfortable band C category.

Table 4.12 Effects of Insulation Alterations

	Dwelling 1	Dwelling 2	Dwelling 3
Energy for Space Heating (kWh/year)	9562 → 8002	4943 → 4551	8133 → 4374
Energy for Water Heating (kWh/year)	2247 → 2242	1821 → 1820	1995 → 2015
Energy for Pumps and Fans (kWh/year)	165 → 165	165 → 165	165 → 165
Energy for Lighting (kWh/year)	698 → 698	611 → 611	480 → 480
EER Rating	70 → 72	75 → 75	66 → 74
EI Rating	68 → 71	76 → 77	65 → 76
Primary Energy Indicator (kWh/m^2/year)	213 → 189	175 → 167	280 → 191
CO_2 Emissions (tonnes/year)	3 → 2.7	1.9 → 1.8	2.5 → 1.7
Cost of Energy (£)	645 → 590	458 → 444	558 → 428
Savings (£)	55	14	130

4.3.4 Heat Pump

The SAP tool was modified for an ASHP complete with a 250l hot water storage tank and radiators, instead of the combi boiler system that the tool was modelling initially.

As can be interpreted from Table 4.13, replacing the space heating and domestic hot water systems from a combi boiler to an ASHP, tends to increase the fuel costs associated. This is due to the price of gas (3.48p/kWh) being much cheaper than that of electricity (13.19p/kWh) (BRE Group, 2012). The EI rating for all cases either increases or stays the same. This results in a significant reduction in CO_2 emissions and in each scenario, there is almost a reduction of 3 in the energy required for the total energy required. Due to the governing mathematics behind the EER being based on cost, in every case it either decreased or remained the same.

The EER rating for Dwelling 1 decreases from a band C to D, while the EI rating increases from a band D to C. The EI Rating for Dwelling 3 increases from a band D to C.

Table 4.13 Effects of Replacing the Heating System with a Heat Pump

	Dwelling 1	Dwelling 2	Dwelling 3
Energy for Space Heating (kWh/year)	9562 → 3447	4943 → 1823	8133 → 2649
Energy for Water Heating (kWh/year)	2247 → 1248	1821 → 1146	1995 → 1083
Energy for Pumps and Fans (kWh/year)	165 → 30	165 → 30	165 → 30
Energy for Lighting (kWh/year)	698 → 698	611 → 611	480 → 480
EER Rating	70 → 66	75 → 74	66 → 66
EI Rating	68 → 70	76 → 76	65 → 69
Primary Energy Indicator (kWh/m^2/year)	213 → 208	175 → 182	280 → 254
CO_2 Emissions (tonnes/year)	3 → 2.8	1.9 → 1.9	2.5 → 2.2
Cost of Energy (£)	645 → 715	458 → 476	558 → 560
Savings (£)	+70	+18	+2

4.3.5 PV

The SAP tool was modified to incorporate PV generation technology into its design. Due to the geometry and size of the respective roofs modelled, some dwellings model a larger installed capacity than others as shown in Figure 4.4.

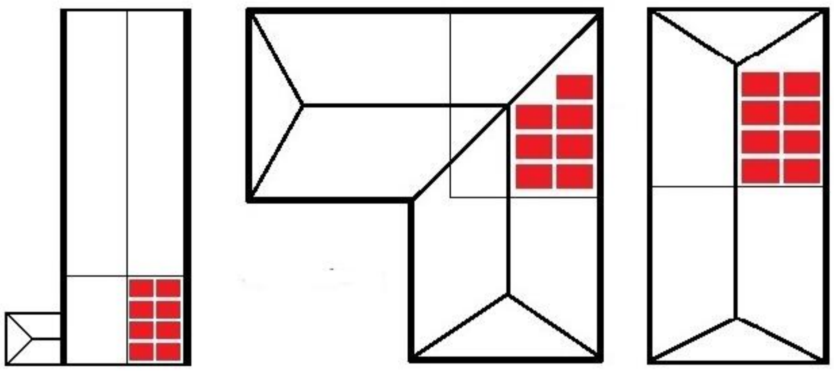


Figure 4.4 PV Layout for Dwelling 1,2 and 3

Both Dwellings 1 and 3 have a large enough roof area to incorporate a 4kW installed capacity system, whereas Dwelling 2 has been modelled to incorporate a 3.5kW system. The orientations are such that: Dwelling 1 faces South-East, Dwelling 2 faces East and Dwelling 3 faces South.

Table 4.14 Effects of PV Generation

	Dwelling 1	Dwelling 2	Dwelling 3
Energy for Space Heating (kWh/year)	9562 → 9562	4943 → 4943	8133 → 8133
Energy for Water Heating (kWh/year)	2247 → 2247	1821 → 1821	1995 → 1995
Energy for Pumps and Fans (kWh/year)	165 → 165	165 → 165	165 → 165
Energy for Lighting (kWh/year)	698 → 698	611 → 611	480 → 480
Energy Generated (kWh/year)	-3058	-2253	-3264
EER Rating	70 → 89	75 → 93	66 → 92
EI Rating	68 → 85	76 → 93	65 → 88
Primary Energy Indicator (kWh/m^2/year)	213 → 96	175 → 49	280 → 88
CO_2 Emissions (tonnes/year)	3 → 1.4	1.9 → 0.5	2.5 → 0.8
Cost of Energy (£)	645 → 241	458 → 126	558 → 128
Savings (£)	404	332	430

As can be seen from Table 4.14, installing a means of renewable generation drastically improves the output results from the SAP tool, without reducing the demand for energy. The SAP assumes that half of the energy generated is used directly within the dwelling and half is sold back to the grid at the purchase price (13.19p/kWh) (BRE Group, 2012). This effectively equates to 100% of the generation being consumed within the dwelling with zero losses. There is also the issue that these dwellings use most of their energy demand for space and water heating, which are gas fuelled systems and the energy generated would be electrical. Exporting all the energy generated at consumer purchase price and being able to purchase it back for the same rate is unrealistic. As of January 2019, the price for exporting a unit of electricity to the grid was 3.79p/kWh (Ofgem, 2019).

Regardless, this change alone allows the EERs for Dwellings 2 and 3 to reach a band A and Dwelling 1 achieves a high band B. The EI ratings follow this trend with dwelling 2 reaching band A and Dwellings 1 and 3 achieving band B ratings.

4.4 Combining the Results

Each of the 5 alterations were applied to each dwelling to observe the results of pushing the recommendation report to the extreme scenario. This then removes the dwelling's reliance on gas, as with the ASHP the full demand has been electrified. This somewhat fixes the issue of the renewable generation being used to effectively power a gas operated system.

Table 4.15 Dwellings 1, 2 and 3 – Full Retrofit

	Dwelling 1	Dwelling 2	Dwelling 3
Energy for Space Heating (kWh/year)	9562 → 2757	4943 → 1662	8133 → 1336
Energy for Water Heating (kWh/year)	2247 → 1248	1821 → 1146	1995 → 1083
Energy for Pumps and Fans (kWh/year)	165 → 30	165 → 30	165 → 30
Energy for Lighting (kWh/year)	698 → 349	611 → 306	480 → 240
Energy Generated (kWh/year)	-3058	-2253	-3264
EER Rating	70 → 92	75 → 94	66 → 105
EI Rating	68 → 93	76 → 94	65 → 104
Primary Energy Indicator (kWh/m^2/year)	213 → 51	175 → 45	280 → -34
CO_2 Emissions (tonnes/year)	3 → 0.7	1.9 → 0.5	2.5 → -0.3
Cost of Energy (£)	645 → 175	458 → 118	558 → -76
Savings (£)	470	340	634

Table 4.15 shows the results of completely retrofitting the dwellings with all 5 suggested measures. The cost of energy required for the occupant has decreased dramatically, averaging a saving of almost £500.

Both the EER and EI rating for every building have been raised significantly, now classed in the most efficient band A category (Figure 4.5). The modelled potential ratings have all been pushed to the limit and Dwelling 3 actually has rating greater than 100, meaning that the dwelling is a net exporter of energy (BRE Group, 2012). The results obtained from Dwelling 3 stem from it's ideally placed, south facing roof, large enouth to house a 4kW PV array.

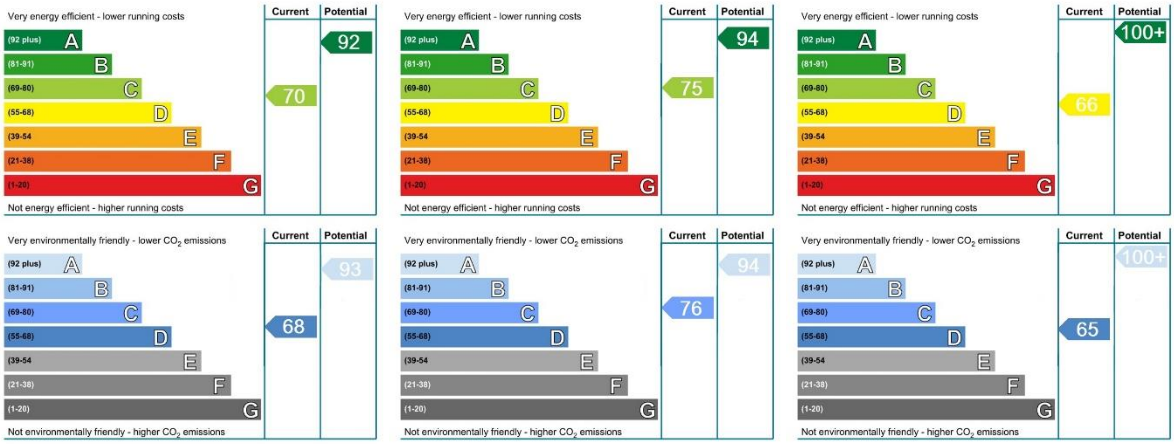


Figure 4.5 EER and EI Ratings for Dwellings 1,2 and 3

4.5 Energy Demand and Generation

Combining the individual energy demand profiles for each dwelling and equating this against the generation profile from PV, allows the annual discrepancy to be more easily interpreted. As would be expected, more energy is consumed during winter months as the energy requirements for space heating, water heating and lighting is greater during this period. Water heating follows a profile which appears more linear, as domestic hot water is required all year round for showering etc. The energy used for lighting follows a similar profile to that of space heating, with more energy being required in winter months due to longer episodes of darkness. The majority of generation from PV systems is during the summer months, when there are longer and more intense spells of sunshine. This unfortunately is generated when the dwellings combined energy demand is at its lowest value, contradicting the assumption of the SAP report.

4.5.1 Dwelling 1 – Demand v Generation

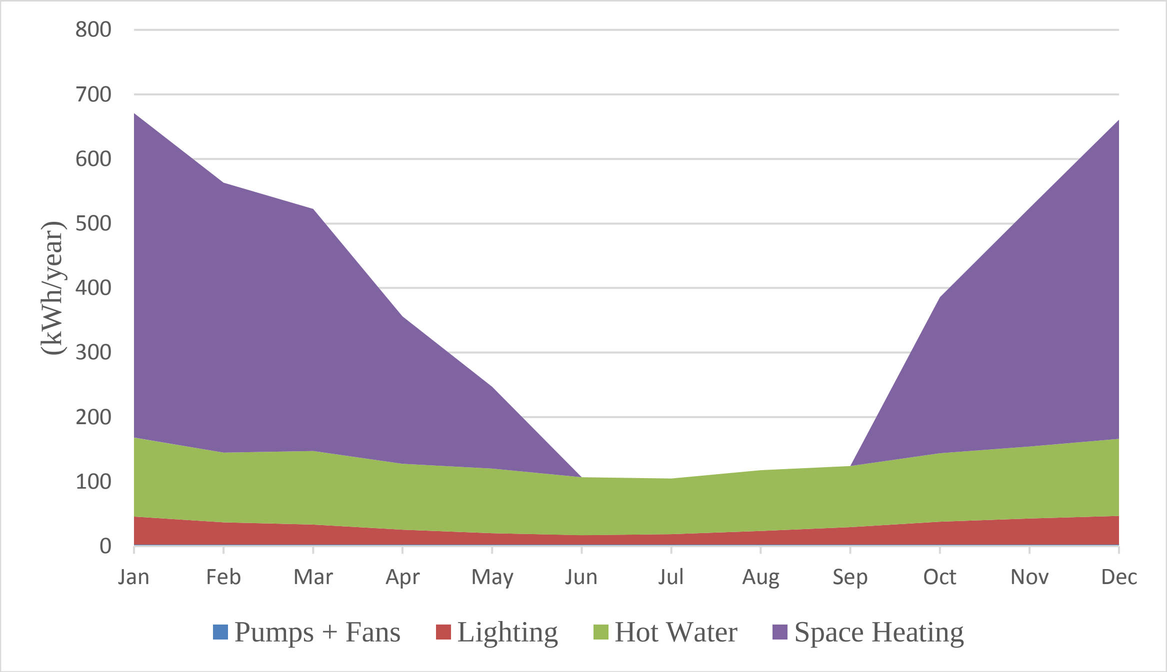


Figure 4.6 Dwelling 1 – Total Energy Demand

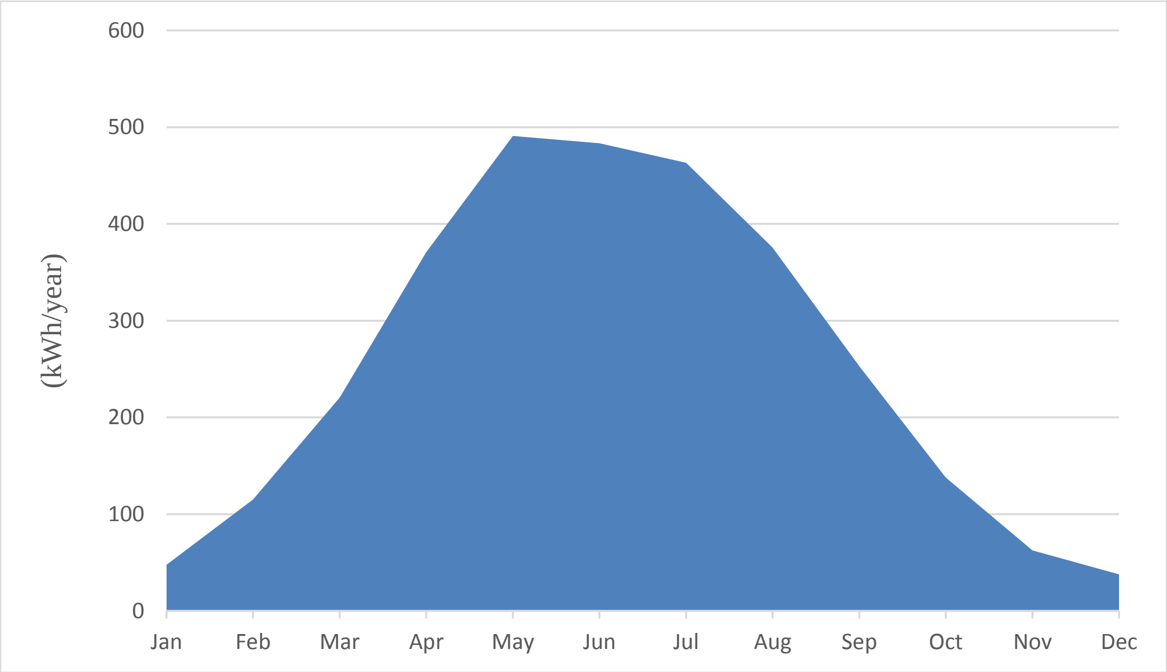


Figure 4.7 Dwelling 1 – Total Energy Generation

4.5.2 Dwelling 2 – Demand v Generation

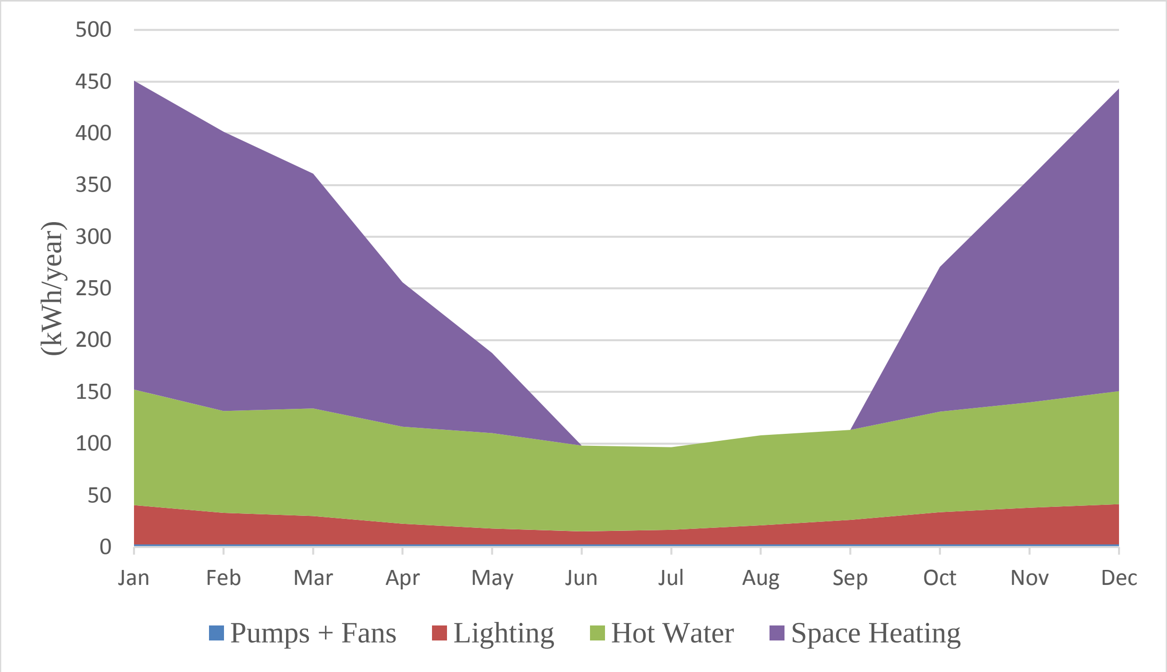


Figure 4.8 Dwelling 2 – Total Energy Demand

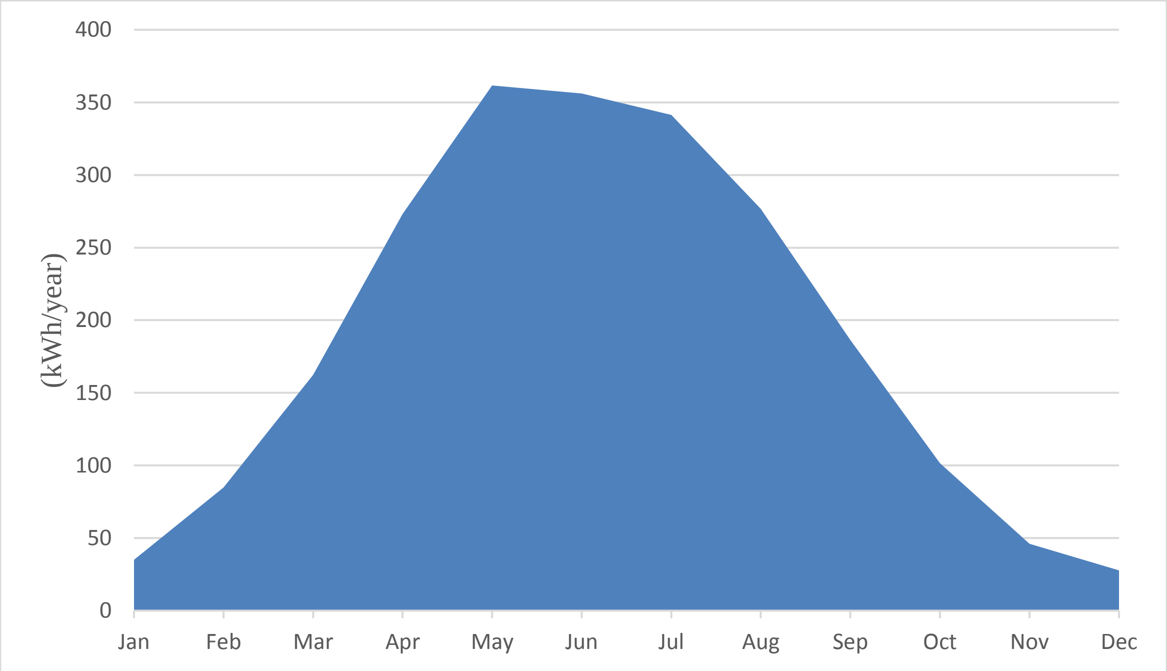


Figure 4.9 Dwelling 2 – Total Energy Generation

4.5.3 Dwelling 3 – Demand v Generation

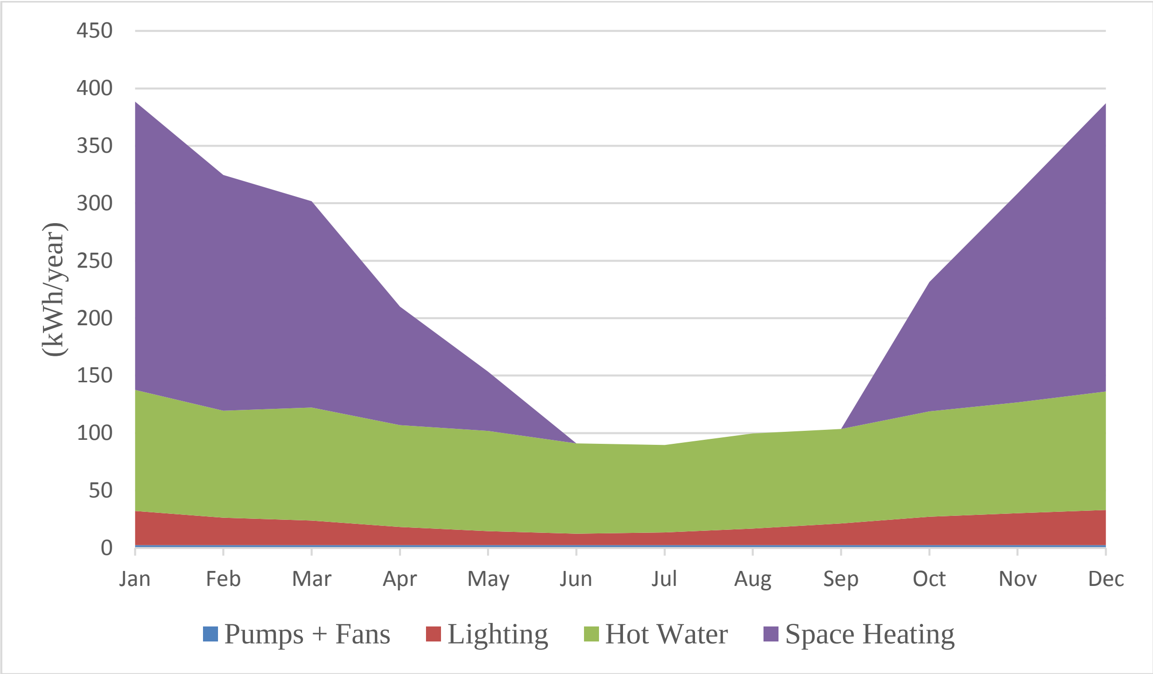


Figure 4.10 Dwelling 3 – Total Energy Demand

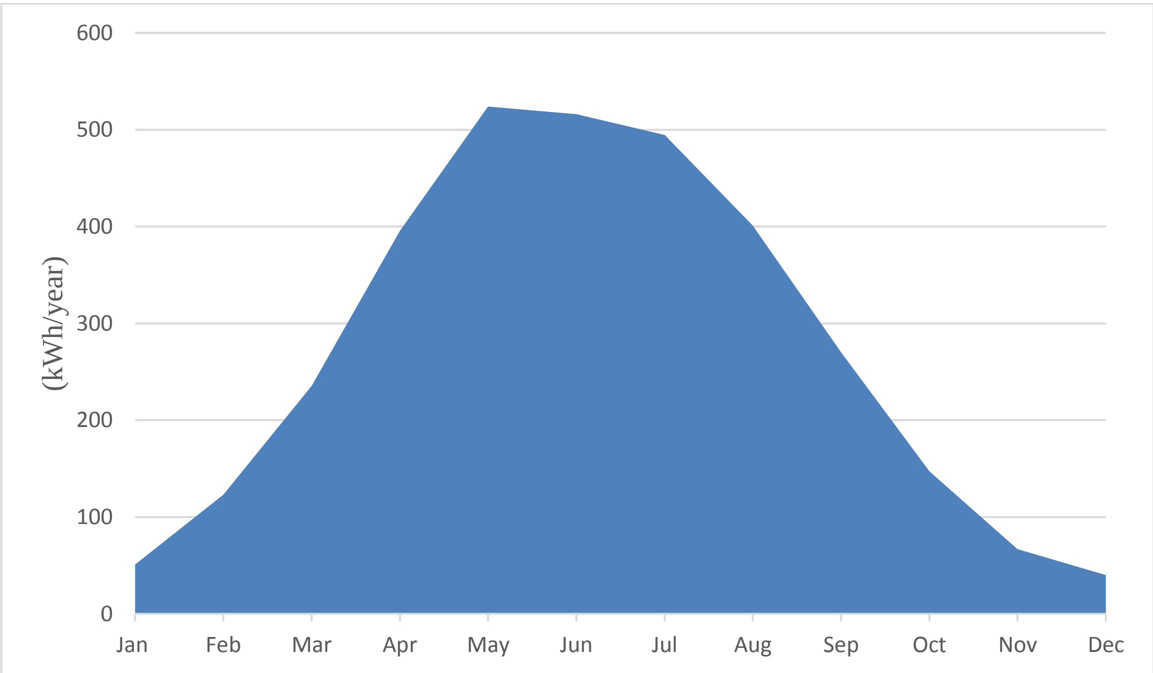


Figure 4.11 Dwelling 3 – Total Energy Generation

5 Conclusions

The retrofitting of existing dwellings is essential in order to reduce the energy consumption of the country as a whole and generation technologies prove fundamental in achieving this. Through carrying out a variety of simulations and iterations, many cases where modelled to show the benefits relating to CO_2 emissions, quantity of energy produced and financially for the consumer. Even a relatively small change in the type of lighting fittings equates to a reduction in half the energy required by lighting. Retrofitting the building envelope of older buildings tends to show the most extreme benefits as the thermal transmittance of such dwellings is not to the standard set in today's times. The roof orientation plays a critical role in the generation that is produced from a PV array.

As shown from Section 4.3.5, if a large PV array was retrofitted to a dwelling, then this alteration alone could drastically improve the results of the SAP. Regardless of the efficiency of the building envelope or heating system, the results can be drastically improved from installing some means of renewable generation.

The improvements modelled show that many benefits stem from upgrading the building fabric, lighting fitting and heating systems. Regardless of any limitations that the SAP report may contain, the overall result is certainly positive. There have been many versions of the SAP report before 2012 and there will inevitably be many to follow, each update hopefully adding for certainty to the results produced.

5.1 Limitations

As previously mentioned, the fact that a renewable means of generation assumes that half the energy produced is consumed within the associated dwelling and that half is sold to the grid at unit cost price, isn't an accurate assumption. The full SAP report is based around calculating its outputs based on cost, therefore this assumption hinders the accuracy of the procedure.

Currently there is no option for adding a means of storage for the electricity generated. Incorporating this into the model would go some way to correcting the assumption. A more realistic price for exporting electricity to the grid should also be included. As the SAP only considers the minimum quantity of energy for living conditions, an occupant will require more energy than suggested in the EPC. Storing any surplus could prove highly beneficial, though this surplus is excluded from any calculations.

The mathematics which governs the EER and EI rating, operates based on cost. This is to reduce the information to units that most consumers can comprehend though doesn't succeed in providing the most beneficial energy reduction improvements. If the outputs of the report were simply in energy or power, then the most beneficial improvements in terms of energy reduction and CO_2 emissions would be made clearer. This could then be equated to the financial aspect on the EPC, to allow consumers to understand both environmental and financial improvements in a more transparent manner, while also providing more accurate results which could be altered as inflation occurs.

5.2 Future Work

In terms of future work relating to this project, a new algorithm could be constructed to incorporate energy storage into the SAP. This would give a more realistic result for a dwelling which is not connected to the grid and has no means of exporting electricity, or for any other dwelling which chooses this method.

An investigation into altering the algorithms present in the SAP to exclude the unit cost of energy completely would be an interesting line of research. Also, if the energy generated by the dwelling was considered in a separate report to that consumed by the dwelling. This would provide more clarity on the actual energy demand of the dwelling, rather than focusing more on generation.

Occupants still have additional energy requirements on top of that conducted in the SAP, therefore improvements to other factors such as the buildings envelope and heating systems are also extremely important in minimising energy consumption, regardless of the source of generation. Research into including this energy demand in the SAP could prove useful. Previous energy bills for similar dwellings (or from the specific dwelling if an existing building) could be averaged to produce a more well-rounded estimation of costs for the consumer and energy consumption. Other countries within the EU have adopted this approach in their EPCs, so a working model is in existence and an effectively trial has been run (Caceres, 2018).

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APPENDIX A (BRE Group, 2012)

Table A.1 Wall U-values (W/m^2K)

Age Band	A	B	C	D	E	F	G	H	I	J	K	L
Wall Type												
Cavity as built	2.1	1.6	1.6	1.6	1.6	1.0	0.60	0.45	0.45	0.30	0.25	0.22
Unfilled cavity with 50 mm external or internal insulation	0.60	0.53	0.53	0.53	0.53	0.45	0.35	0.30	0.30	0.25	0.19	0.17
Unfilled cavity with 100 mm external or internal insulation	0.35	0.32	0.32	0.32	0.32	0.30	0.24	0.21	0.21	0.19	0.17	0.14
Unfilled cavity with 150 mm external or internal insulation	0.25	0.23	0.23	0.23	0.23	0.21	0.18	0.17	0.17	0.15	0.14	0.12
Unfilled cavity with 200 mm external or internal insulation	0.18	0.18	0.18	0.18	0.18	0.17	0.15	0.15	0.14	0.13	0.12	0.10
Filled cavity	0.50	0.50	0.50	0.50	0.50	0.40	0.35	0.45	0.45	0.30	0.25	0.22
Filled cavity with 50 mm external or internal insulation	0.31	0.31	0.31	0.31	0.31	0.27	0.25	0.25	0.25	0.25	0.25	0.17
Filled cavity with 100 mm external or internal insulation	0.22	0.22	0.22	0.2	0.22	0.20	0.19	0.19	0.19	0.19	0.19	0.14
Filled cavity with 150 mm external or internal insulation	0.17	0.17	0.17	0.17	0.17	0.16	0.15	0.15	0.15	0.15	0.15	0.12
Filled cavity with 200 mm external or internal insulation	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.12	0.10
Timber frame as built	2.5	1.9	1.9	1.0	0.80	0.45	0.40	0.40	0.40	0.30	0.25	0.22
Timber frame with internal insulation	0.60	0.55	0.55	0.40	0.40	0.40	0.40	0.40	0.40	0.30	0.25	0.22
System build as built	2.0	2.0	2.0	2.0	1.7	1.0	0.60	0.45	0.45	0.30	0.25	0.22
System build with 50 mm external or internal insulation	0.60	0.60	0.60	0.60	0.55	0.45	0.35	0.30	0.30	0.21	0.19	0.17
System build with 100 mm external or internal insulation	0.35	0.35	0.35	0.35	0.35	0.32	0.24	0.24	0.21	0.19	0.17	0.14
System build with 150 mm external or internal insulation	0.25	0.25	0.25	0.25	0.25	0.21	0.18	0.18	0.17	0.15	0.14	0.12
System build with 200 mm external or internal insulation	0.18	0.18	0.18	0.18	0.18	0.17	0.15	0.15	0.14	0.13	0.12	0.10

Table A.2 Party Wall U-values (W/m^{2}K)

Party Wall Type	Party Wall U-value
Solid / timber frame / system built	0.00
Cavity unfilled	0.50
Cavity filled	0.20
Unable to determine, house or bungalow	0.25
Unable to determine, flat or maisonette	0.00

Table A.3 Roof U-values (W/m^{2}K) for Slates or Tiles

Insulation thickness between joists (mm)	U-value (W/m^{2}K)
None	2.3
12	1.5
25	1.0
50	0.68
75	0.40
100	0.40
150	0.30
200	0.21
250	0.17
270	0.16
300	0.14
350	0.12
400	0.11

Table A.4 Window U-values (W/m^{2}K)

Glazing	Installed	Glazing Gap	U-value	g-value
Single	any	-	4.8	0.85
Double Glazing	< 2003	6 mm in PVC frame	3.1	0.76
		12 mm in PVC frame	2.8	
		18 mm in PVC frame	2.6	
	> 2003	any	2.0	0.72
Secondary Glazing	any	any	2.4	0.76
Triple Glazing	any	any	1.8	0.68

Table A.5 Fuel Prices, Emission Factors and Primary Energy Factors

	Standing Charge (£)	Unit Price p/kWh	Emissions Kg CO_2 Per kWh	Primary Energy Factor	Fuel Code
Fuel					
Gas					
Mains Gas	120	3.48	0.216	1.22	1
Bulk LPG	70	7.60	0.241	1.09	2
Bottled LPG	10	30	0.241	1.09	3
Biogas (inc anaerobic digestion)	70	7.60	0.098	1.10	7
Oil					
Heating Oil		5.44	0.298	1.10	4
Biodiesel from any Biomass Source		7.64	0.123	1.06	73
Biodiesel from Vegetable Oil		7.64	0.083	1.01	73
B30K		6.10	0.245	1.09	75
Bioethanol from any Biomass Source		47.0	0.140	1.08	76
Solid Fuel					
House Coal		3.67	0.394	1.00	11
Anthracite		3.64	0.394	1.00	15
Manufactured Smokeless Fuel		4.61	0.433	1.21	12
Wood Logs		4.23	0.019	1.04	20
Wood Pellets		5.26	0.039	1.26	23
Wood Chips		3.07	0.016	1.12	21
Dual Fuel Appliance		3.99	0.226	1.02	10
Electricity					
Standard Tariff	54	13.19	0.519	3.07	30
7-Hour Tariff (High Rate)	24	15.29	0.519	3.07	32
7-Hour Tariff (Low Rate)		5.50	0.519	3.07	31
10-Hour Tariff (High Rate)	23	14.68	0.519	3.07	34
10-Hour Tariff (Low Rate)		7.50	0.519	3.07	38
14-Hour Tariff (High Rate)	40	13.67	0.519	3.07	38
14-Hour Tariff (Low Rate)		7.41	0.519	3.07	40
24-Hour Heating Tariff	70	6.61	0.519	3.07	35
Electricity Sold to Grid		13.19	0.519	3.07	36

Table A.6 Age Bands of Dwellings in Scotland

Age Band	Year of Construction
A	< 1919
B	1919-1929
C	1930-1949
D	1950-1964
E	1965-1975
F	1976-1983
G	1984-1991
H	1992-1998
I	1999-2002
J	2003-2007
K	2008-2011
L	2012 >

Table A.7 Ventilation Rates

	Ventilation Rate (m^3/hour)
Chimney	40
Open Flue	20
Intermittent Extract Fan	10
Passive Vent	10
Flueless Gas Fire	40

Figure A.8 Transmittance Factors for Glazing

Glazing Type	$g_{\perp}$	g_L
Single Glazed	0.85	0.90
Double Glazed (Air or Argon)	0.76	
Double Glazed (Low-E, Hard coat)	0.72	0.80
Double Glazed (Low-E, Soft coat)	0.63	
Secondary Glazing	0.76	0.80
Triple Glazed (Air or Argon)	0.68	
Triple Glazed (Low-E, Hard coat)	0.64	0.70
Triple Glazed (Low-E, Soft coat)	0.57	

Table A.9 Constants for Calculation of Solar Flux on Non-Horizontal Surfaces

	East/West
k_1	1.44
k_2	-2.36
k_3	1.07
k_4	-0.504
k_5	1.89
k_6	-1.64
k_7	-0.542
k_8	-0.757
k_9	0.604

Table A.10 Living Area Fraction

Number of Rooms	1	2	3	4	5	6	7	8
Living Area Fraction	0.75	0.50	0.30	0.25	0.21	0.18	0.16	0.14
Number of Rooms	9	10	11	12	13	14	15+	
Living Area Fraction	0.13	0.12	0.11	0.10	0.10	0.09	0.09	

APPENDIX BI (Energy Saving Trust, 2019)

Energy Performance Certificate (EPC) — Scotland

Dwellings

DWELLING 1 **, OLD KILPATRICK, GLASGOW, G60 5EA**

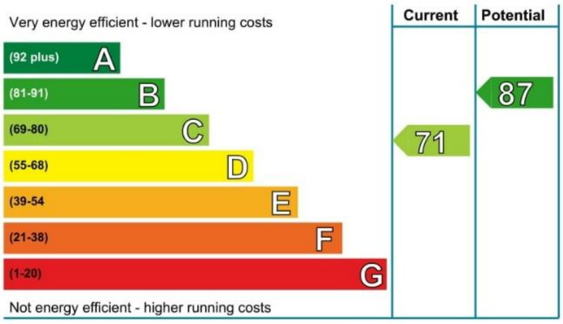
Dwelling type:	End-terrace house	**Reference number:**	9362-1906-0209-5538-0900
Date of assessment:	16 November 2018	**Type of assessment:**	RdSAP, existing dwelling
Date of certificate:	16 November 2018	**Approved Organisation:**	Elmhurst
Total floor area:	81 m²	**Main heating and fuel:**	Boiler and radiators, mains gas
Primary Energy Indicator:	208 kWh/m²/year		

You can use this document to:

- **Compare current ratings of properties to see which are more energy efficient and environmentally friendly**
- **Find out how to save energy and money and also reduce CO_2 emissions by improving your home**

Estimated energy costs for your home for 3 years*	**£2,067**	See your recommendations report for more information
Over 3 years you could save*	**£390**	

* based upon the cost of energy for heating, hot water, lighting and ventilation, calculated using standard assumptions

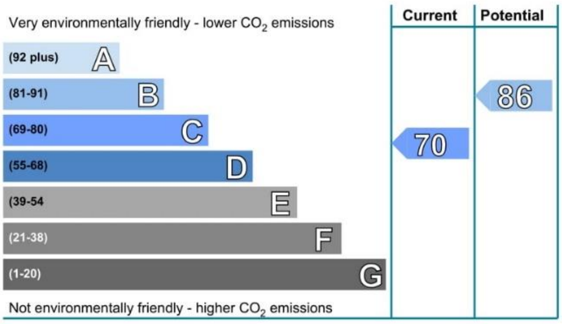


Energy Efficiency Rating

This graph shows the current efficiency of your home, taking into account both energy efficiency and fuel costs. The higher this rating, the lower your fuel bills are likely to be.

Your current rating is **band C (71)**. The average rating for EPCs in Scotland is **band D (61).**

The potential rating shows the effect of undertaking all of the improvement measures listed within your recommendations report.



Environmental Impact (CO_2) Rating

This graph shows the effect of your home on the environment in terms of carbon dioxide (CO_2) emissions. The higher the rating, the less impact it has on the environment.

Your current rating is **band C (70)**. The average rating for EPCs in Scotland is **band D (59).**

The potential rating shows the effect of undertaking all of the improvement measures listed within your recommendations report.

Top actions you can take to save money and make your home more efficient

Recommended measures	Indicative cost	Typical savings over 3 years
1 Floor insulation (suspended floor)	£800 - £1,200	£147.00
2 Low energy lighting	£60	£153.00
3 Solar water heating	£4,000 - £6,000	£90.00

A full list of recommended improvement measures for your home, together with more information on potential cost and savings and advice to help you carry out improvements can be found in your recommendations report.

To find out more about the recommended measures and other actions you could take today to stop wasting energy and money, visit greenerscotland.org or contact Home Energy Scotland on 0808 808 2282.

THIS PAGE IS THE ENERGY PERFORMANCE CERTIFICATE WHICH MUST BE AFFIXED TO THE DWELLING AND NOT BE REMOVED UNLESS IT IS REPLACED WITH AN UPDATED CERTIFICATE

Summary of the energy performance related features of this home

This table sets out the results of the survey which lists the current energy-related features of this home. Each element is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient). The assessment does not take into consideration the condition of an element and how well it is working. 'Assumed' means that the insulation could not be inspected and an assumption has been made in the methodology, based on age and type of construction.

Element	Description	Energy Efficiency	Environmental
Walls	System built, with external insulation Timber frame, as built, insulated (assumed)	★★★★☆ ★★★★☆	★★★★☆ ★★★★☆
Roof	Pitched, 150 mm loft insulation Pitched, insulated (assumed)	★★★★☆ ★★★★☆	★★★★☆ ★★★★☆
Floor	Suspended, no insulation (assumed) Suspended, insulated (assumed)	— —	— —
Windows	Fully double glazed	★★★★☆	★★★★☆
Main heating	Boiler and radiators, mains gas	★★★★☆	★★★★☆
Main heating controls	Programmer, room thermostat and TRVs	★★★★☆	★★★★☆
Secondary heating	None	—	—
Hot water	From main system	★★★★☆	★★★★☆
Lighting	No low energy lighting	★☆☆☆☆	★☆☆☆☆

The energy efficiency rating of your home

Your Energy Efficiency Rating is calculated using the standard UK methodology, RdSAP. This calculates energy used for heating, hot water, lighting and ventilation and then applies fuel costs to that energy use to give an overall rating for your home. The rating is given on a scale of 1 to 100. Other than the cost of fuel for electrical appliances and for cooking, a building with a rating of 100 would cost almost nothing to run.

As we all use our homes in different ways, the energy rating is calculated using standard occupancy assumptions which may be different from the way you use it. The rating also uses national weather information to allow comparison between buildings in different parts of Scotland. However, to make information more relevant to your home, local weather data is used to calculate your energy use, CO_2 emissions, running costs and the savings possible from making improvements.

The impact of your home on the environment

One of the biggest contributors to global warming is carbon dioxide. The energy we use for heating, lighting and power in our homes produces over a quarter of the UK's carbon dioxide emissions. Different fuels produce different amounts of carbon dioxide for every kilowatt hour (kWh) of energy used. The Environmental Impact Rating of your home is calculated by applying these 'carbon factors' for the fuels you use to your overall energy use.

The calculated emissions for your home are 37 kg $CO_2/m^2/yr$.

The average Scottish household produces about 6 tonnes of carbon dioxide every year. Based on this assessment, heating and lighting this home currently produces approximately 3.0 tonnes of carbon dioxide every year. Adopting recommendations in this report can reduce emissions and protect the environment. If you were to install all of these recommendations this could reduce emissions by 1.5 tonnes per year. You could reduce emissions even more by switching to renewable energy sources.

Estimated energy costs for this home

	Current energy costs	Potential energy costs	Potential future savings
Heating	£1,428 over 3 years	£1,302 over 3 years	You could save £390 over 3 years
Hot water	£291 over 3 years	£201 over 3 years	
Lighting	£348 over 3 years	£174 over 3 years	
Totals	**£2,067**	**£1,677**	

These figures show how much the average household would spend in this property for heating, lighting and hot water. This excludes energy use for running appliances such as TVs, computers and cookers, and the benefits of any electricity generated by this home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed below.

Recommendations for improvement

The measures below will improve the energy and environmental performance of this dwelling. The performance ratings after improvements listed below are cumulative; that is, they assume the improvements have been installed in the order that they appear in the table. Further information about the recommended measures and other simple actions to take today to save money is available from the Home Energy Scotland hotline which can be contacted on 0808 808 2282. Before carrying out work, make sure that the appropriate permissions are obtained, where necessary. This may include permission from a landlord (if you are a tenant) or the need to get a Building Warrant for certain types of work.

Recommended measures		Indicative cost	Typical saving per year	Rating after improvement	
				Energy	Environment
1	Floor insulation (suspended floor)	£800 - £1,200	£49	C 73	C 73
2	Low energy lighting for all fixed outlets	£60	£51	C 75	C 74
3	Solar water heating	£4,000 - £6,000	£30	C 76	C 76
4	Solar photovoltaic panels, 2.5 kWp	£5,000 - £8,000	£271	B 87	B 86

Choosing the right improvement package

For free and impartial advice on choosing suitable measures for your property, contact the Home Energy Scotland hotline on 0808 808 2282 or go to www.greenerscotland.org.

energy saving trust®

About the recommended measures to improve your home's performance rating

This section offers additional information and advice on the recommended improvement measures for your home

1 Floor insulation (suspended floor)
Insulation of a floor will significantly reduce heat loss; this will improve levels of comfort, reduce energy use and lower fuel bills. Suspended floors can often be insulated from below but must have adequate ventilation to prevent dampness; seek advice about this if unsure. Further information about floor insulation is available from many sources including www.energysavingtrust.org.uk/scotland/Insulation/Floor-insulation. Building regulations generally apply to this work so it is best to check with your local authority building standards department.

2 Low energy lighting
Replacement of traditional light bulbs with energy saving bulbs will reduce lighting costs over the lifetime of the bulb, and they last many times longer than ordinary light bulbs. Low energy lamps and fittings are now commonplace and readily available. Information on energy efficiency lighting can be found from a wide range of organisations, including the Energy Saving Trust (http://www.energysavingtrust.org.uk/home-energy-efficiency/lighting).

3 Solar water heating
A solar water heating panel, usually fixed to the roof, uses the sun to pre-heat the hot water supply. This can significantly reduce the demand on the heating system to provide hot water and hence save fuel and money. Planning permission might be required, building regulations generally apply to this work and a building warrant may be required, so it is best to check these with your local authority. You could be eligible for Renewable Heat Incentive payments which could appreciably increase the savings beyond those shown on your EPC, provided that both the product and the installer are certified by the Microgeneration Certification Scheme (or equivalent). Details of local MCS installers are available at www.microgenerationcertification.org.

4 Solar photovoltaic (PV) panels
A solar PV system is one which converts light directly into electricity via panels placed on the roof with no waste and no emissions. This electricity is used throughout the home in the same way as the electricity purchased from an energy supplier. Planning permission might be required, building regulations generally apply to this work and a building warrant may be required, so it is best to check with your local authority. The assessment does not include the effect of any Feed-in Tariff which could appreciably increase the savings that are shown on this EPC for solar photovoltaic panels, provided that both the product and the installer are certified by the Microgeneration Certification Scheme (or equivalent). Details of local MCS installers are available at www.microgenerationcertification.org.

Low and zero carbon energy sources

Low and zero carbon (LZC) energy sources are sources of energy that release either very little or no carbon dioxide into the atmosphere when they are used. Installing these sources may help reduce energy bills as well as cutting carbon.
LZC energy sources present: There are none provided for this home

Your home's heat demand

You could receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing your existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments. For more information go to www.energysavingtrust.org.uk/scotland/rhi.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	8,290	(250)	N/A	N/A
Water heating (kWh per year)	2,119			

About this document

This Recommendations Report and the accompanying Energy Performance Certificate are valid for a maximum of ten years. These documents cease to be valid where superseded by a more recent assessment of the same building carried out by a member of an Approved Organisation.

The Energy Performance Certificate and this Recommendations Report for this building were produced following an energy assessment undertaken by an assessor accredited by Elmhurst (www.elmhurstenergy.co.uk), an Approved Organisation Appointed by Scottish Ministers. The certificate has been produced under the Energy Performance of Buildings (Scotland) Regulations 2008 from data lodged to the Scottish EPC register. You can verify the validity of this document by visiting www.scottishepcregister.org.uk and entering the report reference number (RRN) printed at the top of this page.

Assessor's name:
Assessor membership number:
Company name/trading name:
Address:

Phone number:
Email address:
Related party disclosure:

If you have any concerns regarding the content of this report or the service provided by your assessor you should in the first instance raise these matters with your assessor and with the Approved Organisation to which they belong. All Approved Organisations are required to publish their complaints and disciplinary procedures and details can be found online at the web address given above.

Use of this energy performance information

Once lodged by your EPC assessor, this Energy Performance Certificate and Recommendations Report are available to view online at www.scottishepcregister.org.uk, with the facility to search for any single record by entering the property address. This gives everyone access to any current, valid EPC except where a property has a Green Deal Plan, in which case the report reference number (RRN) must first be provided. The energy performance data in these documents, together with other building information gathered during the assessment is held on the Scottish EPC Register and is available to authorised recipients, including organisations delivering energy efficiency and carbon reduction initiatives on behalf of the Scottish and UK governments. A range of data from all assessments undertaken in Scotland is also published periodically by the Scottish Government. Further information on these matters and on Energy Performance Certificates in general, can be found at www.gov.scot/epc.

Advice and support to improve this property

There is support available, which could help you carry out some of the improvements recommended for this property on page 3 and stop wasting energy and money.For more information, visit greenerscotland.org or contact Home Energy Scotland on 0808 808 2282.

Home Energy Scotland's independent and expert advisors can offer free and impartial advice on all aspects of energy efficiency, renewable energy and more.

HOMEENERGYSCOTLAND.ORG
0808 808 2282
FUNDED BY THE SCOTTISH GOVERNMENT

Greener Scotland
Scottish Government

APPENDIX BII (Energy Saving Trust, 2019)

Energy Performance Certificate (EPC)

Dwellings

Scotland

DWELLING 2 , CLYDEBANK, G81 3QW

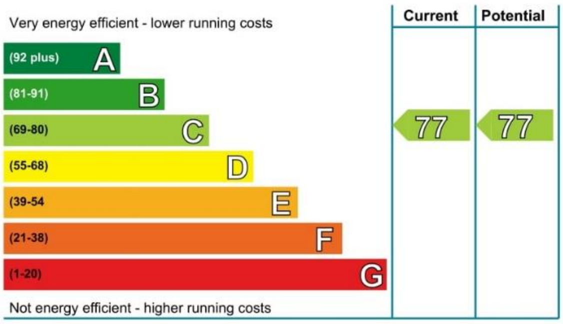
Dwelling type:	Top-floor flat	**Reference number:**	0160-2421-3080-9996-2765
Date of assessment:	19 August 2016	**Type of assessment:**	RdSAP, existing dwelling
Date of certificate:	26 August 2016	**Approved Organisation:**	Elmhurst
Total floor area:	67 m²	**Main heating and fuel:**	Boiler and radiators, mains gas
Primary Energy Indicator:	157 kWh/m²/year		

You can use this document to:

- **Compare current ratings of properties to see which are more energy efficient and environmentally friendly**

Estimated energy costs for your home for 3 years*	£1,506

* based upon the cost of energy for heating, hot water, lighting and ventilation, calculated using standard assumptions

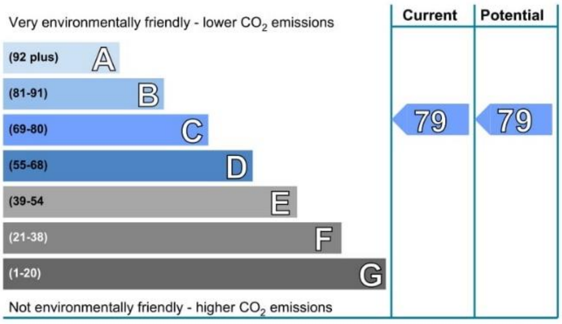


Energy Efficiency Rating

This graph shows the current efficiency of your home, taking into account both energy efficiency and fuel costs. The higher this rating, the lower your fuel bills are likely to be.

Your current rating is **band C (77)**. The average rating for EPCs in Scotland is **band D (61).**

The potential rating shows the effect of undertaking all of the improvement measures listed within your recommendations report.



Environmental Impact (CO_2) Rating

This graph shows the effect of your home on the environment in terms of carbon dioxide (CO_2) emissions. The higher the rating, the less impact it has on the environment.

Your current rating is **band C (79)**. The average rating for EPCs in Scotland is **band D (59).**

The potential rating shows the effect of undertaking all of the improvement measures listed within your recommendations report.

Top actions you can take to save money and make your home more efficient

There are currently no improvement measures recommended for your home.

To find out more about the recommended measures and other actions you could take today to stop wasting energy and money, visit greenerscotland.org or contact Home Energy Scotland on 0808 808 2282.

NCE CERTIFICATE WHICH MUST BE AFFIXED TO THE
ESS IT IS REPLACED WITH AN UPDATED CERTIFICATE

Summary of the energy performance related features of this home

This table sets out the results of the survey which lists the current energy-related features of this home. Each element is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient). The assessment does not take into consideration the condition of an element and how well it is working. 'Assumed' means that the insulation could not be inspected and an assumption has been made in the methodology, based on age and type of construction.

Element	Description	Energy Efficiency	Environmental
Walls	Timber frame, as built, insulated (assumed)	★★★★☆	★★★★☆
Roof	Pitched, 200 mm loft insulation	★★★★☆	★★★★☆
Floor	(another dwelling below)	—	—
Windows	Fully double glazed	★★★☆☆	★★★☆☆
Main heating	Boiler and radiators, mains gas	★★★★☆	★★★★☆
Main heating controls	Programmer, room thermostat and TRVs	★★★★☆	★★★★☆
Secondary heating	None	—	—
Hot water	From main system	★★★★★	★★★★☆
Lighting	Low energy lighting in all fixed outlets	★★★★★	★★★★★

The energy efficiency rating of your home

Your Energy Efficiency Rating is calculated using the standard UK methodology, RdSAP. This calculates energy used for heating, hot water, lighting and ventilation and then applies fuel costs to that energy use to give an overall rating for your home. The rating is given on a scale of 1 to 100. Other than the cost of fuel for electrical appliances and for cooking, a building with a rating of 100 would cost almost nothing to run.

As we all use our homes in different ways, the energy rating is calculated using standard occupancy assumptions which may be different from the way you use it. The rating also uses national weather information to allow comparison between buildings in different parts of Scotland. However, to make information more relevant to your home, local weather data is used to calculate your energy use, CO_2 emissions, running costs and the savings possible from making improvements.

The impact of your home on the environment

One of the biggest contributors to global warming is carbon dioxide. The energy we use for heating, lighting and power in our homes produces over a quarter of the UK's carbon dioxide emissions. Different fuels produce different amounts of carbon dioxide for every kilowatt hour (kWh) of energy used. The Environmental Impact Rating of your home is calculated by applying these 'carbon factors' for the fuels you use to your overall energy use.

The calculated emissions for your home are 28 kg $CO_2/m^2/yr$.

The average Scottish household produces about 6 tonnes of carbon dioxide every year. Based on this assessment, heating and lighting this home currently produces approximately 1.8 tonnes of carbon dioxide every year. You could reduce emissions by switching to renewable energy sources.

Estimated energy costs for this home

	Current energy costs	Potential energy costs	Potential future savings
Heating	£1,041 over 3 years	£1,041 over 3 years	Not applicable
Hot water	£312 over 3 years	£312 over 3 years	
Lighting	£153 over 3 years	£153 over 3 years	
Totals	**£1,506**	**£1,506**	

These figures show how much the average household would spend in this property for heating, lighting and hot water. This excludes energy use for running appliances such as TVs, computers and cookers, and the benefits of any electricity generated by this home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed below.

Recommendations for improvement

None

Low and zero carbon energy sources

Low and zero carbon (LZC) energy sources are sources of energy that release either very little or no carbon dioxide into the atmosphere when they are used. Installing these sources may help reduce energy bills as well as cutting carbon.
LZC energy sources present: There are none provided for this home

Your home's heat demand

You could receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing your existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments. For more information go to www.energysavingtrust.org.uk/scotland/rhi.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	3,606	N/A	N/A	N/A
Water heating (kWh per year)	2,245			

About this document

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APPENDIX BIII (Enegry Saving Trust, 2019)

Energy Performance Certificate (EPC)

Dwellings

Scotland

DWELLING 3 **, DUNTOCHER, CLYDEBANK, G81 6HP**

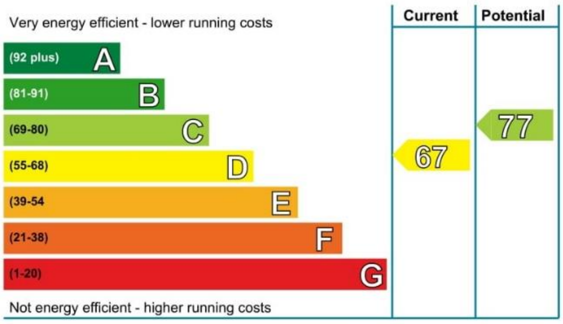
Dwelling type:	Top-floor flat	**Reference number:**	4816-5922-9009-0005-0906
Date of assessment:	05 December 2016	**Type of assessment:**	RdSAP, existing dwelling
Date of certificate:	13 December 2016	**Approved Organisation:**	Elmhurst
Total floor area:	53 m²	**Main heating and fuel:**	Boiler and radiators, mains gas
Primary Energy Indicator:	282 kWh/m²/year		

You can use this document to:

- **Compare current ratings of properties to see which are more energy efficient and environmentally friendly**
- **Find out how to save energy and money and also reduce CO_2 emissions by improving your home**

Estimated energy costs for your home for 3 years*	**£1,953**	See your recommendations report for more information
Over 3 years you could save*	**£627**	

* based upon the cost of energy for heating, hot water, lighting and ventilation, calculated using standard assumptions

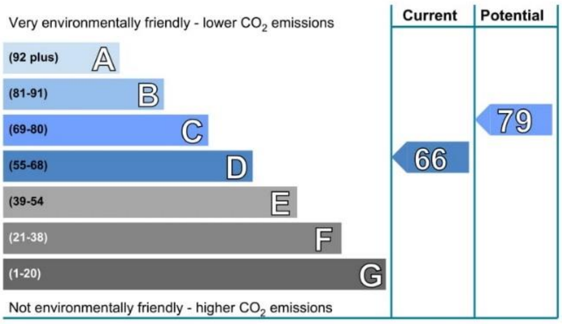


Energy Efficiency Rating

This graph shows the current efficiency of your home, taking into account both energy efficiency and fuel costs. The higher this rating, the lower your fuel bills are likely to be.

Your current rating is **band D (67)**. The average rating for EPCs in Scotland is **band D (61).**

The potential rating shows the effect of undertaking all of the improvement measures listed within your recommendations report.



Environmental Impact (CO_2) Rating

This graph shows the effect of your home on the environment in terms of carbon dioxide (CO_2) emissions. The higher the rating, the less impact it has on the environment.

Your current rating is **band D (66)**. The average rating for EPCs in Scotland is **band D (59).**

The potential rating shows the effect of undertaking all of the improvement measures listed within your recommendations report.

Top actions you can take to save money and make your home more efficient

Recommended measures	Indicative cost	Typical savings over 3 years
1 Cavity wall insulation	£500 - £1,500	£435.00
2 Low energy lighting	£25	£96.00
3 Condensing boiler	£2,200 - £3,000	£93.00

A full list of recommended improvement measures for your home, together with more information on potential cost and savings and advice to help you carry out improvements can be found in your recommendations report.

To find out more about the recommended measures and other actions you could take today to stop wasting energy and money, visit greenerscotland.org or contact Home Energy Scotland on 0808 808 2282.

THIS PAGE IS THE ENERGY PERFORMANCE CERTIFICATE WHICH MUST BE AFFIXED TO THE DWELLING AND NOT BE REMOVED UNLESS IT IS REPLACED WITH AN UPDATED CERTIFICATE

Summary of the energy performance related features of this home

This table sets out the results of the survey which lists the current energy-related features of this home. Each element is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient). The assessment does not take into consideration the condition of an element and how well it is working. 'Assumed' means that the insulation could not be inspected and an assumption has been made in the methodology, based on age and type of construction.

Element	Description	Energy Efficiency	Environmental
Walls	Cavity wall, as built, no insulation (assumed)	★★☆☆☆	★★☆☆☆
Roof	Pitched, 250 mm loft insulation	★★★★☆	★★★★☆
Floor	(another dwelling below)	—	—
Windows	Fully double glazed	★★★☆☆	★★★☆☆
Main heating	Boiler and radiators, mains gas	★★★★☆	★★★★☆
Main heating controls	Programmer, room thermostat and TRVs	★★★★☆	★★★★☆
Secondary heating	None	—	—
Hot water	From main system	★★★★☆	★★★★☆
Lighting	No low energy lighting	★☆☆☆☆	★☆☆☆☆

The energy efficiency rating of your home

Your Energy Efficiency Rating is calculated using the standard UK methodology, RdSAP. This calculates energy used for heating, hot water, lighting and ventilation and then applies fuel costs to that energy use to give an overall rating for your home. The rating is given on a scale of 1 to 100. Other than the cost of fuel for electrical appliances and for cooking, a building with a rating of 100 would cost almost nothing to run.

As we all use our homes in different ways, the energy rating is calculated using standard occupancy assumptions which may be different from the way you use it. The rating also uses national weather information to allow comparison between buildings in different parts of Scotland. However, to make information more relevant to your home, local weather data is used to calculate your energy use, CO_2 emissions, running costs and the savings possible from making improvements.

The impact of your home on the environment

One of the biggest contributors to global warming is carbon dioxide. The energy we use for heating, lighting and power in our homes produces over a quarter of the UK's carbon dioxide emissions. Different fuels produce different amounts of carbon dioxide for every kilowatt hour (kWh) of energy used. The Environmental Impact Rating of your home is calculated by applying these 'carbon factors' for the fuels you use to your overall energy use.

The calculated emissions for your home are 50 kg $CO_2/m^2/yr$.

The average Scottish household produces about 6 tonnes of carbon dioxide every year. Based on this assessment, heating and lighting this home currently produces approximately 2.6 tonnes of carbon dioxide every year. Adopting recommendations in this report can reduce emissions and protect the environment. If you were to install all of these recommendations this could reduce emissions by 0.9 tonnes per year. You could reduce emissions even more by switching to renewable energy sources.

Estimated energy costs for this home

	Current energy costs	Potential energy costs	Potential future savings
Heating	£1,428 over 3 years	£945 over 3 years	You could save £627 over 3 years
Hot water	£294 over 3 years	£264 over 3 years	
Lighting	£231 over 3 years	£117 over 3 years	
Totals	**£1,953**	**£1,326**	

These figures show how much the average household would spend in this property for heating, lighting and hot water. This excludes energy use for running appliances such as TVs, computers and cookers, and the benefits of any electricity generated by this home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed below.

Recommendations for improvement

The measures below will improve the energy and environmental performance of this dwelling. The performance ratings after improvements listed below are cumulative; that is, they assume the improvements have been installed in the order that they appear in the table. Further information about the recommended measures and other simple actions to take today to save money is available from the Home Energy Scotland hotline which can be contacted on 0808 808 2282. Before carrying out work, make sure that the appropriate permissions are obtained, where necessary. This may include permission from a landlord (if you are a tenant) or the need to get a Building Warrant for certain types of work.

	Recommended measures	Indicative cost	Typical saving per year	Rating after improvement	
				Energy	Environment
1	Cavity wall insulation	£500 - £1,500	£145	C 73	C 75
2	Low energy lighting for all fixed outlets	£25	£32	C 75	C 77
3	Replace boiler with new condensing boiler	£2,200 - £3,000	£31	C 77	C 79

Alternative measures

There are alternative improvement measures which you could also consider for your home. It would be advisable to seek further advice and illustration of the benefits and costs of such measures.

- External insulation with cavity wall insulation
- Biomass boiler (Exempted Appliance if in Smoke Control Area)
- Air or ground source heat pump

Choosing the right improvement package

For free and impartial advice on choosing suitable measures for your property, contact the Home Energy Scotland hotline on 0808 808 2282 or go to www.greenerscotland.org.

energy saving trust

About the recommended measures to improve your home's performance rating

This section offers additional information and advice on the recommended improvement measures for your home

1 Cavity wall insulation

Cavity wall insulation, to fill the gap between the inner and outer layers of external walls with an insulating material, reduces heat loss; this will improve levels of comfort, reduce energy use and lower fuel bills. The insulation material is pumped into the gap through small holes that are drilled into the outer walls, and the holes are made good afterwards. As specialist machinery is used to fill the cavity, a professional installation company should carry out this work, and they should carry out a thorough survey before commencing work to ensure that this type of insulation is suitable for this home and its exposure. They should also provide a guarantee for the work and handle any building standards issues. Further information about cavity wall insulation and details of local installers can be obtained from the National Insulation Association (www.nationalinsulationassociation.org.uk).

2 Low energy lighting

Replacement of traditional light bulbs with energy saving bulbs will reduce lighting costs over the lifetime of the bulb, and they last many times longer than ordinary light bulbs. Low energy lamps and fittings are now commonplace and readily available. Information on energy efficiency lighting can be found from a wide range of organisations, including the Energy Saving Trust (http://www.energysavingtrust.org.uk/home-energy-efficiency/lighting).

3 Condensing boiler

A condensing boiler is capable of much higher efficiencies than other types of boiler, meaning it will burn less fuel to heat this property. This improvement is most appropriate when the existing central heating boiler needs repair or replacement, however there may be exceptional circumstances making this impractical. Condensing boilers need a drain for the condensate which limits their location; remember this when considering remodelling the room containing the existing boiler even if the latter is to be retained for the time being (for example a kitchen makeover). Building regulations generally apply to this work and a building warrant may be required, so it is best to check with your local authority building standards department and seek advice from a qualified heating engineer.

Low and zero carbon energy sources

Low and zero carbon (LZC) energy sources are sources of energy that release either very little or no carbon dioxide into the atmosphere when they are used. Installing these sources may help reduce energy bills as well as cutting carbon.

LZC energy sources present: There are none provided for this home

Your home's heat demand

You could receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing your existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments. For more information go to www.energysavingtrust.org.uk/scotland/rhi.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	6,806	N/A	(2,776)	N/A
Water heating (kWh per year)	1,753			

Addendum

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Advice and support to improve this property

There is support available, which could help you carry out some of the improvements recommended for this property on page 3 and stop wasting energy and money.For more information, visit greenerscotland.org or contact Home Energy Scotland on 0808 808 2282.

Home Energy Scotland's independent and expert advisors can offer free and impartial advice on all aspects of energy efficiency, renewable energy and more.

HOMEENERGYSCOTLAND.ORG
0808 808 2282
FUNDED BY THE SCOTTISH GOVERNMENT

Greener Scotland
Scottish Government

APPENDIX C (BRE Group, 2012)

1. Overall dwelling dimensions

	Area (m²)			Average storey height (m)			Volume (m³)	
Basement		(1a)	×		(2a)	=		(3a)
Ground floor		(1b)	×		(2b)	=		(3b)
First floor		(1c)	×		(2c)	=		(3c)
Second floor		(1d)	×		(2d)	=		(3d)
Third floor		(1e)	×		(2e)	=		(3e)
Other floors *(repeat as necessary)*		(1n)	×		(2n)	=		(3n)
Total floor area TFA = (1a)+(1b)+(1c)+(1d)+(1e)…(1n) =		(4)						
Dwelling volume				(3a)+(3b)+(3c)+(3d)+(3e)…(3n) =				(5)

2. Ventilation rate

	main heating		secondary heating		other		total		m³ per hour	
Number of chimneys		+		+		=		× 40 =		(6a)
Number of open flues		+		+		=		× 20 =		(6b)
Number of intermittent fans								× 10 =		(7a)
Number of passive vents								× 10 =		(7b)
Number of flueless gas fires								× 40 =		(7c)
									Air changes per hour	
Infiltration due to chimneys, flues, fans, PSVs	(6a)+(6b)+(7a)+(7b)+(7c) =							÷ (5) =		(8)

If a pressurisation test has been carried out or is intended, proceed to (17), otherwise continue from (9) to (16)

Number of storeys in the dwelling (n_s)			(9)
Additional infiltration	[(9) – 1] × 0.1 =		(10)
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction* *if both types of wall are present, use the value corresponding to the greater wall area (after deducting areas of openings); if equal use 0.35*			(11)
If suspended wooden ground floor, *enter 0.2 (unsealed) or 0.1 (sealed)*, else enter 0			(12)
If no draught lobby, enter 0.05, else enter 0			(13)
Percentage of windows and doors draught proofed			(14)
Window infiltration	0.25 - [0.2 × (14) ÷ 100] =		(15)
Infiltration rate	(8) + (10) + (11) + (12) + (13) + (15) =		(16)
Air permeability value, q_{50}, expressed in cubic metres per hour per square metre of envelope area			(17)
If based on air permeability value, then (18) = [(17) ÷ 20]+(8), otherwise (18) = (16)			(18)
Air permeability value applies if a pressurisation test has been done, or a design or specified air permeability is being used			
Number of sides on which dwelling is sheltered			(19)
Shelter factor	(20) = 1 - [0.075 × (19)] =		(20)
Infiltration rate incorporating shelter factor	(21) = (18) × (20) =		(21)

Infiltration rate modified for monthly wind speed:

Monthly average wind speed from Table U2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$(22)_m$ =	$(22)_1$	$(22)_2$	$(22)_3$	$(22)_4$	$(22)_5$	$(22)_6$	$(22)_7$	$(22)_8$	$(22)_9$	$(22)_{10}$	$(22)_{11}$	$(22)_{12}$

Wind Factor $(22a)_m = (22)_m \div 4$

$(22a)_m$ =	$(22a)_1$	$(22a)_2$	$(22a)_3$	$(22a)_4$	$(22a)_5$	$(22a)_6$	$(22a)_7$	$(22a)_8$	$(22a)_9$	$(22a)_{10}$	$(22a)_{11}$	$(22a)_{12}$

Adjusted infiltration rate (allowing for shelter and wind speed) = $(21) \times (22a)_m$

$(22b)_m$ =	$(22b)_1$	$(22b)_2$	$(22b)_3$	$(22b)_4$	$(22b)_5$	$(22b)_6$	$(22b)_7$	$(22b)_8$	$(22b)_9$	$(22b)_{10}$	$(22b)_{11}$	$(22b)_{12}$

Calculate effective air change rate for the applicable case:

If mechanical ventilation: air change rate through system	0.5	(23a)
If exhaust air heat pump using Appendix N, (23b) = (23a) × F_{mv} (equation (N4)), otherwise (23b) = (23a)		(23b)
If balanced with heat recovery: efficiency in % allowing for in-use factor (from Table 4h) =		(23c)

a) If balanced mechanical ventilation with heat recovery (MVHR) $(24a)_m = (22b)_m + (23b) \times [1 - (23c) \div 100]$

$(24a)_m$ =	$(24a)_1$	$(24a)_2$	$(24a)_3$	$(24a)_4$	$(24a)_5$	$(24a)_6$	$(24a)_7$	$(24a)_8$	$(24a)_9$	$(24a)_{10}$	$(24a)_{11}$	$(24a)_{12}$	(24a)

b) If balanced mechanical ventilation without heat recovery (MV) $(24b)_m = (22b)_m + (23b)$

$(24b)_m$ =	$(24b)_1$	$(24b)_2$	$(24b)_3$	$(24b)_4$	$(24b)_5$	$(24b)_6$	$(24b)_7$	$(24b)_8$	$(24b)_9$	$(24b)_{10}$	$(24b)_{11}$	$(24b)_{12}$	(24b)

c) If whole house extract ventilation or positive input ventilation from outside

if $(22b)_m < 0.5 \times (23b)$, then $(24c) = (23b)$; otherwise $(24c) = (22b)_m + 0.5 \times (23b)$

$(24c)_m$ =	$(24c)_1$	$(24c)_2$	$(24c)_3$	$(24c)_4$	$(24c)_5$	$(24c)_6$	$(24c)_7$	$(24c)_8$	$(24c)_9$	$(24c)_{10}$	$(24c)_{11}$	$(24c)_{12}$	(24c)

d) If natural ventilation or whole house positive input ventilation from loft

if $(22b)_m \geq 1$, then $(24d)_m = (22b)_m$ otherwise $(24d)_m = 0.5 + [(22b)_m^2 \times 0.5]$

$(24d)_m$ =	$(24d)_1$	$(24d)_2$	$(24d)_3$	$(24d)_4$	$(24d)_5$	$(24d)_6$	$(24d)_7$	$(24d)_8$	$(24d)_9$	$(24d)_{10}$	$(24d)_{11}$	$(24d)_{12}$	(24d)

Effective air change rate - enter (24a) or (24b) or (24c) or (24d) in (25)

$(25)_m$ =	$(25)_1$	$(25)_2$	$(25)_3$	$(25)_4$	$(25)_5$	$(25)_6$	$(25)_7$	$(25)_8$	$(25)_9$	$(25)_{10}$	$(25)_{11}$	$(25)_{12}$	(25)

If Appendix Q applies in relation to air change rate, the effective air change rate is calculated via Appendix Q and use the following instead:

Effective air change rate from Appendix Q calculation sheet:

$(25)_m$ =	$(25)_1$	$(25)_2$	$(25)_3$	$(25)_4$	$(25)_5$	$(25)_6$	$(25)_7$	$(25)_8$	$(25)_9$	$(25)_{10}$	$(25)_{11}$	$(25)_{12}$	(25)

3. Heat losses and heat loss parameter

Items in the table below are to be expanded as necessary to allow for all different types of element e.g. 4 wall types.
The κ-value is the heat capacity per unit area, see Table 1e

Element	Gross area, m²		Openings m²		Net area A, m²		U-value W/m²K	=	A × U W/K	κ-value kJ/m²·K	A × κ kJ/K	
Solid door						×						(26)
Semi-glazed door						×						(26a)
Window						×	* below	=				(27)
Roof window						×	* below	=				(27a)
Basement floor						×		=				(28)
Ground floor						×		=				(28a)
Exposed floor						×		=				(28b)
Basement wall		-		=		×		=				(29)
External wall		-		=		×		=				(29a)
Roof		-		=		×		=				(30)
Total area of external elements ΣA, m²						(31)						
Party wall						×		=				(32)
(party wall U-value from Table 3.6, κ according to its construction)												
Party floor												(32a)
Party ceiling												(32b)
Internal wall **												(32c)
Internal floor												(32d)
Internal ceiling												(32e)

** for windows and roof windows, use effective window U-value calculated using formula 1/[(1/U-value)+0.04] as given in paragraph 3.2*
*** include the areas on both sides of internal walls and partitions*

Fabric heat loss, W/K = Σ (A × U)	(26)…(30) + (32)	=		(33)
Heat capacity C_m = Σ(A × κ)	(28)…(30) + (32) + (32a)…(32e)	=		(34)
Thermal mass parameter (TMP = C_m ÷ TFA) in kJ/m²K	= (34) ÷ (4)	=		(35)

For design assessments where the details of the construction are not known precisely the indicative values of TMP in Table 1f can be used instead of a detailed calculation. Also TMP calculated separately can be used in (35).

Thermal bridges : Σ (L × Ψ) calculated using Appendix K				(36)
if details of thermal bridging are not known (36) = 0.15 × (31)				
Total fabric heat loss	(33) + (36) =			(37)

Ventilation heat loss calculated monthly $(38)_m = 0.33 \times (25)_m \times (5)$

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
$(38)_m$ =	$(38)_1$	$(38)_2$	$(38)_3$	$(38)_4$	$(38)_5$	$(38)_6$	$(38)_7$	$(38)_8$	$(38)_9$	$(38)_{10}$	$(38)_{11}$	$(38)_{12}$	(38)

Heat transfer coefficient, W/K $(39)_m = (37) + (38)_m$

$(39)_m$ =	$(39)_1$	$(39)_2$	$(39)_3$	$(39)_4$	$(39)_5$	$(39)_6$	$(39)_7$	$(39)_8$	$(39)_9$	$(39)_{10}$	$(39)_{11}$	$(39)_{12}$

Average = $\Sigma(39)_{1…12}$ /12= (39)

Heat loss parameter (HLP), W/m²K $(40)_m = (39)_m \div (4)$

$(40)_m$ =	$(40)_1$	$(40)_2$	$(40)_3$	$(40)_4$	$(40)_5$	$(40)_6$	$(40)_7$	$(40)_8$	$(40)_9$	$(40)_{10}$	$(40)_{11}$	$(40)_{12}$

Average = $\Sigma(40)_{1\ldots12}$ /12= (40)

Number of days in month (Table 1a)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
$(41)_m$ =	$(41)_1$	$(41)_2$	$(41)_3$	$(41)_4$	$(41)_5$	$(41)_6$	$(41)_7$	$(41)_8$	$(41)_9$	$(41)_{10}$	$(41)_{11}$	$(41)_{12}$	(41)

4. Water heating energy requirement **kWh/year**

Assumed occupancy, N (42)

if TFA > 13.9, N = 1 + 1.76 × [1 - exp(-0.000349 × (TFA -13.9)²)] + 0.0013 × (TFA -13.9)

if TFA ≤ 13.9, N = 1

Annual average hot water usage in litres per day $V_{d,average}$ = (25 × N) + 36 (43)

Reduce the annual average hot water usage by 5% if the dwelling is designed to achieve a water use target of not more that 125 litres per person per day (all water use, hot and cold)

Hot water usage in litres per day for each month $V_{d,m}$ = factor from Table 1c × (43)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$(44)_m$ =	$(44)_1$	$(44)_2$	$(44)_3$	$(44)_4$	$(44)_5$	$(44)_6$	$(44)_7$	$(44)_8$	$(44)_9$	$(44)_{10}$	$(44)_{11}$	$(44)_{12}$

Total = $\Sigma(44)_{1\ldots12}$ = (44)

Energy content of hot water used = 4.18 × $V_{d,m} \times n_m \times \Delta T_m$ / 3600 kWh/month (see Tables 1b, 1c, 1d)

$(45)_m$ =	$(45)_1$	$(45)_2$	$(45)_3$	$(45)_4$	$(45)_5$	$(45)_6$	$(45)_7$	$(45)_8$	$(45)_9$	$(45)_{10}$	$(45)_{11}$	$(45)_{12}$

Total =$\Sigma(45)_{1\ldots12}$ = (45)

If instantaneous water heating at point of use (no hot water storage), enter "0" in (46) to (61)

For community heating include distribution loss whether or not hot water tank is present

Distribution loss $(46)_m$ = 0.15 x $(45)_m$

$(46)_m$ =	$(46)_1$	$(46)_2$	$(46)_3$	$(46)_4$	$(46)_5$	$(46)_6$	$(46)_7$	$(46)_8$	$(46)_9$	$(46)_{10}$	$(46)_{11}$	$(46)_{12}$	(46)

Storage volume (litres) including any solar or WWHRS storage within same vessel (47)

If community heating and no tank in dwelling, enter 110 litres in (47)

Otherwise if no stored hot water (this includes instantaneous combi boilers) enter '0' in (47)

Water storage loss:

a) If manufacturer's declared loss factor is known (kWh/day): (48)

Temperature factor from Table 2b (49)

Energy lost from water storage, kWh/day (48) × (49) = (50)

b) If manufacturer's declared loss factor is not known :

Hot water storage loss factor from Table 2 (kWh/litre/day) (51)

If community heating see section 4.3

Volume factor from Table 2a (52)

Temperature factor from Table 2b (53)

Energy lost from water storage, kWh/day (47) × (51) × (52) × (53) = (54)

Enter (50) or (54) in (55) (55)

Water storage loss calculated for each month $(56)_m = (55) \times (41)_m$

$(56)_m$ =	$(56)_1$	$(56)_2$	$(56)_3$	$(56)_4$	$(56)_5$	$(56)_6$	$(56)_7$	$(56)_8$	$(56)_9$	$(56)_{10}$	$(56)_{11}$	$(56)_{12}$	(56)

If the vessel contains dedicated solar storage or dedicated WWHRS storage, $(57)_m = (56)_m \times [(47) - V_s] \div (47)$, else $(57)_m = (56)_m$

where V_s is V_{ww} from Appendix G3 or (H11) from Appendix H (as applicable).

$(57)_m$ =	$(57)_1$	$(57)_2$	$(57)_3$	$(57)_4$	$(57)_5$	$(57)_6$	$(57)_7$	$(57)_8$	$(57)_9$	$(57)_{10}$	$(57)_{11}$	$(57)_{12}$	(57)

Primary circuit loss for each month from Table 3

(modified by factor from Table H4 if there is solar water heating and a cylinder thermostat, although not for community DHW systems)

$(59)_m$ =	$(59)_1$	$(59)_2$	$(59)_3$	$(59)_4$	$(59)_5$	$(59)_6$	$(59)_7$	$(59)_8$	$(59)_9$	$(59)_{10}$	$(59)_{11}$	$(59)_{12}$	(59)

Combi loss for each month from Table 3a, 3b or 3c (enter "0" if not a combi boiler)

$(61)_m$ =	$(61)_1$	$(61)_2$	$(61)_3$	$(61)_3$	$(61)_3$	$(61)_3$	$(61)_3$	$(61)_3$	$(61)_3$	$(61)_3$	$(61)_3$	$(61)_{12}$	(61)

Total heat required for water heating calculated for each month $(62)_m = 0.85 \times (45)_m + (46)_m + (57)_m + (59)_m + (61)_m$

$(62)_m$ =	$(62)_1$	$(62)_2$	$(62)_3$	$(62)_4$	$(62)_5$	$(62)_6$	$(62)_7$	$(62)_8$	$(62)_9$	$(62)_{10}$	$(62)_{11}$	$(62)_{12}$	(62)

Solar DHW input calculated using Appendix G or Appendix H (negative quantity) (enter "0" if no solar contribution to water heating)
(add additional lines if FGHRS and/or WWHRS applies, see Appendix G)

$(63)_m$ =	$(63)_1$	$(63)_2$	$(63)_3$	$(63)_4$	$(63)_5$	$(63)_6$	$(63)_7$	$(63)_8$	$(63)_9$	$(63)_{10}$	$(63)_{11}$	$(63)_{12}$	(63)

Output from water heater for each month, kWh/month $(64)_m = (62)_m + (63)_m$

$(64)_m$ =	$(64)_1$	$(64)_2$	$(64)_3$	$(64)_4$	$(64)_5$	$(64)_6$	$(64)_7$	$(64)_8$	$(64)_9$	$(64)_{10}$	$(64)_{11}$	$(64)_{12}$	

Total per year (kWh/year) = $\Sigma(64)_{1...12}$ = (64)

if $(64)_m < 0$ then set to 0

Heat gains from water heating, kWh/month $0.25 \times [0.85 \times (45)_m + (61)_m] + 0.8 \times [(46)_m + (57)_m + (59)_m]$

$(65)_m$ =	$(65)_1$	$(65)_2$	$(65)_3$	$(65)_4$	$(65)_5$	$(65)_6$	$(65)_7$	$(65)_8$	$(65)_9$	$(65)_{10}$	$(65)_{11}$	$(65)_{12}$	(65)

include $(57)_m$ in calculation of $(65)_m$ only if hot water store is in the dwelling or hot water is from community heating

5. Internal gains (see Tables 5 and 5a)

Metabolic gains (Table 5), watts

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
$(66)_m$ =	$(66)_1$	$(66)_2$	$(66)_3$	$(66)_4$	$(66)_5$	$(66)_6$	$(66)_7$	$(66)_8$	$(66)_9$	$(66)_{10}$	$(66)_{11}$	$(66a)_{12}$	(66)

Lighting gains (calculated in Appendix L, equation L9 or L9a), also see Table 5

$(67)_m$ =	$(67)_1$	$(67)_2$	$(67)_3$	$(67)_4$	$(67)_5$	$(67)_6$	$(67)_7$	$(67)_8$	$(67)_9$	$(67)_{10}$	$(67)_{11}$	$(67)_{12}$	(67)

Appliances gains (calculated in Appendix L, equation L13 or L13a), also see Table 5

$(68)_m$ =	$(68)_1$	$(68)_2$	$(68)_3$	$(68)_4$	$(68)_5$	$(68)_6$	$(68)_7$	$(68)_8$	$(68)_9$	$(68)_{10}$	$(68)_{11}$	$(68)_{12}$	(68)

Cooking gains (calculated in Appendix L, equation L15 or L15a), also see Table 5

$(69)_m$ =	$(69)_1$	$(69)_2$	$(69)_3$	$(69)_4$	$(69)_5$	$(69)_6$	$(69)_7$	$(69)_8$	$(69)_9$	$(69)_{10}$	$(69)_{11}$	$(69)_{12}$	(69)

Pumps and fans gains (Table 5a)

$(70)_m$ =	$(70)_1$	$(70)_2$	$(70)_3$	$(70)_4$	$(70)_5$	$(70)_6$	$(70)_7$	$(70)_8$	$(70)_9$	$(70)_{10}$	$(70)_{11}$	$(70)_{12}$	(70)

Losses e.g. evaporation (negative values) (Table 5)

$(71)_m$ =	$(71)_1$	$(71)_2$	$(71)_3$	$(71)_4$	$(71)_5$	$(71)_6$	$(71)_7$	$(71)_8$	$(71)_9$	$(71)_{10}$	$(71)_{11}$	$(71)_{12}$	(71)

Water heating gains (Table 5)

$(72)_m$ =	$(72)_1$	$(72)_2$	$(72)_3$	$(72)_4$	$(72)_5$	$(72)_6$	$(72)_7$	$(72)_8$	$(72)_9$	$(72)_{10}$	$(72)_{11}$	$(72)_{12}$	(72)

Total internal gains = $(66)_m + (67)_m + (68)_m + (69)_m + (70)_m + (71)_m + (72)_m$

$(73)_m$ =	$(73)_1$	$(73)_2$	$(73)_3$	$(73)_4$	$(73)_5$	$(73)_6$	$(73)_7$	$(73)_8$	$(73)_9$	$(73)_{10}$	$(73)_{11}$	$(73)_{12}$	(73)

6. Solar gains

Solar gains are calculated using solar flux from U3 in Appendix U and associated equations to convert to the applicable orientation. Rows (74) to (82) are used 12 times, one for each month, repeating as needed if there is more than one window type,

	Access factor Table 6d		Area m²		Solar flux W/m²		$g_\perp$ Specific data or Table 6b		FF Specific data or Table 6c		Gains (W)	
North		×		×		× 0.9 ×		×		=		(74)
Northeast		×		×		× 0.9 ×		×		=		(75)
East		×		×		× 0.9 ×		×		=		(76)
Southeast		×		×		× 0.9 ×		×		=		(77)
South		×		×		× 0.9 ×		×		=		(78)
Southwest		×		×		× 0.9 ×		×		=		(79)
West		×		×		× 0.9 ×		×		=		(80)
Northwest		×		×		× 0.9 ×		×		=		(81)
Roof windows	1.0	×		×		× 0.9 ×		×		=		(82)

Solar gains in watts, calculated for each month $(83)_m = \Sigma(74)_m \ldots(82)_m$

$(83)_m$ =	$(83)_1$	$(83)_2$	$(83)_3$	$(83)_4$	$(83)_5$	$(83)_6$	$(83)_7$	$(83)_8$	$(83)_9$	$(83)_{10}$	$(83)_{11}$	$(83)_{12}$	(83)

Total gains – internal and solar $(84)_m = (73)_m + (83)_m$, watts

$(84)_m$ =	$(84)_1$	$(84)_2$	$(84)_3$	$(84)_4$	$(84)_5$	$(84)_6$	$(84)_7$	$(84)_8$	$(84)_9$	$(84)_{10}$	$(84)_{11}$	$(84)_{12}$	(84)

7. Mean internal temperature (heating season)

Temperature during heating periods in the living area from Table 9, T_{h1} (°C) | 21 | (85)

Utilisation factor for gains for living area, $\eta_{1,m}$ (see Table 9a)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
$(86)_m$ =	$(86)_1$	$(86)_2$	$(86)_3$	$(86)_4$	$(86)_5$	$(86)_6$	$(86)_7$	$(86)_8$	$(86)_9$	$(86)_{10}$	$(86)_{11}$	$(86)_{12}$	(86)

Mean internal temperature in living area T_1 *(follow steps 3 to 7 in Table 9c)*

$(87)_m$ =	$(87)_1$	$(87)_2$	$(87)_3$	$(87)_4$	$(87)_5$	$(87)_6$	$(87)_7$	$(87)_8$	$(87)_9$	$(87)_{10}$	$(87)_{11}$	$(87)_{12}$	(87)

Temperature during heating periods in rest of dwelling from Table 9, T_{h2} (°C)

$(88)_m$ =	$(88)_1$	$(88)_2$	$(88)_3$	$(88)_4$	$(88)_5$	$(88)_6$	$(88)_7$	$(88)_8$	$(88)_9$	$(88)_{10}$	$(88)_{11}$	$(88)_{12}$	(88)

Utilisation factor for gains for rest of dwelling, $\eta_{2,m}$ (see Table 9a)

$(89)_m$ =	$(89)_1$	$(89)_2$	$(89)_3$	$(89)_4$	$(89)_5$	$(89)_6$	$(89)_7$	$(89)_8$	$(89)_9$	$(89)_{10}$	$(89)_{11}$	$(89)_{12}$	(89)

Mean internal temperature in the rest of dwelling T_2
(follow steps 8 to 9 in Table 9c, if two main heating systems see further notes in Table 9c)

$(90)_m$ =	$(90)_1$	$(90)_2$	$(90)_3$	$(90)_4$	$(90)_5$	$(90)_6$	$(90)_7$	$(90)_8$	$(90)_9$	$(90)_{10}$	$(90)_{11}$	$(90)_{12}$	(90)

Living area fraction f_{LA} = Living area ÷ (4) = | | (91)

Mean internal temperature (for the whole dwelling) $= f_{LA} \times T_1 + (1 - f_{LA}) \times T_2$

$(92)_m$ =	$(92)_1$	$(92)_2$	$(92)_3$	$(92)_4$	$(92)_5$	$(92)_6$	$(92)_7$	$(92)_8$	$(92)_9$	$(82)_{10}$	$(92)_{11}$	$(92)_{12}$	(92)

Apply adjustment to the mean internal temperature from Table 4e, where appropriate

$(93)_m$ =	$(93)_1$	$(93)_2$	$(93)_3$	$(93)_4$	$(93)_5$	$(93)_6$	$(93)_7$	$(93)_8$	$(93)_9$	$(93)_{10}$	$(93)_{11}$	$(93)_{12}$	(93)

8. Space heating requirement

Set T_i to the mean internal temperature obtained at step 11 of Table 9b, so that $T_{i,m} = (93)_m$ and re-calculate the utilisation factor for gains using Table 9a

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Utilisation factor for gains, η_m:													
$(94)_m$ =	$(94)_1$	$(94)_2$	$(94)_3$	$(94)_4$	$(94)_5$	$(94)_6$	$(94)_7$	$(94)_8$	$(94)_9$	$(94)_{10}$	$(94)_{11}$	$(94)_{12}$	(94)
Useful gains, $\eta_m G_m$, W = $(94)_m \times (84)_m$													
$(95)_m$ =	$(95)_1$	$(95)_2$	$(95)_3$	$(95)_4$	$(95)_5$	$(95)_6$	$(95)_7$	$(95)_8$	$(95)_9$	$(95)_{10}$	$(95)_{11}$	$(95)_{12}$	(95)
Monthly average external temperature from Table U1													
$(96)_m$ =	$(96)_1$	$(96)_2$	$(96)_3$	$(96)_4$	$(96)_5$	$(96)_6$	$(96)_7$	$(96)_8$	$(96)_9$	$(96)_{10}$	$(96)_{11}$	$(96)_{12}$	(96)
Heat loss rate for mean internal temperature, L_m , W = $(39)_m \times [(93)_m - (96)_m]$													
$(97)_m$ =	$(97)_1$	$(97)_2$	$(97)_3$	$(97)_4$	$(97)_5$	$(97)_6$	$(97)_7$	$(97)_8$	$(97)_9$	$(97)_{10}$	$(97)_{11}$	$(97)_{12}$	(97)
Space heating requirement for each month, kWh/month = $0.024 \times [(97)_m - (95)_m] \times (41)_m$													
$(98)_m$ =	$(98)_1$	$(98)_2$	$(98)_3$	$(98)_4$	$(98)_5$	–	–	–	–	$(98)_{10}$	$(98)_{11}$	$(98)_{12}$	

Total per year (kWh/year) = $\Sigma(98)_{1...5,10..12}$ = | | (98)

Space heating requirement in kWh/m²/year | (98) ÷ (4) = | | (99)

For range cooker boilers where efficiency is obtained from the Product Characteristics Database, multiply the results in $(98)_m$ by $(1 - \Phi_{case}/\Phi_{water})$ where Φ_{case} is the heat emission from the case of the range cooker at full load (in kW); and Φ_{water} is the heat transferred to water at full load (in kW). Φ_{case} and Φ_{water} are obtained from the database record for the range cooker boiler. Where there are two main heating systems, this applies if the range cooker boiler is system 1 or system 2.

8c. Space cooling requirement

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Heat loss rate L_m (calculated using 24°C internal temperature and external temperature for the applicable climate (see Appendix U)													
$(100)_m$ =						$(100)_6$	$(100)_7$	$(100)_8$					(100)
Utilisation factor for loss η_m													
$(101)_m$ =						$(101)_6$	$(101)_7$	$(101)_8$					(101)
Useful loss, $\eta_m L_m$ (watts) = $(100)_m \times (101)_m$													
$(102)_m$ =						$(102)_6$	$(102)_7$	$(102)_8$					(102)
Gains (internal gains as for heating except that column (A) of Table 5 is always used; solar gains calculated for the applicable climate, see Appendix U)													
$(103)_m$ =						$(103)_6$	$(103)_7$	$(103)_8$					(103)
Space cooling requirement for month, whole dwelling, continuous (kWh) = $0.024 \times [(103)_m - (102)_m] \times (41)_m$													
$(104)_m$ =						$(104)_6$	$(104)_7$	$(104)_8$					

Total = $\Sigma(104)_{6..8}$ = (104)

Cooled fraction f_C = cooled area ÷ (4) = (105)

Intermittency factor (Table 10b)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$(106)_m$						$(106)_6$	$(106)_7$	$(106)_8$				

Total = $\Sigma(106)_{6..8}$ = (106)

Space cooling requirement for month = $(104)_m \times (105) \times (106)_m$

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$(107)_m$						$(107)_6$	$(107)_7$	$(107)_8$				

Total = $\Sigma(107)_{6..8}$ = (107)

Space cooling requirement in kWh/m²/year (107) ÷ (4) = (108)

8f. Fabric Energy Efficiency (calculated only under special conditions, see section 11)

Fabric Energy Efficiency (99) + (108) = (109)

9a. Energy requirements – Individual heating systems including micro-CHP

For any space heating, space cooling or water heating provided by community heating use the alternative worksheet 9b.

Space heating:

Fraction of space heat from secondary/supplementary system (Table 11)	*"0" if none*		(201)
Fraction of space heat from main system(s)	(202) = 1 – (201) =		(202)
Fraction of main heating from main system 2	*if no second main system enter "0"*		(203)
Fraction of total space heat from main system 1	(204) = (202) × [1 – (203)] =		(204)
Fraction of total space heat from main system 2	(205) = (202) × (203) =		(205)

Efficiency of main space heating system 1 (in %) (206)
(from database or Table 4a/4b, adjusted where appropriate by the amount shown in the 'space efficiency adjustment' column of Table 4c; for gas and oil boilers see 9.2.1)

If there is a second main system complete (207)
Efficiency of main space heating system 2 (in %) (207)
(from database or Table 4a/4b, adjusted where appropriate by the amount shown in the 'space efficiency adjustment' column of Table 4c; for gas and oil boilers see 9.2.1)

Efficiency of secondary/supplementary heating system, % *(from Table 4a or Appendix E)* (208)

Cooling System Energy Efficiency Ratio (see Table 10c) (209)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh/year	
Space heating requirement (calculated above)														
	$(98)_1$	$(98)_2$	$(98)_3$	$(98)_4$	$(98)_5$	–	–	–	–	$(98)_{10}$	$(98)_{11}$	$(98)_{12}$		
Space heating fuel (main heating system 1), kWh/month														
$(211)_m = (98)_m \times (204) \times 100 \div (206)$														
$(211)_m$	$(211)_1$	$(211)_2$	$(211)_3$	$(211)_4$	$(211)_5$	–	–	–	–	$(211)_{10}$	$(211)_{11}$	$(211)_{12}$		
									Total (kWh/year) $=\Sigma(211)_{1..5,10..12}$ =					(211)
Space heating fuel (main heating system 2), kWh/month, omit if no second main heating system														
$(213)_m = (98)_m \times (205) \times 100 \div (207)$														
$(213)_m$	$(213)_1$	$(213)_2$	$(213)_3$	$(213)_4$	$(213)_5$	–	–	–	–	$(213)_{10}$	$(213)_{11}$	$(213)_{12}$		
									Total (kWh/year) $=\Sigma(213)_{1..5,10..12}$ =					(213)
Space heating fuel (secondary), kWh/month														
$(215)_m = (98)_m \times (201) \times 100 \div (208)$														
$(215)_m$	$(215)_1$	$(215)_2$	$(215)_3$	$(215)_4$	$(215)_5$	–	–	–	–	$(215)_{10}$	$(215)_{11}$	$(215)_{12}$		
									Total (kWh/year) $= \Sigma(215)_{1..5,10..12}$ =					(215)

Water heating

Output from water heater (calculated above)

$(64)_1$	$(64)_2$	$(64)_3$	$(64)_4$	$(64)_5$	$(64)_6$	$(64)_7$	$(64)_8$	$(64)_9$	$(64)_{10}$	$(64)_{11}$	$(64)_{12}$

Efficiency of water heater (216)
(From database or Table 4a/4b, adjusted where appropriate by the amount shown in the 'DHW efficiency adjustment' column of Table 4c, for gas and oil boilers use the summer efficiency, see 9.2.1)

if water heating by a hot-water-only boiler, $(217)_m$ = value from database record for boiler or Table 4a
otherwise if gas/oil boiler main system used for water heating, $(217)_m$ = value calculated for each month using equation (8) in section 9.2.1
otherwise if separate hot water only heater (including immersion) $(217)_m$ = applicable value from Table 4a
otherwise (other main system 1 or 2 used for water heating) $(217)_m$ = (216)

$(217)_m$ =	$(217)_1$	$(217)_2$	$(217)_3$	$(217)_4$	$(217)_5$	$(217)_6$	$(217)_7$	$(217)_8$	$(217)_9$	$(217)_{10}$	$(217)_{11}$	$(217)_{12}$	(217)
Fuel for water heating, kWh/month													
$(219)_m = (64)_m \times 100 \div (217)_m$													
$(219)_m$	$(219)_1$	$(219)_2$	$(219)_3$	$(219)_4$	$(219)_5$	$(219)_6$	$(219)_7$	$(219)_8$	$(219)_9$	$(219)_{10}$	$(219)_{11}$	$(219)_{12}$	
										Total $= \Sigma(219a)_{1...12}$ =			(219)

(for a DHW-only community scheme use (305), (306) and (310a) or (310b), with (304a)=1.0 or (304b)=1.0, instead of (219)

Space cooling

Space cooling fuel, kWh/month

$(221)_m = (107)_m \div (209)$

$(221)_m$						$(221)_6$	$(221)_7$	$(221a)_8$				

Total = $\Sigma(221)_{6..8}$= [ ] (221)

Annual totals	kWh/year	kWh/year	
Space heating fuel used, main system 1		(211)	
Space heating fuel used, main system 2		(213)	
Space heating fuel used, secondary		(215)	
Water heating fuel used		(219)	
Space cooling fuel used (if there is a fixed cooling system, if not enter 0)		(221)	
Electricity for pumps, fans and electric keep-hot (Table 4f):			
mechanical ventilation fans - balanced, extract or positive input from outside			(230a)
warm air heating system fans			(230b)
central heating pump or water pump within warm air heating unit			(230c)
oil boiler pump			(230d)
boiler flue fan			(230e)
maintaining electric keep-hot facility for gas combi boiler			(230f)
pump for solar water heating			(230g)
pump for storage WWHRS (see section G3.3)			(230h)
Total electricity for the above, kWh/year — sum of (230a)…(230h) =			(231)
Electricity for lighting (calculated in Appendix L)			(232)
Energy saving/generation technologies (Appendices M ,N and Q)			
Electricity generated by PVs (Appendix M) (negative quantity)			(233)
Electricity generated by wind turbine (Appendix M) (negative quantity)			(234)
Electricity used or net electricity generated by micro-CHP (Appendix N) (negative if net generation)			(235)
Electricity generated by hydro-electric generator (Appendix M) (negative quantity)			(235a)

Appendix Q items: annual energy (items not already included on a monthly basis)	Fuel	kWh/year	
Appendix Q, <item 1 description>			
energy saved or generated (enter as negative quantity)			(236a)
energy used (positive quantity)			(237a)
Appendix Q, <item 2 description>			
energy saved or generated (enter as negative quantity)			(236b)
energy used (positive quantity)			(237b)
(continue this list if additional items)			
Total delivered energy for all uses — (211)...(221) + (231) + (232)…(237b) =			(238)

10a. Fuel costs – Individual heating systems including micro-CHP

	Fuel kWh/year		Fuel price (Table 12)		Fuel cost £/year	
Space heating - main system 1	(211)	×		× 0.01 =		(240)
Space heating - main system 2	(213)	×		× 0.01 =		(241)
Space heating - secondary	(215)	×		× 0.01 =		(242)
Water heating (electric off-peak tariff)						
High-rate fraction (Table 13, or Appendix F for electric CPSU)					(243)	
Low-rate fraction	1.0 – (243) =				(244)	
High-rate cost	(219) × (243)	×		× 0.01 =		(245)
Low-rate cost	(219) × (244)	×		× 0.01 =		(246)
Water heating cost (other fuel)	(219)	×		× 0.01 =		(247)
(for a DHW-only community scheme use (342a) or (342b) instead of (247)						
Space cooling	(221)	×		× 0.01 =		(248)
Pumps, fans and electric keep-hot	(231)	×		× 0.01 =		(249)
(if off-peak tariff, list each of (230a) to (230g) separately as applicable and apply fuel price according to Table 12a						
Energy for lighting	(232)	×		× 0.01 =		(250)
Additional standing charges (Table 12)						(251)
Energy saving/generation technologies	(233) to (235a) as applicable, repeat line (252) as needed					
<description>	one of (233) to (235a)	×		× 0.01 =		(252)
Appendix Q items:	repeat lines (253) and (254) as needed					
<description>, energy saved	one of (236a) etc	×		× 0.01 =		(253)
<description>, energy used	one of (237a) etc	×		× 0.01 =		(254)
Total energy cost				(240)...(242) + (245)...(254) =		(255)

11a. SAP rating – Individual heating systems including micro-CHP

Energy cost deflator (Table 12):		0.42	(256)
Energy cost factor (ECF)	[(255) × (256)] ÷ [(4) + 45.0] =		(257)
SAP rating (Section 13)			(258)

12a. CO_2 emissions – Individual heating systems including micro-CHP

	Energy kWh/year		Emission factor kg CO_2/kWh		Emissions kg CO_2/year	
Space heating - main system 1	(211)	×		=		(261)
Space heating - main system 2	(213)	×		=		(262)
Space heating - secondary	(215)	×		=		(263)
Energy for water heating *(for a DHW-only community scheme use (361) to (373) instead of (264)*	(219)	×		=		(264)
Space and water heating	(261) + (262) + (263) + (264)			=		(265)
Space cooling	(221)	×		=		(266)
Electricity for pumps, fans and electric keep-hot	(231)	×		=		(267)
Electricity for lighting	(232)	×		=		(268)
Energy saving/generation technologies (233) to (235a) as applicable, repeat line (269) as needed						
<description>	one of (233) to (235a)	×		=		(269)
Appendix Q items repeat lines (270) and (271) as needed						
<description>, energy saved *	one of (236a) etc	×		=		(270)
<description>, energy used *	one of (237a) etc	×		=		(271)
* where the item is concerned only with CO_2 emissions use the right-hand column only.						
Total CO_2, kg/year	sum of (265)…(271)			=		(272)
Dwelling CO_2 Emission Rate	(272) ÷ (4)			=		(273)
EI rating (section 14)						(274)

13a. Primary energy – Individual heating systems including micro-CHP

Same as 12a using primary energy factor instead of CO_2 emission factor to give primary energy in kWh/year

APPENDIX D (BRE Group, 2012)

Item	Data	Comment
	FOR THE DWELLING AS A WHOLE	
Country	One of: - England & Wales - Scotland - Northern Ireland	
Region	One of those in SAP 2012 Table U1	Derived from the postcode of the property
Transaction type	One of: - marketed sale - non-marketed sale - rental ~~- not sale or rental~~ - stock condition survey - assessment for Green Deal - following Green Deal - FIT application - RHI application - ECO assessment - none of the above	Non-marketed sale includes right-to-buy
Tenure	One of: - owner-occupied - rented (social) - rented (private) - unknown	Private rented includes institutions (e.g. university)
Dwelling type	One of: - house - bungalow - flat - maisonette - park home	
Built form and detachment	Classification according to S1	Detachment does not need to be recorded for flats/maisonettes, provided that internal dimensions are being used
Number of rooms	Number of habitable rooms Number of heated habitable rooms	Total as defined in S9.1, inclusive of main property and any extension A heated room is one with a fixed heat emitter in the room

Item	Data	Comment
Dimension type	Measured internally or externally	Applies to areas and perimeters. Room heights always measured internally within the room. See S3
Conservatory	One of: - no conservatory - separated, no fixed heaters - separated, fixed heaters - not separated	
Non-separated conservatory only	Floor area Glazed perimeter Double glazed (yes/no) Height (number of half storeys of main dwelling)	See section 3.3.3
Flats and maisonettes only	Heat loss corridor, one of: - no corridor - heated corridor - unheated corridor	
	If unheated corridor, length of sheltered wall	The length of wall between flat and corridor. If a flat or maisonette is sheltered on more than one storey this is the total of the sheltered lengths on each storey
	Floor level relative to the lowest level of the building (0 for ground floor)	This is the lowest floor level if property has more than one storey. If there is a basement, the basement is level 0 and the other floors from 1 upwards
	Property position, one of: - basement - ground floor - mid floor - top floor	This is used for the description of the dwelling type on the EPC (e.g. 'Top-floor flat')
Number of extensions	Between 0 and 4	
FOR EACH BUILDING PART A building part is main dwelling, extension 1, extension 2, extension 3 or extension 4		
Age Band	According to S2	

Item	Data	Comment
Below the building part	Whether the lowest floor is/has: - ground floor - above partially/intermittently heated space (commercial premises) - above unheated space - to external air - same dwelling below - another dwelling below	A partially heated space below applies when it is above non-domestic premises. An unheated space below applies when it is above a space not used for habitation. If above more than one type, it is classified according to the largest floor area concerned.
Above the building	Whether the highest floor has: - pitched roof (slates or tiles), access to loft - pitched roof (slates or tiles), no access - pitched roof, sloping ceiling - pitched roof (thatched) - flat roof - same dwelling above - another dwelling above	For a park home select pitched or flat as appropriate
Dimensions	Area, average room height and exposed perimeter for each storey (from lowest occupied floor up to lowest occupied + 6). Party wall length on each storey	For rooms-in-roof, measure flor area only, inside the dwelling.
Floor construction	One of: - unknown - solid - suspended timber - suspended, not timber	For lowest floor of the building part. Not if another dwelling or other premises below.
Floor insulation	One of: - unknown - as built - retro-fitted	Not if another dwelling or other premises below. There must be evidence for retro-fit insulation.
Floor insulation thickness	One of: - unknown - 50 mm - 100 mm - 150 mm or more	Only if floor insulation is retro-fitted. Applies to ground floors and exposed upper floors.
Floor U-value	Value in W/m^2K	‘Insulation thickness’ and ‘U-value’ are mutually exclusive alternatives.
Wall construction	One of: - stone (granite or whinstone) - stone (sandstone or limestone) - solid brick - cob - cavity - timber frame - park home wall - system build (i.e. any other)	“park home wall” is the only option for a park home.

Item	Data	Comment
Wall thickness	Wall thickness in mm (or unknown if it cannot be measured)	Wall thickness varies for the same construction, use the average of the measured values.
Wall insulation type	One of: - as built - external - filled cavity - internal - cavity plus external - cavity plus internal - unknown	External, cavity or internal insulation to be indicated only if added subsequent to the original construction and evidence exists. If it has only the insulation that was part of the original construction it is 'as built'.
Wall insulation thickness	One of: - unknown - 50 mm - 100 mm - 150 mm - 200 mm	Only if wall insulation is external, internal, or cavity (filled or unfilled) plus external or internal.
Wall U-value	Value in W/m^2K. Can be given where known for any wall.	'Insulation thickness' and 'U-value' are mutually exclusive alternatives.
Wall dry-lined or lath and plaster	Yes/no	Only for uninsulated stones, solid brick or cavity walls in age bands A to E.
Alternative wall (for any building part with an alternative wall)	All the above items for walls, plus - net area of alternative wall - is sheltered wall (yes/no)	Sheltered wall applies only to the building part of a flat or maisonette that is adjacent to an unheated corridor or stairwell. If sheltered its area is calculated from the shelter length and not specified separately.
Party wall construction	One of: - solid masonry, timber frame or system built - masonry cavity unfilled - masonry cavity filled - not applicable - unable to determine	Except for detached properties there must be at least one building part with a party wall. 'not applicable' applies to a detached property and to building parts of other properties not adjoining a party wall.
Roof insulation (if not same or another dwelling above)	One of: - none - at joists - at rafters - flat roof insulation - sloping ceiling insulation - unknown	'None' does not apply to a flat roof or to a pitched roof with sloping ceiling. There must be evidence for joist, rafter, flat roof or sloping ceiling insulation, otherwise it is 'unknown'. 'At rafters' can apply to a thatched roof.

Item	**Data**	**Comment**
Roof insulation thickness (loft space) (pitched roof with insulation at joists, applies to roof or parts of roof without roof room)	One of: - 12, 25, 50, 75, 100, 150, 200, 250, 270, 300, 350, 400+ mm	Only for roof insulation at joist level and where can be accessed. If none or unknown this is recorded via the preceding item.
Rafter insulation thickness	One of: - unknown - as built - 50 mm - 100 mm - 150 mm or more	Only if roof insulation is 'at rafters'
Flat roof insulation thickness	One of: - unknown - as built - 50 mm - 100 mm - 150 mm or more	Only if roof insulation is 'flat roof insulation'
Sloping ceiling insulation thickness	One of: - unknown - as built - 50 mm - 100 mm - 150 mm or more	Only if roof insulation is 'sloping ceiling insulation'.
Roof U-value	Value in W/m^2K	'Insulation thickness' (loft, rafter, flat roof or sloping ceiling) and 'U-value' are mutually exclusive alternatives
Roof room age band	According to S2	The age band of the roof rooms can be different to that of the rest of the building part.
Roof rooms connected	Yes/no	Whether the roof rooms are connected to or are adjacent to another building part of the same dwelling. An adjacent part can be another roof room or a normal storey
Roof rooms insulation	One of: - unknown - as built - flat ceiling only - all elements	Only when there is a roof room in the building part concerned There must be evidence for insulation of flat ceiling or all elements, otherwise it is 'as built' or 'unknown'.

Item	Data	Comment
Roof room insulation thickness (on flat part of roof or roof room)	One of: - 12, 25, 50, 75, 100, 150, 200, 250, 270, 300, 350, 400+ mm, not applicable	Only if roof room insulation is 'flat ceiling only' or 'all elements'. 'Not applicable' is for the case of (documentary) evidence of insulation of all elements, but it is a vaulted ceiling with no flat part.
Roof room insulation thickness (other parts of roof room)	One of: - unknown - as built - 50 mm - 100 mm - 150 mm or more	Only if roof room insulation is 'all elements'.
Roof room area and U-value details	Area and U-value for: - flat ceiling - sloping ceiling - stud wall - gable wall (up to 2 of each of these)	Only where these details are collected; if so they supersede roof room insulation and roof room insulation thickness.
FOR THE DWELLINGAS A WHOLE		
Number of external doors	Total number of external doors	Doors to a heated access corridor are not included in the door count.
	Number of insulated external doors	Only if their U-value is known.
Insulated door U-value (when there are insulated doors)	Value in W/m^2K	Average for the insulated external doors (where applicable)
Windows (of the dwelling only, not including any conservatory)	Area: one of – typical – less that typical – much less than typical – more than typical – much more than typical	'Typical' refers to normal construction for the property type and age band concerned. If assessed as much more or much less than typical the area of each window should be measured.
If window area is typical, less than typical or more than typical	Proportion with multiple glazing Multiple glazing type, one of: - d/g pre year xxxx - d/g during or post year xxxx - d/g unknown date - secondary glazing - triple glazing - double, known U-value - triple, known U-value	As percentage xxxx is: - 2002 in England & Wales - 2003 in Scotland - 2006 in Northern Ireland.
PVC window frames	PVC window frames (yes/no)	To be included when the multiple glazing type is d/g pre year xxxx or d/g unknown date.

Item	**Data**	**Comment**
Window glazing gap	Glazing gap, one of: - 6 mm - 12 mm - 16 mm or more	To be included if PVC window frames
Window U-value	Value in W/m^2K	Only when multiple glazing is double or triple with known U-value
Window g-value	Value to 2 d.p.	
Window data source	Manufacturer or BFRC	
If window area is much less or much more than typical	For each window: - location (building part) - window or roof window - area (including frame) - glazing type (as above, plus single) - PVC window frame (yes/no) - Glazing gap (6/12/16+) - orientation (one of S, SE, E ,NE, N, NW ,W, SW, horizontal) - U-value - g-value - data source	This option can also be used if more than one type of multiple glazing. PVC frame only when the glazing type is d/g pre year xxxx or d/g unknown date. Glazing gap only for PVC frame. U-value, g-value and data source only when multiple glazing type is double or triple with known U-value.
Draught proofing	Between 0 and 100%	Percentage of all windows and doors draught proofed
Fireplaces	Number of open fireplaces	
Main heating system (option to say 'none')	Fuel for main heating	If none, the calculation is done for portable electric heaters with no controls.
	Product index number whenever possible for boilers, micro-CHP, heat pumps, warm air systems, storage heaters, otherwise system (marked "rd") from Table 4a or 4b	If product can be identified, its characteristics are obtained via the database. Storage heaters (high heat retention types only): index number of each heater
	Flue type, one of - open - room-sealed	Applies to boilers, micro-CHP and warm-air systems. For fires and room heaters use normal flue type indicated in Table 4a
	For gas boilers 1998 or later, the ignition type, one of - auto-ignition - permanent pilot light	Not if from database
	For gas boilers 1998 or later, then whether or not fan-flued	Not if from database
	For gas and oil boilers, for heat pumps to water and for electric CPSUs, the heat emitter type, one of: - radiators - underfloor - fan coil units	If underfloor downstairs and radiators upstairs, select radiators

Item	Data	Comment
	For wet systems, central heating pump age, one of: - 2012 or earlier - 2013 or later - unknown	Fan coil units only for heat pumps. Unknown if the pump cannot be located.
	For heat pumps, MCS installation (yes/no)	'Yes' only if documentary evidence available.
	Design flow temperature of heat generator, one of: - unknown - over 45°C - <= 45°C and over 35°C - <= 35°C	Applicable to heat pumps and condensing boilers. Unknown unless documentary evidence is available giving the design flow temperature. Option "<= 45°C and over 35°C" not available for heat pumps from SAP Tables.
Second main heating system (where applicable)	Details of system as above. Plus the percentage of heated floor area served by the second system. System 1 is that heating the living area.	Estimate percentage to nearest 10%. If there is a boiler providing DHW only, assign it as the 2nd main system with a space heating percentage of zero
Community heating system	Index number of community heat network if known, otherwise fuel used by community system and heat generator type, one of: - boilers - CHP and boilers - heat pump	If fuel cannot be ascertained, assume mains gas.
Main heating controls	Item from Table 4e according to main system type. Compensating controller (yes/no/not applicable). Product index number of controller if applicable	For both main systems if there are two.
Secondary heating system	Fuel for secondary heating, and system from room heater section of Table 4a	'None' if no secondary heating system.
Water heating	Either - from main heating system, or - from 2nd main system, or - from secondary system, or - any other water heater marked "rd" in hot-water-only section of Table 4a, or - no DHW system present	If no system, the calculation is done for an electric immersion, see text below Table S17. Fuel also needed if not from main system.

Item	Data	Comment
	Cylinder size, one of: - no cylinder - no access - normal (up to 130 litres) - medium (131-170 litres) - large (> 170 litres)	Separate thermal store (hot-water only or integrated) treated as if it were a cylinder.
	Cylinder insulation type (unless no access), one of: - none - loose jacket - factory-applied	
	Cylinder insulation thickness, one of: 0, 12, 25, 38, 50, 80, 120, 160 mm	
	If immersion, whether single or dual	
	Cylinder-stat (unless no access): yes/no	
Solar water heating	Solar panel (yes/no)	
Solar water heating details known	yes/no. If yes, then details: - tilt: one of horizontal, 30°, 45°, 60°, vertical - orientation (if not horizontal): one of S, SE, E ,NE, N, NW ,W, SW - overshading: very little, modest, significant or heavy - solar water pump: electrically powered, solar powered or unknown - type(s) of showers in the property, one of - non-electric only - electric only * - both electric/non-electric - no shower	Only if solar panel present * where the water is heated as the shower runs. If the shower is supplied from a hot-water cylinder it is classified as non-electric even though the cylinder is electrically heated.
Solar collector details known	Yes/no. If yes then details: - collector aperture area - collector type (evacuated tube, flat plate or unglazed) - collector zero loss efficiency - collector linear heat loss coefficient - collector 2nd order heat loss coefficient	Only if solar panel present and solar water heating details known. Documentary evidence is required to enter collector values.
Solar store details known	Yes/no. If yes, then details: - combined solar store (yes/no) - total hot water store volume - dedicated solar volume	Only if solar panel present and solar water heating details known and solar collector details known.
Flue gas heat recovery	Yes/no. If yes, then: - product index number	Only if located in the database.

Item	Data	Comment
PV for flue gas heat recovery	Details of the PV: - kWp - tilt: one of horizontal, 30°, 45°, 60°, vertical - orientation (if not horizontal): one of S, SE, E ,NE, N, NW, W, SW - overshading: very little, modest, significant or heavy	Only for systems with a PV powered immersion.
Baths and showers	Number of rooms with bath and/or shower Number of rooms with mixer shower and no bath Number of rooms with mixer shower and bath	These items are always collected, to enable a recommendation for wastewater heat recovery to be made.
Wastewater heat recovery	none or instantaneous or storage. If instantaneous type present: - number of systems (1 or 2) - system 1 product index number - number of mixer showers with system 1 in rooms with bath - number of mixer showers with system 1 in rooms without bath - system 2 product index number - number of mixer showers with system 2 in rooms with bath - number of mixer showers with system 2 in rooms without bath	Only if located in the database. Number of rooms with bath and/or shower includes rooms with only an electric shower. If two showers found in a room, count as one. Only mixer showers count for instantaneous wastewater heat recovery. Mixer shower means a shower where the hot water is provided by a boiler (combi or regular), heat pump or immersion heater. A mixer shower attached to bath taps is recorded as a mixer shower only if there is a permanent bracket over the bath at least 1.5 m above the plughole and there is a shower curtain or screen.
	If storage type present: - product index number - total showers and bath - number of showers and bath routed through WWHRS	Only if located in the database.
Space cooling system present	Yes/no	
Mechanical ventilation	Yes/no, and if 'yes' whether extract-only or balanced	Applies to whole house ventilation system only. Otherwise natural ventilation is assumed. Intermittent extract fans (kitchen and bathrooms) are not a mechanical ventilation system for SAP calculations, but continuously running extract fans in wet rooms are treated as mechanical extract ventilation.

Item	Data	Comment
Electricity meter	Dual/single/18-hour/ 24-hour/unknown	See S12
Mains gas available	Yes/no	'Yes' means that there is a gas meter or a gas-burning appliance (e.g. cooker) in the dwelling. A closed-off gas pipe does not count. Where a boiler is present attached to a heating system (not in a box), and the mains gas meter has been removed for security reasons, enter a gas boiler as the main form of heating and indicate that mains gas is present. Can be relevant to improvement recommendations.
Photovoltaic array	yes/no, and if yes then either: a) % of external roof area with PVs, or b) details of the PV: - kWp - pitch: one of horizontal, 30°, 45°, 60°, vertical - orientation (if not horizontal): one of S, SE, E ,NE, N, NW ,W, SW - overshading: very little, modest, significant or heavy In either case, whether the PVs are connected to the dwelling's electricity meter (yes/no, separately for each PV if more than one)	b) to be used when the information on kWp is available. In this case up to 3 PV arrays can be specified A convection will define what to do when the situation is not immediately obvious.
Terrain	One of: - dense urban - low rise urban or suburban - rural	Used to generate wind turbine recommendation where appropriate data item must always be collected.
Wind turbine	Yes/no	
Wind turbine details known	Yes/no. If yes, then details: -number of turbines - rotor diameter - height above ridge	Only if wind turbine present.
Lighting	Total number of fixed lighting outlets	LEDs are considered as low energy lights.
	Total number of low-energy fixed lighting outlets	Where there are 4 or more downlighters/ceiling lights, divide the bulb count by 2. Include fixed under-cupboard kitchen strip lights.
Swimming pool	A swimming pool is not included in the data set.	Count the room containing the swimming pool as a habitable room and ass addendum 4 (see S15)