

Development of an energy efficiency retrofit cost-benefit calculator phase two

Report for CIC Start Online, June 2012

This paper describes the phase 2 development of Carbon HEART (Home Energy Analysis Retrofit Tool). It outlines the results of the collaboration between Changeworks, and the Urban Energy Research Group in the School of Built Environment at Heriot-Watt University funded under a CIC Start Online Academic Consultancy Award.

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1.0 Executive Summary

This paper reports on the development of a spreadsheet-based calculation and analytical tool, originated by Changeworks. This was subsequently substantially enhanced, in partnership with the Urban Energy Research Group (UERG) in the School of Built Environment at Heriot-Watt University, using two CIC Start Online Academic Consultancy Awards. Details of the project team are covered in Appendix 1.

Carbon HEART (Home Energy Analysis Retrofit Tool) is designed to inform future investment decisions by social landlords concerned with improving the energy efficiency of their stock. It has potential application for private sector landlords and individual households. Prior to the CIC Start phase 1 enhancements undertaken in collaboration with UERG, it lacked the necessary functionality and practical applicability for use as a commercial consultancy tool. Through academic collaboration the calculator was enhanced so that it could more efficiently assess energy efficiency options for both individual as well as groups of residential properties. The most up-to-date version of the calculator utilises key data from running National Home Energy Rating (NHER) surveys, but can be easily adapted to accommodate data extracted from other modelling tools.

Having developed a calculator that could be applied commercially, it was recognised through testing that further development opportunities existed. An application for phase 2 work through CIC start allowed these areas to be explored. This worked focused on:

1. More accurate assessment of environmental benefits based on different tenant behaviours and preferences;
2. More detailed social analysis, modelling fuel poverty levels and tenancy security using different income scenarios, health patterns and fuel prices;
3. Maximising economic benefits from the Green Deal and Energy Company Obligation (ECO) finance schemes.

This report outlines results of the Phase 2 work and summarises plans for its commercial development by Changeworks. As a highly detailed and flexible analysis tool, *Carbon HEART* will be the mainstay of Changeworks' offering to clients in the social housing sector, helping them develop well-targeted and cost-effective carbon reductions and interventions aimed at reducing fuel poverty.

2.0 Background

The initial development of the model is described in a previous (December 2012) report to CIC Start. This work helped Changeworks to develop retrofit advisory services for local authorities and housing associations, to help them identify cost-effective strategies to address climate change and fuel poverty objectives. The result of the work with Heriot-Watt University was *Carbon HEART* (Home Energy Analysis Retrofit Tool) an Excel-based calculator. Field-testing and development by Changeworks revealed opportunities to further enhance and refine the tool. This phase 2 work was supported through a CIC Start academic grant.

3.0 Objectives

For phase 1 the key objective was to develop a tool that would allow more accurate and tailored stock analysis, rather than generic modelling using which relies on broad assumptions (particularly those associated with cost and energy use). Instead, *Carbon HEART* uses actual dimensional and cost data for calculations, which can be updated for each project and client. The tool is suitable for many different property types and/or multiple dwellings within a single envelope such as flats.

Phase 2 objectives built on this approach by focusing on:

1. More accurate assessment of environmental benefits based on different tenant behaviours and preferences;
2. More detailed social analysis, modelling fuel poverty levels and tenancy security using different income scenarios, health patterns and fuel prices;
3. Maximising economic benefits from the Green Deal and Energy Company Obligation (ECO) finance schemes.

4.0 Phase two development

Following on from the initial success of the Phase 1 collaboration with Heriot-Watt and consultation with potential clients it was recognised that the tool would benefit from further enhancement. In particular, the tool needed to provide landlords with better information concerning the impact of improvements on tenants with differing lifestyles and heating patterns. Being able to manipulate these factors is critical if improvement options delivered via the Green Deal and ECO are to be properly modelled. To deliver this functionality, Heriot-Watt University was commissioned to enhance the tool to do the following:

1. Consider Variability issues, Low, Medium and High scenarios e.g. households opting for lower or higher heating temperatures, heating usage beyond the 'Standard Heating Regime' and the 'Rebound' effect;
2. Provide A Green Deal sensitivity sheet/ year-on-year baseline cost changes/ income increments;
3. Provide an energy company obligation (ECO) calculator linked to the Green Deal for measures not meeting the Golden Rule;
4. Allow matching grant availability to income status/ 'Passported' benefits. (75% of social housing tenants are on a benefit);
5. More detailed CO2 assessment based on carbon intensity by energy generation;

6. Better information on carbon saved as a percentage of current/ of existing/ of future targets;
7. The introduction of critical thresholds as indicators of more radical approaches, changes in property management/ letting policy, stock transfer or demolition.

The work was complete by Sophie Simpson and David Jenkins of Heriot-Watt's Urban Energy Research Group, who worked with Changeworks during April and May 2012 to develop the enhanced functionality required. The process involved initial enhancements of the sheet followed by testing by Changeworks utilising data from two No-Fines property archetypes with a number of variant sub-archetypes. This was matched with a range of heating patterns reflecting different lifestyles of tenants. The resulted in a number of changes to the calculator, as follows:

- **More detailed calculation of CO₂ emissions:**
 - The 'Fuel Data' sheet was updated to incorporate a column to enter the CO₂ intensity associated with different fuel types and generation;
 - The 'Scenario Results' sheet has been updated so it automatically calculates the CO₂ emissions for each end use based on kWh values determined by the modelling, the fuel type selected and the corresponding CO₂ intensity;
 - The second 'Property Details' sheet and the 'Scenario Results' sheet were updated with additional rows to enter data on secondary cooking fuel energy use;
 - An additional sheet was created to illustrate the breakdown of CO₂ emissions by end use for the baseline and improvement scenarios using bar graphs. This allows reporting on a project, archetype and sub-archetype basis. Graphs now feature reduction targets based on specified future percentage reduction targets.

- **Modification of the sheets reporting on Green Deal costs and repayments:**
 - An additional sheet was included to maintain a database of additional one-off costs in relation to installing the improvement measures, and any ongoing maintenance costs;
 - An additional sheet was added to reference the retrofit measures applicable to individual sub-archetypes, and to record any additional costs or on-going maintenance costs that may be incurred for each improvement scenario;
 - An additional sheet was added summarising the preliminary cost of installation, any additional costs and whether these should be included within the calculation of the Green Deal loan repayments. Details of the loan can now be entered and any of the properties requiring ECO assistance are highlighted;
 - The three Green Deal output sheets from the previous version of the spreadsheet were combined to report the results of each scenario on a single sheet, for any sub-archetype selected from a drop-down menu. This allows further investigation of the effect of variations in the loan interest rate or repayment period;
 - A duplicate of the above sheet was created, which instead of varying the loan interest rate and repayment period considers the impact of percentage increases (inflation) on fuel bills.

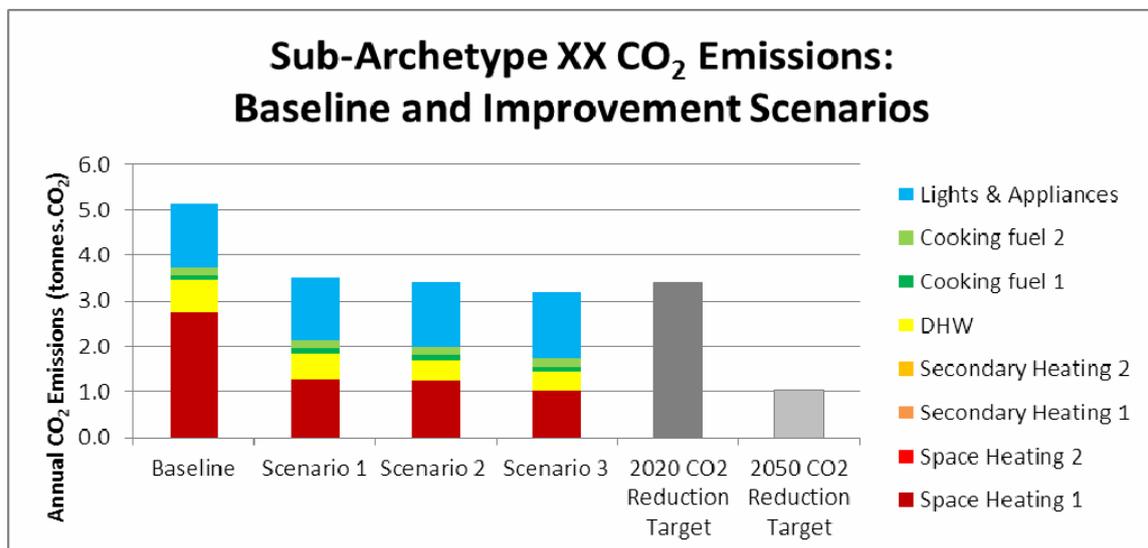
- **Ability to investigate the effect of different householder behaviours:**
 - This includes a sheet to paste the number of sub-archetypes within each archetype, to carry out the 'Delete Column' command as for the original spreadsheet;
 - A second sheet features a table into which fuel data from the original spreadsheet can be pasted;
 - A third sheet records data describing the sub-archetypes as well as kWh data for the baseline properties and three improvement scenarios;
 - Sheets four to six allow kWh data to be entered for the baseline and three improvement scenarios for each sub-archetype, where the calculation methodology has been modified to represent alternative operational behaviour in each the properties;
 - Three sheets visually demonstrate the effect of these changes on annual building energy consumption, operational costs and CO₂ emissions using bar graphs.

5 Test outputs from the enhanced tool

Using the two No-Fines blocks and sub-archetypes, ease of data entry and the integrity of the final calculations were established. The following graphs illustrate test outputs from the tool and describe the enhanced functions:

5.1 CO₂ emissions

Output in relation to carbon savings based on modelling three retrofit scenarios, and the baseline are illustrated in graph 1 below.



Graph 1 Test outputs for CO₂ emissions

This shows that all the scenarios modelled will meet the 2020 CO₂ targets and the challenge of attempting to meet the 2050 targets based on today's technologies. It also shows the limited additional savings achieved by installing the more expensive measures in scenarios

two and three. Given that scenario 1 is substantially cheaper than the others, this tool supports advice to the property owner to pursue this strategy.

5.2 Modification of the sheets reporting on Green Deal costs and repayments:

The outputs related to analysis of the Green Deal are shown in table 1 below

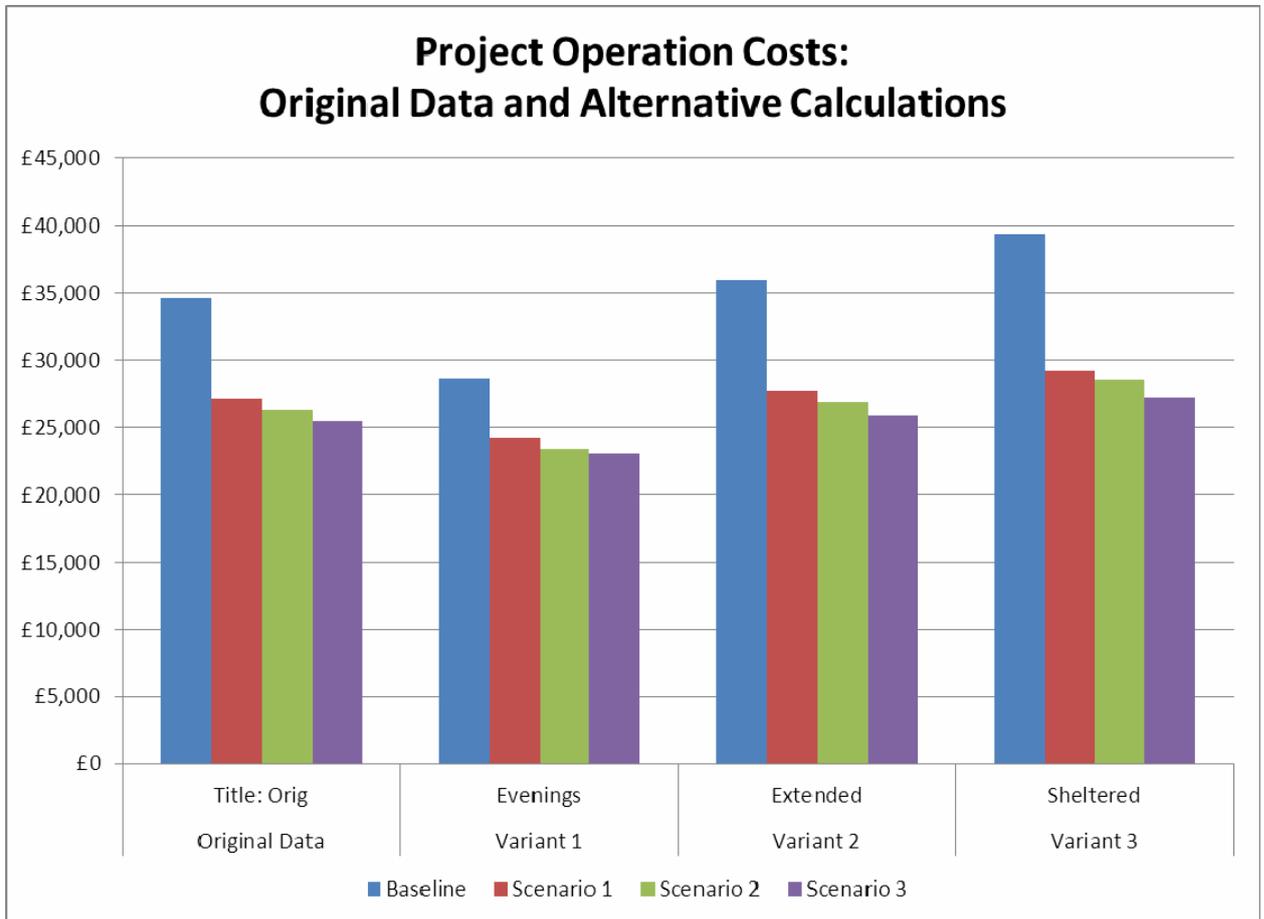
Archetype	Archetype 1		
	1a	1b	1c
Sub-Archetype			
Description 1	2 bedroom	2 bedroom	2 bedroom
Description 2	Ground Floor	Mid Floor	Top Floor
Description 3	a	b	c
Description 4	0	0	0
No of sub-archetypes	2	2	2
BASELINE			
Total costs, £/year	£1,353.88	£1,145.49	£1,272.05
SCENARIO 1			
Annual Building Operation Costs, £/year	£1,034.25	£947.49	£998.53
Savings £/year	£319.63	£198.00	£273.52
Cost of work	£10,625	£6,669	£6,931
Installation Costs £	£732.00	£732.00	£732.00
Include in cost of work? Yes/No	yes	no	
Additional Costs £	£952.68	£952.68	£952.68
Include in cost of work? Yes/No	yes		
Professional Costs	15%	15%	19%
Include in cost of work? Yes/No	yes		
Adjusted Cost of Work £	£14,155.90	£6,668.70	£6,931.18
Remaining Costs	£0.00	£2,937.69	£3,321.69
Maintenance Costs (£/year)	£150.00	£150.00	£150.00
Interest Rate	8%	8%	8%
Repayment Period (years)	20	20	20
Repayment value	-£1,441.81	-£679.22	-£705.96
Target Bill Reduction	10%	10%	10%
ECO necessary?	YES	YES	YES

Table 1 Green Deal Outputs

The above table illustrates the analysis of one of the two archetypes. This shows the client that the chosen retrofit strategy will require substantial ECO subsidy if the tenant to be better off, as required by the Green Deal's 'Golden Rule'. In this case a 10% savings is specified, but this could be varied. The tool is designed to ensure that all costs associated with the work are included, and also allows interest rates to be varied. By being able to manipulate data to identify robust cost-per-tonne-of-CO₂ figures the tool provides essential information for clients entering negotiations with Green Deal providers.

5.3 Provision of an additional sheet to investigate the effect of variations to the calculation methodology to consider different operational behaviour

The impact of user behaviour was modelled for tenants in the No-fines archetype. The results are shown in Graph 2.



Graph 2 Impact of heating behaviours

The above graph shows the significant impact of user behaviour, comparing modelled behaviour (based on the inbuilt assumptions in the NHER software) with a range of alternative, and arguably more realistic, user behaviours. This shows reductions where tenants are at home mainly for evenings and weekends (variant 1), less change with a higher occupancy pattern (variant 2) and increases for householders who spend more time in the home (as result age and health conditions, for example) (variant 3). If tenants fell into the latter category then the tool helps to justify additional investment due to higher bill and CO₂ saving potential.

6 Future development and applicability

Carbon HEART provides accurate costs for planning retrofit projects and undertaking feasibility studies prior to major capital investments. Its focus on dimensional data and sub-archetypes means that the outputs are far less generic than those delivered through using

other software. The tool is particularly applicable to multiple blocks and hard-to-treat housing types, both priorities for strategies to tackle emissions and climate change. It also has applicability where there are common or varying users' behaviours that need to be understood before CO₂ savings can be accurately predicted.

Given these capabilities the tool has a potential market amongst social and corporate landlords as a cost-effective analysis service, particularly in relation to meeting social landlords' obligations under their SHQS Standard Delivery Plans. The costing element might be applied across a property portfolio to address whole life costs and best value, including bulk discounts that might be secured by restructuring capital work programmes.

The current tool is designed to take NHER survey outputs. This can be easily updated for a range of other common modelling tools, such as RdSAP which is to be used for Green Deal assessments.

7 Commercial development of the tool

Changeworks aims to make the tool available to all Scottish social landlords in summer 2012, allowing them to plan how their capital programmes can be adapted in relation to the Green Deal and the ECO. Marketing materials have been created and a webpage set up (<http://www.changeworks.org.uk/projects/carbon-heart/629/>). A short case study is available based on the Phase 1 calculator (http://www.changeworks.org.uk/uploads/CarbonHEART_CaseStudy_FifeCouncilMay.pdf).

Further promotion will coincide with the finalisation of new housing quality standards, which will drive the review of capital programmes and investment strategies. Changes to how fuel poverty is being measured (the Hills Review) are also being monitored for potential applicability of the model as an advice tool. A longer-term aspiration is providing strategic advice to the private sector. This will be explored further in late 2012, when new minimum housing standards are subject to public consultation.

So *Carbon HEART* can be used outside the Scottish market, partnering opportunities with energy advice organisations in England are also being explored. A further market is providing services to energy companies seeking to identify CO₂ savings to meet ECO requirements.

In 2012 it is expect that half of a full-time equivalent post will be retained and protected, with scope to make this a full-time equivalent post as the market develops.

Appendix 1 Biographies of the project team

Changeworks Consultancy

Stuart Hay is Sustainable Futures Manager at Changeworks. He previously worked in policy and campaigning, with Friends of the Earth Scotland, the Scottish Wildlife Trust, Help the Aged and as a researcher in the Scottish Parliament. Since joining Changeworks in 2008, he has led a team developing a range of innovative and awarding winning projects, with a strong focus on energy conservation in the built environment and barriers to the deployment of micro-generation technologies. Stuart has managed ground-breaking research work for a range of high profile clients including the Energy Saving Trust, WWF Scotland, Consumer Focus Scotland, the Joseph Rowntree Foundation and eaga Charitable Trust, as well as offering support to a wide range of Climate Challenge Fund groups across Scotland.

Robert Barnham is a Senior Project Officer at Changeworks. He previously was Director of Energy Action Scotland, and earlier managed a Technical Aid Centre in Dundee, where he set up the first community based insulation project in Scotland. He qualified as an architect and has an MA in Urban Design and a RIBA Diploma in Urban Design. He has worked in the public, private and voluntary sectors. Since joining Changeworks in 1991 he has worked on various pilot projects as well as building-specific projects focussing on energy efficiency and carbon reduction. He has extensive experience of community-based work, developing training resources and delivering training to a wide cross section of client groups.

Gary Pearson is a Surveyor and Technical Officer at Changeworks joining in 1998. He has ten years experience of conducting domestic energy surveys, for a wide range of property types. He undertakes NHER and Energy Performance Certificate surveys and energy analysis, and reports on energy modelling options for local authorities, housing associations and government organisations. Recent work has included energy modelling for the City of Edinburgh Council on hard-to-treat non-traditional properties, and energy efficiency and renewable energy options for rural properties for Historical Scotland. He also carried out the data analysis for the Home Energy Conservation Area reports for three Scottish local authorities and on improvements carried out under the Central Heating Programme and Warm Deal grants, and wrote the related annual reports on behalf of the Scottish Government.

The Urban Research Group, the School for the Built Environment, Heriot-Watt University

Dr David Jenkins is a Research Fellow and has been with the UERG since 2005. His background is in low-energy buildings (their simulation using dynamic building packages), application of future climate projections, fuel poverty and micro-generation. He has worked on several research projects including Tarbase and Low Carbon Futures and leads the Group's consultancy activities. He obtained a PhD in modelling daylight technologies in buildings, with a view to reducing building energy consumption and carbon emissions. He has an MSci in Physics and Astronomy from University College London.

Sophie Simpson has been a Research Associate with UERG since 2010 working on the CALEBRE project, looking at low-carbon refurbishments and the impact of retrofitting a mechanical ventilation system with heat recovery into an existing dwelling, and the energy implications in relation to building air tightness. Prior to this she worked for an engineering company, carrying out detailed building performance simulation and modelling to assist and advise architects and building services on energy efficient designs for domestic and non-domestic buildings. Sophie has an MEng in Product Design and Engineering from University of Glasgow/Glasgow School of Art.



Refurbishment Cost Model Version 2

David Jenkins

Sophie Simpson

Urban Energy Research Group

School of Built Environment

Heriot-Watt University



1 Amendments made to cost refurbishment model

Changes have been made to the tool throughout, many of which will become evident when following the guide in Section 2. However, a summary of the main changes are given below:

- 1) More detailed calculation of CO₂ emissions:
 - The '17_FuelData' sheet has been updated to incorporate a column to enter CO₂ intensity associated with different fuel types and generation
 - The '9_ScenarioResults-by SA' sheet has been updated to automatically calculate the CO₂ emissions for each end use based on kWh values determined by the modelling, the fuel type selected and the corresponding carbon intensity entered in '17_FuelData'.
 - Both '2_PropDetails' and '9_ScenarioResults-by SA' have been updated to feature additional rows to enter data on a second cooking fuel energy use.
 - An additional sheet has been included to visually show the breakdown of CO₂ emissions by end use for the baseline and three improvement scenarios using bar graphs. These report on a project basis, archetype basis and individual sub-archetype basis. The graphs feature reduction targets based on specified future percentage reduction targets.

- 2) Modification of the sheets reporting on Green Deal costs and repayments:
 - An additional sheet has been included to maintain a database of additional one-off costs in relation to installing the improvement measures, and any on-going maintenance costs.
 - An additional sheet has been added to reference the retrofit measures applicable to individual sub-archetypes and record any additional costs or on-going maintenance costs these may incur for each of the improvement scenarios.
 - An additional sheet has been added summarising the preliminary cost of installation, any additional costs and whether these should be included within the calculation of the Green Deal loan repayments. Details of the loan can be entered and any of the properties requiring ECO assistance are highlighted.
 - The three Green Deal output sheets from the previous version of the spread sheet have been combined to report the results of the three scenarios on a single sheet, for any sub-archetype selected from a drop down menu. This now allows the user to further investigate the effect of variations in the loan interest rate or repayment period.
 - A duplicate of the previous sheet is included, but instead of varying the loan interest rate and repayment period it considers the impact of percentage increases to the fuel bills.

- 3) Provision of an additional sheet to investigate the effect of variations to the calculation methodology to consider different operational behaviour:
 - This includes a sheet to paste the number of sub-archetypes within each archetype, to carry out the 'DeleteColumn' command as for the original spreadsheet.

- A second sheet features a table into which fuel data from the original spread sheet can be pasted.
- A third sheet records data describing the sub-archetypes as well as kWh data for the baseline properties and three improvement scenarios.
- Sheets four to six allow kWh data to be entered for the baseline and three improvement scenarios for each sub-archetype, where the calculation methodology has been modified to represent alternative operational behaviour of the properties.
- Three sheets visually demonstrate the effect of these changes on annual building energy consumption, operational costs and CO₂ emissions using bar graphs.

2 Guide to using the original spreadsheet tool

This section describes the operation of the tool and its application.

2.1 Description of worksheets

The workbook has a large number of individual sheets, some of which require input from the user, some used for calculations, while others are used to output information. A number of sheets are hidden and not needed by the user (and so are not included below). A description of the active sheets is provided below.

1_Archetypes

This is the first input page and requires the user to choose the number of archetypes, and sub-archetypes within each archetype (with a maximum of ten archetypes and ten sub-archetypes, creating up to 100 different dwelling types). The user should always use consecutive numbers for archetypes (e.g. if there are three archetypes then they should be archetypes 1, 2 and 3). Additional information can also be added to keep a record of the distinction between each archetype, such as breakdown of social/private sector dwellings (though this is actually inputted in **2_PropDetails**). If further categorisation is required, then “Block” information can be filled in. This allows the user to group a series of dwellings across archetypes.

2_PropDetails

The data input sheet loosely follows the outline of assessor data collection sheet. Sub-archetypes are assigned a column each for data input, though blank columns will be deleted when “DeleteColumns” macro is run. Cells highlighted in blue indicate a drop down menu. Shaded cells will become available depending on data input previously (e.g. Mechanical Ventilation “TYPE” can only be accessed if it has been indicated that “mechanical ventilation” is present in the cell above).

“Heating and Hot water” links to **3_HtngSystems**. Details can be inputted in **3_HtngSystems** to describe the system type and then, returning to **2_PropDetails**, this can then be accessed via a drop down menu and assigned to the sub-archetypes as appropriate. System data which can vary between sub-archetypes, such as ‘Install Year’, is entered on **2_PropDetails** in the appropriate column.

3_HtngSystems

This captures more detailed information (in line with assessor data collection document) relating to space heating and hot water systems. Currently, the boxed area to the right allows different systems (e.g. boiler, CHP, Electric Heating) to be captured with variables accessible through drop down menus in the main table (e.g. for boilers – is there boiler interlock – yes/no?). The system labels are referenced by **2_PropDetails** when detailing which systems are present in each sub-archetype. This sheet is mainly for reference purposes, to maintain a record of baseline heating systems.

4_OpeningSchedule

This sheet allows details for different window/opening types to be described. Ideally, for similar type windows, separate descriptions should be set up where the openings exist in different construction types within the same property (e.g. a window in an unfilled cavity wall is different to the same window in a filled cavity wall).

At this point the “Ctrl + Shift + Q” command should be used to organise data so that is referenced correctly for the following sheets **BEFORE DETAILED INFORMATION IS ENTERED**. It is possible to apply this after, but would require data for the following sheets to be rechecked to ensure the alphabetical organisation has not shifted entered values about.

5_WindowData

This allows window and opening data, specific to each sub-archetype, to be entered.

6_Dimension Data

Construction type is selected from the drop-down menus in column A and dimensions are completed as appropriate for each sub-archetype. If a construction type is used several times, this can be selected from the drop-down menus. The total value is then summated and reported at the top of the page.

For each construction, the middle section of the input data is based on the assessor data collection sheet. The last section is specific dimension data used in the calculations of costs etc.

7_ScenarioMeasures

This is where scenarios are defined. Using columns B, C and D, select the relevant measures for each scenario using an “x”. In the subsequent columns, use the dropdown to select whether a particular measure should be ignored for a particular sub-archetype. For example, a top floor flat wouldn't use ground floor insulation, and a ground floor flat wouldn't use loft insulation. By selecting “Override” the spreadsheet will automatically make the cost of that measure in that sub-archetype, zero. The list of measures on the left hand side is picked up from **18_MeasuresCosts**. If additional measures are needed, add them into the “Other” section in **18_MeasuresCosts**, and they will automatically appear in this sheet. However, these additional technologies will be accounted for on a “per dwelling” basis, rather than, e.g., per m². It is therefore set up for individual technologies that are used on a number-of-units basis, and will not be automatically sized for the specific dwelling.

8_ScenarioCosts

This sheet, requiring no input, calculates the cost of each scenario measure for each sub-archetype, again using the same list from **18_MeasuresCosts**. Row 27 provides the total cost for each scenario for the sub-archetype (per dwelling).

9_ScenariosResults-by SA

All results in this sheet are per sub-archetype. In cell "A12" the appropriate version of SAP can be selected. This has been done based on the SHQS list of 2001, 2005 and 2009, but are analogous to v9.81, v9.90 etc. NHER values are entered in the yellow cells and fuel type is chosen from the drop down menus (with the exception of the baseline building which references the 'fuel type' data entered in **2_PropDetails**). The SHQS calculation is done by recognising which version of SAP has been used, however you do have to select the fuel type (replacing the previous gas/electric version, enabling the complete choice from SHQS table). If the sub-archetype does not meet fuel poverty thresholds (i.e. more than 10% of the stated income is being spent on energy), or if it fails under any of the SHQS calcs, the respective cells will turn red. This sheet also requires the NHER values for the three refurbishment scenarios (if being used). Both the operational energy costs and CO₂ emissions for the different end-uses of each sub-archetype are calculated from the kWh values entered for the baseline building and the three improvement scenarios. The calculation references carbon intensity and fuel cost data from the **17_FuelData** sheet, which acts as a database. Currently this has been populated with carbon intensity data from SAP 2009, but this can be modified and there is a facility to record the source of the data. Any changes to the carbon intensity and tariff data will be automatically updated within the spreadsheet. The only exception to this is where the 'Fuel Description' title has been changed, in which case the reference from the drop down menu will need to be reselected to update with the modified title to ensure the calculations reference the correct data.

10_Sub-archetypeSummary

This is a complete list of all calculated sub-archetype information, upon which other output pages are based.

11_ArchetypeSummary

This translates the sub-archetype output into useful archetype-based output. A graphical representation is given for capital costs, CO₂ savings, CO₂ saved per pound, and SAP improvements. Where appropriate, this is broken down by sub-archetype.

12_ProjectSummary

This sheet provides outputs that are suitable for describing the entire project, i.e. all sub-archetypes originally defined. A comparison between the refurbishment scenarios, and compared to the baseline scenario, is provided across the most important metrics.

13_CO2 emissions

This sheet provides outputs regarding CO₂ emissions associated with the entire project, each archetype, and individual sub-archetypes where the user wishes to consider this further. The graphs report the CO₂ emissions for the baseline building and the three retrofit scenarios. In addition to this, future CO₂ reduction targets (specified at the top of the sheet) are reported in the graphs, based on a percentage reduction in Baseline CO₂ emissions, to provide an indication of how close the improvement scenarios are to reaching these. The CO₂ emissions associated with the baseline and three improvement scenarios are broken down into each end-use, based on the kWh and carbon intensity data entered in **9_ScenariosResults-by SA** and **17_FuelData** respectively.

14a_AddtnlGreenDealCosts

The additional costs associated with the installation of the retrofit technologies (which were not included in **8_ScenarioCosts**) for the individual sub-archetypes are entered in this sheet for each of the improvement scenarios. The extra costs have been split into four categories: 'Installation Costs'; 'Additional Costs'; 'Professional Costs'; and 'Maintenance Costs'. Three columns are assigned to each sub-archetype to enter data on extra costs associated with installing and maintaining the retrofit measures. The left column is a drop down menu which allows one of the four cost types to be selected. The central column is also a drop down menu, where the data available to select varies depending on the cost type specified, and the third column automatically updates based on the data entered in the first two. The first two cost types (Installation and Additional) relate to any costs associated with implementing the retrofit technologies, such as reduced rent or decant costs. Data on this is maintained in **19_Additional Project Costs**, on the left hand side under 'One Off Payments'. Where either of these two cost types are selected from the drop down menu in the leftmost column, the drop down menu in the centre column will update to reference the 'One Off Payments' list, and automatically update the final right hand column with the corresponding value based on the data entered in **19_Additional Project Costs**. Professional costs are calculated as a percentage of the total costs (i.e. the cost of the measures plus any additional and installation costs). Where this cost type has been selected from the drop down menu in the left hand column, the drop down menu in the central column will allow you to select a percentage value. Maintenance costs relate to ongoing costs associated with the retrofit technologies once installed. Data on this is maintained in **19_Additional Project Costs**, on the right hand side under 'Regular Payments'. Where this cost type has been selected the drop down menu in the centre column will update to reference the 'Regular Payments' list, and automatically update the final right hand column with the corresponding values based on the data entered in **19_Additional Project Costs**. Where the regular payments do not occur on an annual basis (for example only every two or three years), the payment value is divided to give the cost per year, for comparison of maintenance costs to other sub-archetypes. Below this section is a summary of the retrofit technologies applied based on those selected **7_ScenarioMeasures**, and excluding any that were over-ridden. The purpose of this is to act as a reminder of what additional costs are appropriate for each individual sub-archetype. The user must scroll down the sheet to view and enter data for the other two retrofit scenarios.

14b_GreenDealSummary

Based on the data entered in previous sheets, this provides a summary of costs associated with the baseline building and three improved scenarios for all sub-archetypes. For each of the improvement scenarios, the user can see the operational costs, the preliminary cost of work calculated from sheet **8_ScenarioCosts**, and any extra costs determined by the previous sheet, **14a_AddtnlGreenDealCosts**. The user can select whether the Green Deal loan repayments include these extra costs, and total costs are reported in the form of:

- (i) 'Adjusted cost of work' (preliminary costs and any others selected to be included as part of the Green Deal loan),
- (ii) 'Remaining cost of work' (any extra costs not included as part of the Green Deal loan), and
- (iii) 'Maintenance Costs' (£/year)

For each of the three scenarios, the user enters details on the interest rate and repayment period of the loan to determine the repayment value. Finally, the user enters the target bill reduction. This describes the percentage reduction in the bill costs the user should still hope to see after the cost of the repayment has been added to the fuel bills. For example, where the annual bill is £1000, for a specification of a 10% reduction in bill costs the occupant would expect to pay no more than £900 over the year. Therefore, where the scenario measures have actually reduced the bill to £500, the Green Deal loan repayments should not exceed £400 in order to meet this bill reduction. If the user does not wish to include this, the target bill reduction can be entered as zero. If, based on the criteria entered, the Green Deal repayments either exceed the expected savings (taking into account the target bill reduction), or are greater than £10,000, the spread sheet will indicate whether an ECO contribution is necessary and calculate how much. A section to include notes is available to the user to enter details of potential grants once more information on these become available.

14c_GreenDealSAAnalysis

Any individual sub-archetype reported on the previous sheet can be analysed in greater detail using the **14c_GreenDealSAAnalysis** spreadsheet. The user selects a specific sub-archetype from the drop down menu at the top of the page, and details of costs (preliminary costs of installing the measures, extra costs, adjusted cost of work and anticipated savings) for the three different scenarios are automatically summarised. The user can view the annual savings, loan repayments, balance/loss/profit and cumulative loss/profit over a 25 year period (note that inflation has not been taken into account) for each of the three scenarios for the given sub-archetype. Using the arrow buttons, the user can investigate the effect of adjusting the interest rate and repayment period to consider the impact this has on requiring ECO assistance. It should be noted that, although the model allows multiple refurbishment technologies to be included in each scenario, the Green Deal (at time of writing) should be applied to an individual technology. Therefore, for a true Green Deal analysis, only one refurbishment technology should be included in a given scenario. The user can still apply this payback analysis to a scenario of multiple technologies, but should be aware that this may not be how the Green Deal will work.

14d_GDSAAnalysis Adjust

This sheet replicates the previous sheet; however instead of allowing the user to consider the effect of adjusting the interest rate and repayment period, a section at the top of the spread sheet allows the user to apply a percentage increase in the cost of the fuel bills. As before the user can consider the impact that adjusting this value has on the requirement for ECO assistance.

15_Income

This currently assumes an average income for all dwellings to calculate fuel poverty status. However this can be updated to allow different average incomes by sub-archetype, or even archetype.

16_SHQS

This sheet is just a database for SHQS analysis, showing the criteria required to pass SHQS criteria 35 for different SAP versions.

17_FuelData

This is a database of carbon intensities and fuel tariffs for different fuels types and methods of generation. Single and split tariffs can be chosen for a variety of fuels. Columns B, C, D and E can be updated with new values for carbon intensities, tariff charges and split tariff threshold as required.

18_MeasuresCosts

This database lists all the current refurbishment choices and their estimated costs. Again this can be updated with new costs, but also new technologies can be added under “Other” as required, with associated costs.

19_Additional Project Costs

This database maintains data on any extra costs associated with implementing and maintaining any of the retrofit measures, in the form of ‘One of payments’ on the left or ‘Regular Payments’ on the right. The information is referenced by **14a_AdditionalGreenDealCosts**. The database can be updated as more information becomes available, but the numbering system of 01. – 40. must be maintained to ensure the workbook operates correctly. For ‘Regular Payments’ the cost value is entered in column ‘F’ and frequency of payment selected from the drop down menu in column ‘G’. This then converts the costs to a £/year basis for comparison.

(14_GreenDealRefSheet)

This sheet is used to construct the list of retrofit measures applied to each individual sub-archetype for each of the scenarios. The data is referenced by other sheets, but no information needs to be input or edited on this sheet.

2.2 Step-by-step instructions

Below is a step-by-step description of how to use the spreadsheet tool to input, calculate and output useful information for a given number of dwellings.

1. Enter number of archetypes and sub-archetypes in “1_Archetypes”. This allows a maximum of 100 sub-archetypes (within ten archetypes). Run the “DeleteColumns” macro by pressing “Ctrl + Shift + P”. This will delete superfluous columns throughout the workbook for blank sub-archetypes.
2. Enter property details in “2_PropDetails”
3. If required, define and label heating and hot water systems in “3_HtngSystems”, which will be updated in “2_PropDetails”
4. Define window/opening types in “4_OpeningSchedule” and run the “AlphaSort” macro (press “Ctrl + Shift + Q”). This will order the information alphabetically (which is required for calculations later on)
5. Assign the windows of step 4 for each sub-archetype in “5_WindowData”.
6. Input the more detailed data required in “6_DimensionData”
7. In “7_ScenarioMeasures”, choose three refurbishment scenarios by checking (place an “x”) in columns B, C and D the specific refurbishments that are required. If a particular refurbishment is not valid for a sub-archetype (e.g. cavity wall insulation for

- a solid-walled dwelling), choose “override” in the respective drop-down cell (column E onwards)
8. Review individual sub-archetype refurbishment costs for each scenario in “8_ScenarioCosts”. If accurate fuel poverty data is required, “15_Income” should be completed.
 9. Input NHER savings data for each sub-archetype in “9_ScenariosResults-by SA”, which then produces list of outputs for those dwellings. CO₂ and cost savings are based on carbon intensities and tariffs from “17_FuelData” and “18_MeasuresCosts” (which can be edited if required)
 10. Review sub-archetype, archetype and project outputs in “10_Sub-archetypeSummary”, “11_ArchetypeSummary”, “12_ProjectSummary” and “13_CO2 emissions”.
 11. Enter any additional costs associated the sub-archetypes for each improvement scenario in “14a_AdditionalGreenDealCosts”.
 12. For sheet “14b_GreenDealSummary” select whether any of the extra costs are to be included as part of the green deal loan calculation. This will report an ‘adjusted cost of work’, ‘remaining costs’ and any ongoing ‘maintenance costs’. Enter details of the loan interest rate and repayment period. Based on this criteria, any sub-archetypes requiring ECO assistance will be highlighted.
 13. For Green Deal scenario output sheets, choose a sub-archetype and examine Green Deal-related output.

3 Guide to using the original spreadsheet tool

3.1 Description of ‘Variability’ worksheets

The workbook has a number of individual sheets, some of which require input from the user, some used for calculations, while others are used to output information. A description of the active sheets are provided below.

1_Archetypes

The purpose of this sheet is the same as for the original spread sheet: to delete unnecessary columns. The user can paste the number of sub-archetypes from the original spread sheet into this new sheet and use “Cntrl + Shft + P” to activate the ‘DeleteColumn’ command. This may take a couple of minutes, after which the user can proceed onto the following sheets.

2_FuelData

To ensure the same information is applied in this analysis as is used for the original investigation, the user should refer to sheet “17_FuelData” in the original calculation spread sheet, highlight the area equivalent to the area marked by the dashed red boundary in “2_FuelData”, and copy and paste this information into “2_FuelData in the ‘Variability’ spread sheet. This will allow the following sheets to reference the same fuel data, without having to maintain links with the original spreadsheet.

3_OrigData

The user can copy and paste information describing and reporting the number of each sub-archetype. This can be copied from “2_PropDetails” of the original spread sheet into the area outlined by the dashed red line. Following sheets in the ‘Variability’ spread sheet will automatically update to show this same information.

The user should then refer to “9_ScenarioResults–by SA” in the original spread sheet to copy information about the fuel type and corresponding kWh values for the baseline properties (rows 16 to 31), scenario 1 (166 to 181), scenario 2 (319 to 334) and scenario 3 (473 to 488). This information is pasted into the sections marked in “3_OrigData” in the ‘Variability’ spread sheet.

4_Variant1, 5_Variant2 and 6_Variant3

The user can enter a title and description in cells D2 and D3 outlining the changes to the calculation methodology. Then, as for the previous sheet, they should enter data on fuel type and corresponding kWh values for the baseline and three improvement scenarios. This data will represent results based on the modified calculation methodology.

Energy, Cost and CO₂

These sheets graph the results for the original calculations and modified calculations, for the baseline and three improvement scenarios. The sheets report the results for annual energy consumption, annual operational costs (excluding maintenance) and annual CO₂ emissions, at a project level, archetype level and sub-archetype level where this has been selected from a drop down menu.

3.2 Step-by-step instructions for use of the ‘Variability’ spreadsheet

1. Paste the number of sub-archetypes in “1_Archetypes” from the original spread sheet. Run the “DeleteColumns” macro by pressing “Ctrl + Shift + P”. This will delete superfluous columns throughout the workbook for blank sub-archetypes to match the format of the original spreadsheet.
2. Copy and paste data from “17_FuelData” in the original spread sheet into the area outlined by a red dashed line in sheet “2_FuelData” in the variability spread sheet.
3. On sheet “3_OrigData”, paste information into the appropriate sections for:
 - a. Description and number of sub-archetypes
 - b. Fuel type and corresponding kWh values for the baseline building
 - c. Fuel type and corresponding kWh values for the three improvement scenarios
4. On sheets “4_Variant1”, “5_Variant2” and “6_Variant3” paste information into the appropriate sections for:
 - a. A title and description of the variation to the calculation methodology
 - b. Fuel type and corresponding kWh values for the baseline building
 - c. Fuel type and corresponding kWh values for the three improvement scenarios
5. Compare the impact on annual results in relation to operational energy, operational costs and CO₂ emissions for the original and altered calculations (for the baseline and three improvement strategies) on sheets “Energy”, “Costs” and “CO₂” respectively. This is reported at a project level, archetype level and individual sub-archetype level where this is selected from a drop down menu.