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# RETROKIT
# STRATEGIC PLANNING TOOLKIT FOR BUILDING ENERGY RETROFITS

*Final Report*

**RD&D project undertaken by XD Sustainable Energy Consulting Ltd**

Date: 22 September

Funded by

**Sustainable Energy Research, Development & Demonstration Programme**


Source: Irish Green Building Council – final workshop on national renovation strategy, Dublin, Jan 2017.

# I. Introduction

The RetroKit RDD project's aim is to develop cost-effective tools for strategic planning of energy retrofit in the residential sector at a local and regional level, that will inform and guide policy-making and investment decision-making. Potential users and beneficiaries of the proposed solution include building stock owners in the private and public sector (e.g. housing associations, local authorities, OPW, etc.), local development companies and SECs, as well as local and national policy-makers. We tested the proposed energy retrofit planning toolkit with 2 case studies in Kerry and Cork in order to demonstrate its capability. We have also researched further development strategies for the tool in terms of advanced modelling capability, user interface and its application to buildings in the tertiary sector.

In the following sections of this document, we will outline the approach we have taken to develop RetroKit and the outcomes of the project.

# II. Literature review

The first step was to conduct a wide search of relevant literature from institutional, academic and research at an Irish and international level. The search focused on the following themes: residential energy usage, planning energy retrofits and GIS applications for spatial energy analysis.

A total of 85 publications were identified and 65 were selected for review. We then compiled a document with, for each publication, a bibliography entry, a link to online location where available, an executive summary and key findings. The following sections outlines main findings on what are considered by the team as key aspects of the RetroKit solutions development.

## 1. Archetypes

Identifying suitable dwelling archetypes to facilitate the modelling of the housing stock was a key aspect of the literature review. A total of 9 studies focussing on the topic were reviewed to identify appropriate methodologies for the definition of archetypes and how they are used. Archetypes are generally developed to represent of the overall building stock variability in terms of geometric form, constructional materials and operation. Once archetypes are defined based on meaningful characteristics, the typical approach is to create a building physics model of an 'average' dwelling representing an archetype using statistical data available for dwellings pertaining to that archetype. The models can then be applied to e.g. calculate baseline energy performance, test retrofit scenarios, etc. These results can then be extrapolated to the overall housing stock being analysed if the number of dwellings belonging to this archetype is known. The review indicate that the characteristics mainly used in archetype definition include:

- Year of construction: Used in most references, recommended as primary archetype identifier;
- Tenure: used in about half of references, might be of limited use to determine suitability of house retrofit measures.
- Building type: used in most references as archetype identifier and can be a determining factor for selection of retrofit measures.
- Heating system and fuel: used in half of the references as archetype identifier; important to identify appropriate measures on energy supply side.
- Wall type: Used in half of the references as archetype identifier; useful to help identify appropriate wall retrofit measures, particularly when combined with U value data.
- Level of energy efficiency: Used in less than half of the references as archetype identifier; could indicate required depth of upgrade.
- Roof U-value: Used in only a couple of the references as archetype identifier; could indicate roof potential for upgrade.

Adopting all the above archetype characteristics and associated sub-groupings, would result in a very large (well over 1000) number of archetypes to be considered. We therefore reduced the number of categories to four: a) age group, b) wall type c) main fuel for heating d) type of house. We also grouped ranges within categories based on observations of the BER dataset available in the BER Research Tool for the national stock.

## 2. Spatial analysis

Geographical Information System (GIS)-based approaches to modelling energy systems are increasingly being used to support sustainable energy planning at local to regional scales, especially in the context of urban energy systems (UES). A review of GIS-based models for UES by [1] revealed there are four key areas in which GIS is presently being applied:

1. Modelling Energy Potential – e.g. quantifying the benefits of energy retrofitting scenarios, such as green roof retrofitting, in terms of, for example, cost or energy savings
2. Modelling Energy Consumption – e.g. estimating energy usage of large building stocks
3. Environmental Assessment – e.g. assessing the potential environmental consequences (positive or negative) or risks associated with existing or proposed changes to energy systems
4. Decision Support – e.g. for supporting decision making with regard to energy retrofit options

Recent studies usually rely on data obtained from local authorities and/or census data. When performed at dwelling level, often energy usage and other variables must be estimated based on known characteristics of the buildings, such as age and type.  Map overlay tools can be used to examine spatial relationships between different variables (e.g. fuel poverty and disposable income).  More complex analyses, such as spatial multiple criteria analysis (MCA), can be used to map priority areas for different types of energy retrofit based on multiple and conflicting criteria.  The results of such analyses often form the basis of decision support systems.

GIS-based decision support tools to support residential energy retrofit measures targeted at property managers/local housing authorities in Ireland are currently non-existent, although said to be under development. By integrating some of the methods described in the literature, it is possible to build a customized toolkit for these end-users in Ireland.

## 3. **Retrofit planning**

Our literature review of energy retrofit planning provides a strong foundation for the development of our methodology. There is a growing body of research in this area across the EU, which is largely aimed at addressing the needs of policy-making. Most housing stock energy modelling has been done at national level and primarily consisted in a bottom-up analysis of energy in the residential sector to complement top-down analysis of the residential sector as an energy sink. In the absence of large statistically representative datasets about residential energy performance, these studies relied on creating building physics models of archetype average dwellings (see review of archetype literature above) and extrapolating results to the whole housing stock based on the number of dwellings per archetype. These building physics models are generally close to or equivalent to models used for asset rating under the EPBD (SAP in UK, DEAP in Ireland). This approach relies on manually modelling a large number of archetypes, and is labour intensive.

More recent studies have built on these analyses to model different retrofit strategies to inform policy-making in this area. Key attributes of the building fabric and building services of dwelling archetypes are modified to reflect energy efficiency and low-carbon/renewable energy measures, and the building physics models are used to measure the impact of these measures on energy use and generally CO2 emissions, which are then extrapolated to the overall housing stock as for baseline analysis. Such modelling studies are used to measure the impact of different retrofit scenarios and/or policy-instruments.

Capital expenditure, operational expenditure, energy savings are often coupled with the technical analysis discussed above to integrate the economic impact of energy retrofit strategies. Marginal abatement cost curves are regularly used in policy studies to identify least cost pathways to energy demand reduction. A limited number of studies apply market diffusion theory to model EE technology adoption scenarios and measure macro-economic impact of retrofit policy interventions.

A limited number of studies have tried to quantify the rebound/comfort taking effects to try and ascertain actual energy savings post-retrofit versus theoretical savings estimated with building physics models, as well as to identify social and behavioural factors explaining this variation. Equally, there is an emerging body of research into the co-benefits of energy retrofits (in particular in terms of health and fuel poverty) as well as lifecycle analysis of energy retrofit measures (notably taking into consideration embodied energy). The majority of studies concentrate on national level analysis.

# III. Methodology Statement

The methodology retained for the development of the RetroKit prototype was informed by the following activities undertaken by the team:

a) The literature review and its findings, as described above;
b) Meetings and correspondence with key;
c) Workshops with team members to share individual research findings, brainstorming and mind-mapping on their application for the development of RetroKit.

## A. Requirements Specification:

Out of the process described above, we have defined the software requirements specification and developed an outline design for the RetroKit software tool. The following requirements have been identified:

a) A database of the housing stock to be analysed, with the following attributes for each dwelling unit: unique identifier, location, dimensions, energy-related properties of the building fabric and services. The database can also be used to store other datasets such as socio-economic and environmental attributes.
b) A method of collecting the data outlined above and of populating the baseline housing stock database that is efficient and replicable.
c) A method to rationalise the housing stock into archetypes i.e. coherent groupings whose building properties are sufficiently homogenous to be analysed as a group and applied similar retrofit measures.
d) A tool to rapidly calculating the energy performance of the housing stock before retrofit and for different scenarios of retrofit. The calculation methodology should be in line with the EPBD requirement for Building Energy Rating of dwellings. This calculation should be done for a) for each dwelling (ideally); b) for each archetype.
e) A method to define different scenarios of energy retrofit by selecting, for each dwelling archetype, a suite of energy efficiency and/or renewable energy measures that are appropriate for different depths of energy retrofit.
f) A method to determine the post-retrofit properties of a dwelling's fabric and services, based on the measures selected above for each archetype, and if a set of conditions linked to relevant pre-retrofit properties of each dwelling are met. E.g. The pre-retrofit U-value of dwelling's wall would be changed to a post-retrofit U-value reflecting full-fill cavity insulation, if: a) that measure has been selected for the archetype it belongs to; b) its initial U-value indicates that the cavity is empty or partially filled.
g) A method to calculate the lifecycle cost of the retrofit measures applied, including capital and operational expenditures, based on a database of costs for all potential measures representative of market conditions. Estimates of future costs would also be useful for forecasting future scenarios.
h) A tool to calculate the housing stock's pre- and post-retrofit energy performance and associated set of key performance indicators (KPIs), based on the pre and post-retrofit properties of its dwellings. KPIs measure the impact(s) of each scenario in energy, environmental and financial terms, and possibly other socio-economic factors such as fuel poverty.
i) A tool to support decision-making for optimisation of energy retrofit pathways to achieve selected target(s), e.g. % energy demand reduction, CO2 abatement, maximum budget available, eliminate fuel poverty, etc.
j) A tool for capturing, storing, analysing and visualising geographical data in a digital environment, to support spatial planning and decision-making for the energy retrofit of the housing stock analysed. The tool will

integrate pre- and post-retrofit datasets, with a granularity relevant to the type of analysis undertaken (e.g. at the dwelling level, Small Area Level, etc.) and the resolution of the geographical data available.

k) A method to assist the production of deliverables for the clients and relevant parties including a report on the analysis and an energy retrofit action plan for the housing stock analysed. This includes the compilation of analysis results into powerful graphics and other visuals to facilitate reporting and presentation of the results.

## B. Software Architecture & Design

This section outlines the proposed software architecture & initial design for RetroKit, in layman's term. This is the result of a series of a series of internal workshops and is informed by the literature review. It provides a blueprint for developing the software and defines a structured solution to meet the technical and operational requirements defined above, while optimising quality attributes like performance, maintainability, security, etc.

There are a number of key considerations underlying the proposed software architecture:

a) The core team has no or limited coding capability in relevant software languages.
b) The project's budget and timeline don't allow for developing this coding capability internally.
c) Our budget for an IT consultant was foreseen for planning Phase II of software development, and would be inadequate to outsource professional software development services.

In light of the above considerations, we have decided to rely primarily on Microsoft Excel to develop the Retrokit software prototype, for the following reasons:

a) We are all advanced users of Excel and have developed tools to analyse residential energy usage for large housing stock samples [lit ref].
b) A lot of datasets come in tabular format (e.g. CSO, BER Research tool, etc.), or can be formatted easily in tables, or imported into other applications (e.g. GIS) from a tabular format.
c) Several relevant tools, such as the UK Cambridge model [lit ref], are Excel based, which facilitates integration with RetroKit.
d) Most users (e.g. clients and third-parties) have existing MS Excel licences and are familiar with its utilisation. RetroKit datasets and analysis results can readily be exchanged with these users, without having to negotiate licences, access, etc.

The following elements constitute the software architecture:

- A database of the housing stock to be analysed will be created in an MS Excel spreadsheet. This data will be harvested primarily from SEAI's BER Research Tool database, providing for each dwelling DEAP calculations' input and output data.
- A GIS application to map dwellings where there xy coordinates are available, and to conduct spatial analyses of variables such as KPIs, including BER, fuel expenditure, energy retrofit CAPEX per area/zone/estate (before and after scenarios/optimisation), black spots for fuel poverty, potential areas for district heating, etc.
- Each dwelling is given an archetype number based on relevant attributes in the Stock DB, e.g. 5320 = all Semi-d houses, constructed in 2011-later, with electric heating and 'any' wall type. This archetype number allows to quickly understand the key characteristics of a dwelling and select relevant energy conservation measures that can be applied to it.
- A DEAP Calculator will take input from the pre-retrofit or post-retrofit housing stock databases and calculate energy performance KPIs as per the DEAP methodology.
- A database of the housing stock pre-retrofit was be created with a set of baseline KPIs will be computed for each dwelling, utilising DEAP calculation results (e.g. BER, heating requirement/m2, primary or delivered energy/m2, CO2/m2, etc.) in combination with other factors & datasets where available (e.g. fuel expenditure, risk of fuel poverty, NOCs & SOCs emissions, etc.). Average KPIs will be calculated per dwelling archetype as well as for the whole housing stock analysed.

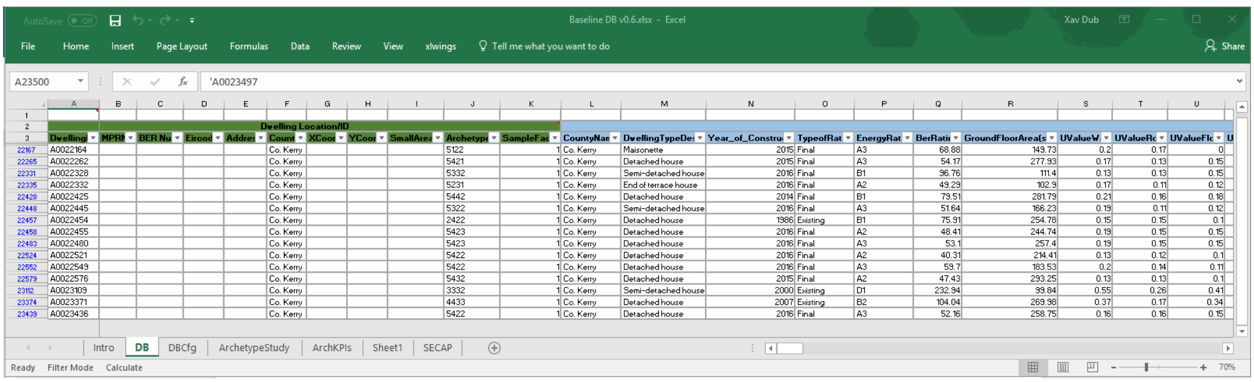
- A Scenario Selector helps the user select a range of energy conservation measures (ECM) to be applied for each archetype in the housing stock, and define a retrofit scenario. A matrix of benchmark and post-retrofit values for each ECM was created, which also includes, for each measure, a unit cost estimate.
- Based on the retrofit scenario defined with the Scenario Selector, a post-retrofit housing stock (Post-Retro DB) will be generated by applying ECMs where there is a fit, running DEAP calculations with post-retrofit attributes, calculate the CAPEX and OPEX for the retrofits, and compile post-retrofit KPIs (energy performance, environmental, financial).
- For each scenario, KPIs will be calculated for each archetype (e.g. average post-retrofit BER, total CAPEX, average LCOE, etc.) and for all the housing stock analysed. These will be mapped and compared to pre-retrofit KPIs.
- The process of scenario analysis described above can be repeated for any number of different scenarios defined by the user. The Energy Retrofit Optimiser creates a matrix of KPIs for the different scenarios analysed and generate an overall score for each scenario. The comparing and scoring of scenarios will facilitate fine-tuning them for a given set of decision-making criteria or a given target. This process will contribute to helping the user determining the optimal retrofit scenario for the stock analysed.
- The data generated by the scenario analysis, in particular their KPIs, will be used to create maps, graphs and other visuals (infographics) to facilitate the comparative analysis and decision-making process, and communicate the results to the clients and relevant third-parties.
- A report template will be used to collate the results of the analysis and present them to the client. This report will include: a) housing stock baseline analysis, b) selected retrofit scenario analysis, c) retrofit action plan; together with key visuals and maps.

## IV. Outline of solutions developed

The different components of the RetroKit package and their interrelationships are showcased in the following section.

Pre-retrofit/Baseline Database: The Baseline DB is built for a given housing stock on the basis of DEAP XML files obtained from the client, wherever feasible, by finding the relevant entry in the SEAI BER Research Tool and adding it to the Baseline DB. Where XML files are not available, relevant datasets are built directly from the BER Research Tool. This approach provides consistency in the data being compiled in the Baseline DB across all types of case studies.

The figure below gives a screenshot of the Kerry County Baseline DB, as a tab within an Excel spreadsheet.

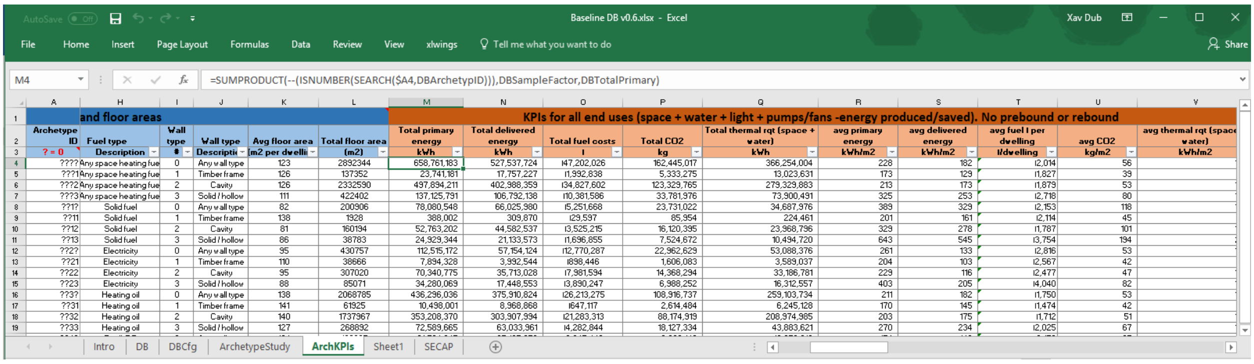



The creation of the Baseline DB for the case studies has enabled us to develop a process of BER data acquisition which is robust and replicable in most situations.

A series of KPIs are derived from the outputs of the DEAP calculations for the individual dwellings contained in the Baseline DB, and they are averaged for each dwelling Archetype (300 Archetypes in total). The KPIs are presented in a specific Excel tab (ArchKPI), alongside the Baseline DB tab, and include:

- Dwelling count per archetype, total treated floor area and average treated floor area per dwelling;
- Energy Performance KPIs (total per archetype, average per dwelling and average per m2 of treated floor area):
- delivered and primary energy; respectively for 4 energy use categories (space heating, domestic hot water, lighting, pumps & fans) and their sum;
- space heating requirement and domestic hot water heating requirement (output from heat producing appliances).
- Environmental Performance KPIs: energy-related CO2 emissions (total per archetype, average per dwelling and average per m2 of treated floor area), again across the above 4 energy usage categories and their total;
- Estimated energy cost, across the 4 energy usage categories.
- Energy produced and saved, as accounted for in the for example from solar PV system

The following figure presents a screenshot of the Archetype KPIs tab for the Kerry County Baseline DB.



The Archetype KPI table can be interrogated using filters to obtain KPIs for sections of the housing stock as well as 'whole stock' KPIs. We have also allowed for factors which reflect the potential variation between calculated energy usage (by DEAP) and 'real' energy usage, before (pre-bound) and after (re-bound) energy retrofit. While there is a growing body of research on the difference between 'calculated' and 'real' energy usage, the evidence isn't sufficiently strong to extrapolate to our housing cohorts, and these pre-bound and re-bound factors have been set to 1 for now. In addition, we have inserted 'sample multipliers' which allow to extrapolate the Archetype KPIs to the whole housing stock of a case study.

The Baseline DB includes a functionality which uses the Baseline DB and associated Archetype KPI analysis to compile a Residential Emission Inventory compatible with the requirements of the **Covenant of Mayors' Sustainable Energy and Climate Action Plan**, as per the screenshot below. The baseline energy usage analysis and emission inventory of the SECAP for Irish and international local authorities has been identified as a key market segment for the RetroKit solutions.

| Metric | FINAL ENERGY CONSUMPTION [MWh] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fossil fuels | | | | | | | | Renewable energies | | | | | Total |
| | Electricity | Heat/cold | Natural gas | Liquid gas | Heating oil | Diesel | Gasoline | Lignite | Coal | Other fossil fuels | Plant oil | Biofuel | Other biomass | Solar thermal | Geothermal | |
| MWH Delivered | 188,232 | 1,180 | 3,510 | 20,608 | 309,745 | - | - | - | 20,332 | 86,476 | - | 1.599 | 4,542 | 3,098 | 7,576 | 645,299 |
| % Delivered Energy | 29.17% | 0.18% | 0.54% | 3.19% | 48.00% | 0.00% | 0.00% | 0.00% | 3.15% | 13.40% | 0.00% | 0.00% | 0.70% | 0.48% | 1.17% | 100.00% |
| Fuel Cost € | €45,859,553 | €0 | €237,953 | €2,309,583 | €17,686,425 | €0 | €0 | €0 | €1,125,081 | €5,764,330 | €0 | €112 | €364,846 | €0 | €0 | €73,347,882 |
| MWh primary | 391,522 | - | 3,861 | 22,669 | 340,719 | - | - | - | 23,170 | 95,123 | - | 2 | 4,996 | - | - | 882,062 |
| kgCO2 | 76,986,826 | - | 712,454 | 4,781,006 | 84,250,573 | - | - | - | 7,589,204 | 31,921,775 | - | 102 | 113,545 | - | - | 206,355,484 |

A Retrofit Scenario Analyser has been developed with the following functionalities:

- A database of 55 energy conservation measures (ECM) which, for each ECM, defines the conditions for their application; the resulting post-retrofit specification and capital costs. The cost database discussed above has been developed based on a survey of energy retrofit costs for a total of 55 ECMs, among a panel of main contractors who are market leaders in housing energy retrofit in Ireland.

- A Scenario Builder which provides an interface for the user to define a retrofit scenario for a given housing stock and generates ‘post retrofit’ attributes for DEAP calculations, as well as a bill of quantity for the ECM applied, as well as the CAPEX and energy credits associated with the ECM applied.

The screenshot below gives an insight into the RetroKit Scenario Analyser (Scenario Builder tab):

**Retrokit Scenario Builder**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Measure Numbe** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| | **Measure Category** | Cavity Wall Insulatio | | External Wall Insulatio | | External Wall Insulatio | | Internal Wall Insulatio | | Internal Wall Insulatio | | Ceiling level Insulatio | | Room in Roof | | Room in Roof | | Suspended GF | Solid GF | Air Tightness | |
| | **Measure Description** | CWI no fill to FF | CWI partial to FF | EWI solid + 100 mm | EWI solid + 200 mm | EWI CWI + 100 mm | EWI CWI + 200 mm | IWI solid + 50 mm | IWI solid + 70 mm | IWI CWI + 50 mm | IWI CWI + 70 mm | Ceiling no insulation to 300 mm | Ceiling 70 mm to 400 mm | RinR 70 mm bet rafters to 50 mm drylining | RinR 70 mm bet rafters to 100 mm drylining | RinR Uninsulated rafters to 50 mm drylining | RinR Uninsulated rafters to 100 mm drylining | SusGF Zero to 120 mm insulation | Solid GF Zero to 60 mm insulation | AT Shallow sealing | AT Dee sealin |
| **Define Packages** | | | | | | | | | | | | | | | | | | | | | |
| None | | | | | | | | | | | | | | | | | | | | | |
| P1 | Shallow Retro | 1 | 1 | | | | | | | | | 1 | 1 | | | | | | | 1 | |
| P2 | Medium Retro | 1 | 1 | | | | | 1 | 1 | | | 1 | 1 | | | | | 1 | | 1 | |
| P3 | Deep Retro | 1 | 1 | | | | | 1 | 1 | | | 1 | 1 | 1 | | 1 | | 1 | | | |
| P4 | NZEB | 1 | 1 | 1 | | 1 | | | | | | 1 | 1 | | 1 | | 1 | 1 | | | |
| TEST | TEST | | | | | | | | | | | | | | | | | | | | |

All post-retrofit dwelling attributes are then processed with DEAP and DEAP calculations outputs (delivered energy, primary energy, CO2, etc.) are combined to create the post-retrofit housing stock database. Archetype and whole-stock KPIs are derived, which can be compared with the Baseline KPIs and other scenarios KPIs.

The table below presents the results of the RetroScenario Analyser for a medium retrofit scenario applied to Kerry County housing stock (see case studies):

| | | | Total_Annual_Energy_CO2_€ KPIs | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Age Band** | **Dwellings in Arch** | **ArchetypeID** | **TotalDeliv** | **TotalCO2** | **TotalPrimary** | **TotalPrimary/m2 TFA** | **Average BER** | **EnergyCost€.1** | **EnergyCredits** | **CapexRetrofit** |
| | | | kWh/yr | kgCO2/yr | kWh/yr | kWh/m2,yr | | €/yr | kWh/yr | € |
| 0 - 1970 | 16,595 | 1??? | 8,062 | 2,836 | 15,417 | 155 | C1 | 1,093 | 8,543 | 19,331 |
| 1971 - 1990 | 14,222 | 2??? | 6,391 | 2,294 | 12,236 | 138 | B3 | 868 | 12,689 | 18,688 |
| 1991 - 2000 | 8,157 | 3??? | 6,592 | 2,336 | 12,714 | 117 | B2 | 878 | 12,860 | 19,565 |
| 2001 - 2010 | 14,114 | 4??? | 6,530 | 2,350 | 12,692 | 104 | B2 | 909 | 11,711 | 18,098 |
| 2011 - 2017 | 192 | 5??? | 7,076 | 2,693 | 13,964 | 84 | B1 | 993 | 8,746 | 13,083 |
| **Weighted Average:** | | | **6,982** | **2,485** | **13,427** | | | **951** | **11,151** | **18,846** |

| | | | Total_Annual_Energy_CO2_€ KPIs | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Age Band** | **Dwellings in Arch** | **ArchetypeID** | **TotalDeliv** | **TotalCO2** | **TotalPrimary** | **EnergyCost€.1** | **EnergyCredits** | **CapexRetrofit** |
| | | | MWh/yr | tCO2/yr | MWh/yr | k€/yr | MWh/yr | k€ |
| 0 - 1970 | 16,595 | 1??? | 133,795 | 47,057 | 255,848 | 18,133 | 141,771 | 320,792 |
| 1971 - 1990 | 14,222 | 2??? | 90,895 | 32,620 | 174,024 | 12,346 | 180,465 | 265,779 |
| 1991 - 2000 | 8,157 | 3??? | 53,767 | 19,053 | 103,709 | 7,162 | 104,900 | 159,588 |
| 2001 - 2010 | 14,114 | 4??? | 92,167 | 33,170 | 179,140 | 12,833 | 165,292 | 255,432 |
| 2011 - 2017 | 192 | 5??? | 1,359 | 517 | 2,681 | 191 | 1,679 | 2,512 |
| **Total** | **53,280** | | **371,982** | **132,418** | **715,403** | **50,665** | **594,106** | **1,004,102** |

The process described above can be repeated by the software user to analyse different scenarios, for example to compare the impact of shallow/medium/deep energy retrofit approaches to a given housing stock. A summary table brings together the scenarios’ KPIs and facilitates comparing their respective merits e.g. in terms of primary energy reduction, avoided CO2 emissions, cost per unit of energy saved, etc. The process of comparing and contrasting the results of the different scenarios modelled enables focusing and fine tuning the best performing scenarios, by benchmarking their KPIs. The table below provides a sample of the Optimiser outputs:

| Age Band | Dwellings in Arch | Archetype ID | Total Delivered Energy Saved (MWh/yr) Shallow | Medium | Medium + | Deep | Deep + |
|---|---|---|---|---|---|---|---|
| 0 - 1970 | 16,595 | 1??? | 60,401 | 117,223 | 310,291 | 342,019 | 356,243 |
| 1971 - 1990 | 14,222 | 2??? | 21,843 | 56,828 | 163,799 | 177,214 | 189,054 |
| 1991 - 2000 | 8,157 | 3??? | 8,059 | 29,377 | 91,745 | 97,898 | 105,046 |
| 2001 - 2010 | 14,114 | 4??? | 10,800 | 39,642 | 123,373 | 127,332 | 138,522 |
| 2011 - 2017 | 192 | 5??? | 154 | 272 | 1,319 | 1,341 | 1,454 |
| **Total** | **53,280** | | **101,257** | **243,342** | **690,528** | **745,804** | **790,320** |

| Age Band | Dwellings in Arch | Archetype ID | Total Capital Expenditure (k€) Shallow | Medium | Medium + | Deep | Deep + |
|---|---|---|---|---|---|---|---|
| 0 - 1970 | 16,595 | 1??? | 28,317 | 117,928 | 320,792 | 549,303 | 600,431 |
| 1971 - 1990 | 14,222 | 2??? | 21,306 | 98,666 | 265,779 | 403,027 | 445,585 |
| 1991 - 2000 | 8,157 | 3??? | 9,936 | 53,859 | 159,588 | 215,604 | 241,298 |
| 2001 - 2010 | 14,114 | 4??? | 14,984 | 91,734 | 255,432 | 328,628 | 368,852 |
| 2011 - 2017 | 192 | 5??? | 127 | 614 | 2,512 | 2,713 | 3,118 |
| **Total** | **53,280** | | **74,671** | **362,800** | **1,004,102** | **1,499,276** | **1,659,284** |

| Age Band | Dwellings in Arch | Archetype ID | Total Primary Energy Saved (MWh/yr) Shallow | Medium | Medium + | Deep | Deep + |
|---|---|---|---|---|---|---|---|
| 0 - 1970 | 16,595 | 1??? | 80,611 | 150,862 | 318,380 | 375,920 | 405,507 |
| 1971 - 1990 | 14,222 | 2??? | 29,266 | 73,969 | 157,460 | 181,524 | 206,151 |
| 1991 - 2000 | 8,157 | 3??? | 12,268 | 36,671 | 89,385 | 100,388 | 115,256 |
| 2001 - 2010 | 14,114 | 4??? | 16,703 | 51,784 | 112,413 | 119,552 | 142,828 |
| 2011 - 2017 | 192 | 5??? | 212 | 346 | 924 | 963 | 1,197 |
| **Total** | **53,280** | | **139,061** | **313,633** | **678,561** | **778,347** | **870,939** |

| Age Band | Dwellings in Arch | Archetype ID | Total Energy Credits (k€/yr) Shallow | Medium | Medium + | Deep | Deep + |
|---|---|---|---|---|---|---|---|
| 0 - 1970 | 16,595 | 1??? | 2,493 | 6,100 | 17,012 | 25,639 | 25,639 |
| 1971 - 1990 | 14,222 | 2??? | 2,716 | 7,506 | 21,656 | 32,045 | 32,045 |
| 1991 - 2000 | 8,157 | 3??? | 877 | 3,646 | 12,588 | 17,275 | 17,275 |
| 2001 - 2010 | 14,114 | 4??? | 928 | 5,642 | 19,835 | 24,521 | 24,521 |
| 2011 - 2017 | 192 | 5??? | 5 | 27 | 202 | 215 | 215 |
| **Total** | **53,280** | | **7,019** | **22,920** | **71,293** | **99,694** | **99,694** |

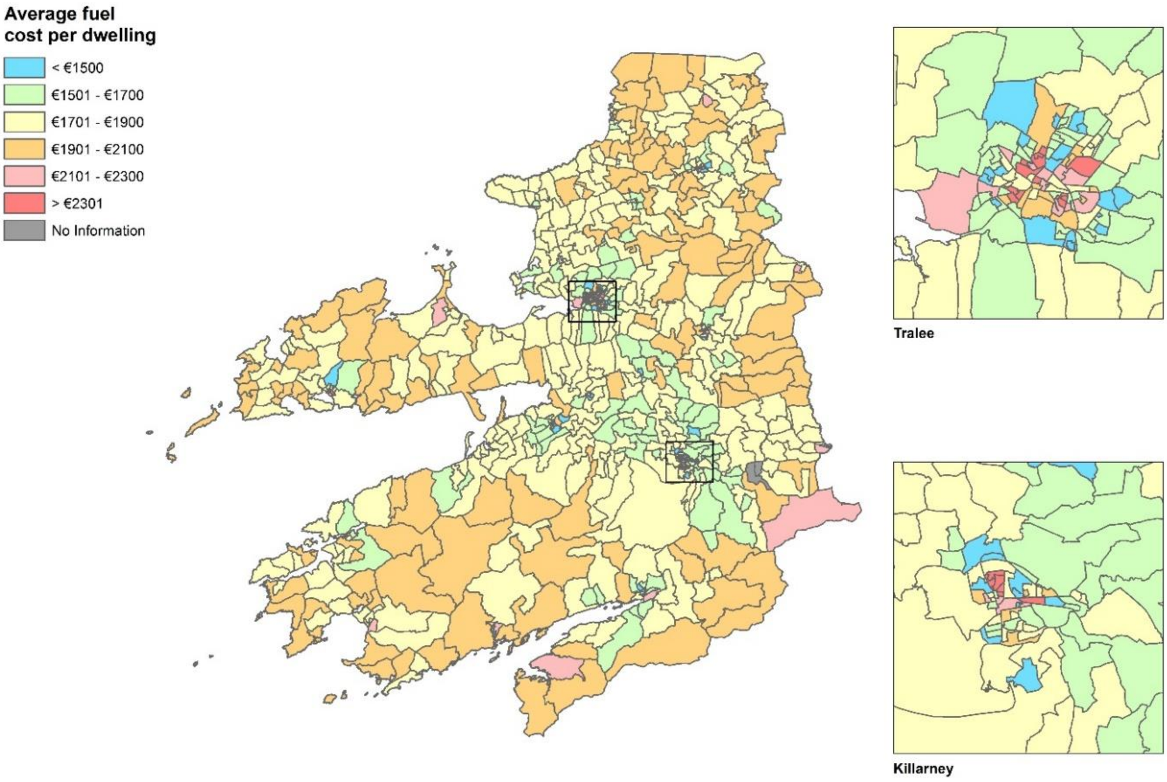
The Retrofit Scenario Analyser provides a basis to establish a bill of quantity (DB Qties) and cost estimates (DB Costs) and energy credits (DB ECs) of ECM applied, per dwelling, per archetype and for the whole stock. The picture below give a screenshot of the DB Qties, DB Costs and DB ECs for a medium scenario applied to Kerry housing stock (see case studies):

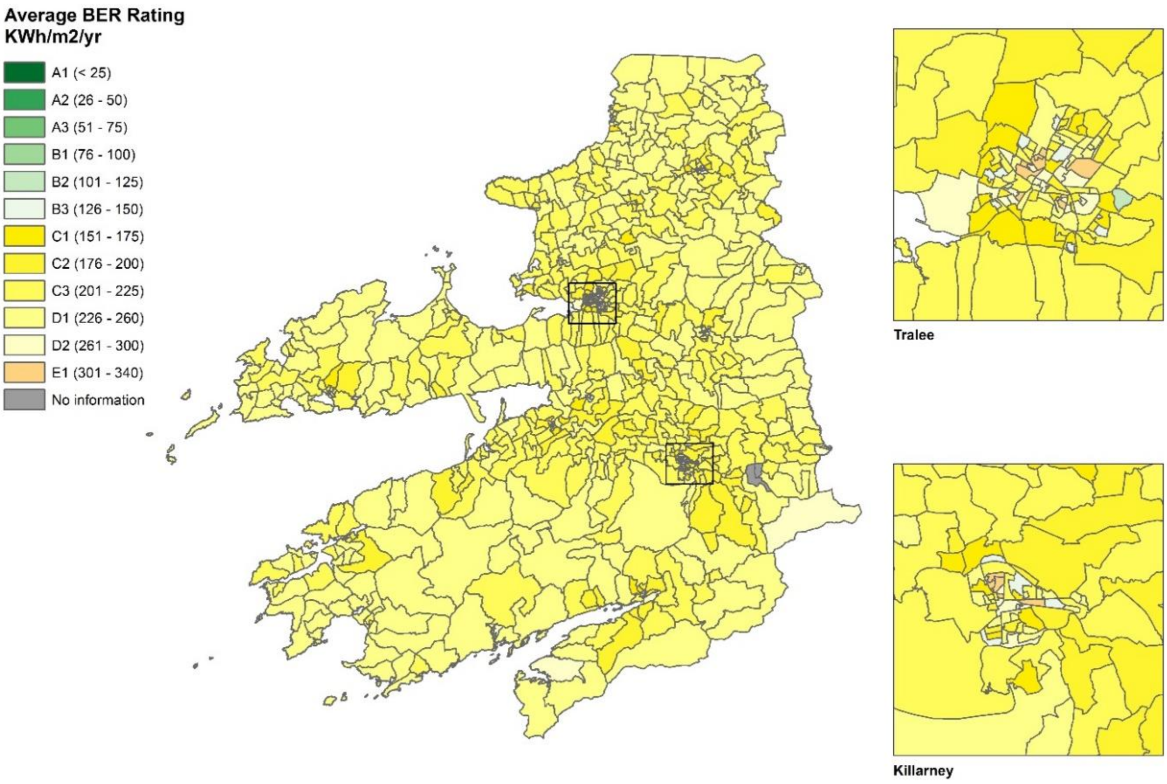
| | | ECM Quantities (m2 or 1) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DwellingID | ArchetypeID | CWI no fill to FF | CWI partial to FF | EWI solid + 100 mm | EWI solid + 200 mm | EWI CWI + 100 mm | EWI CWI + 200 mm | IWI solid + 50 mm | IWI solid + 70 mm | IWI CWI + 50 mm | IWI CWI + 70 mm | Ceiling no insulation to 300 mm | Ceiling 70 mm to 400 mm | RinR 70 mm bet rafters to 50 mm drylining | RinR 70 mm bet rafters to 100 mm drylining | RinR Uninsulated rafters to 50 mm | RinR Uninsulated rafters to 100 mm | SusGF Zero to 120 mm insulation | Solid GF Zero to 60 mm insulation | AT Shallow sealing | AT Deep sealing | AT Chimney draft limiter | Op Full window replacement to DG |
| **AR1** | 1112 | 0 | 89.585 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **AR2** | 1113 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **AR3** | 1121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18.48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **AR4** | 1122 | 49.43917 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 43.98444 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **AR5** | 1123 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29.92226 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **AR6** | 1131 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **AR7** | 1132 | 0 | 92.63333 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 79.82333 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

| | | | ECM CAPEX 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total CAPEX (€) | DwellingID | ArchetypeID | CWI no fill to FF | CWI partial to FF | EWI solid + 100 mm | EWI solid + 200 mm | EWI CWI + 100 mm | EWI CWI + 200 mm | IWI solid + 50 mm | IWI solid + 70 mm | IWI CWI + 50 mm | IWI CWI + 70 mm | Ceiling no insulation to 300 mm | Ceiling 70 mm to 400 mm | RinR 70 mm bet rafters to 50 mm drylining | RinR 70 mm bet rafters to 100 mm drylining | RinR Uninsulated rafters to 50 mm drylining | RinR Uninsulated rafters to 100 mm drylining | SusGF Zero to 120 mm insulation | Solid GF Zero to 60 mm insulation | AT Shallow sealing | AT Deep sealing | AT Chimney draft limiter |
| €22,665 | **AR1** | 1112 | 0 | 895.85 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2237.2 | 0 |
| €18,915 | **AR2** | 1113 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2237.2 | 0 |
| €19,868 | **AR3** | 1121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 953.72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2237.2 | 0 |
| €23,683 | **AR4** | 1122 | 603.1578 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1310.782 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2237.2 | 0 |
| €20,029 | **AR5** | 1123 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1113.912 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2237.2 | 0 |
| €18,969 | **AR6** | 1131 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2237.2 | 0 |
| €18,854 | **AR7** | 1132 | 0 | 926.3333 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1812.527 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2237.2 | 0 |

| Total Credits | Dwelling Location/ID | | ECM Energy Credits (kWh) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (kWh) | DwellingID | ArchetypeID | CWI no fill to FF | CWI partial to FF | EWI solid + 100 mm | EWI solid + 200 mm | EWI CWI + 100 mm | EWI CWI + 200 mm | IWI solid + 50 mm | IWI solid + 70 mm | IWI CWI + 50 mm | IWI CWI + 70 mm | Ceiling no insulation to 300 mm | Ceiling 70 mm to 400 mm | RinR 70 mm bet rafters to 50 mm drylining | RinR 70 mm bet rafters to 100 mm drylining | RinR Uninsulated rafters to 50 mm | RinR Uninsulated rafters to 100 mm | SusGF Zero to 120 mm insulation | Solid GF Zero to 60 mm insulation | AT Shallow sealing | AT Deep sealing | AT Chimney draft limiter |
| 10265 | **AR1** | 1112 | 0 | 2050 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| 6905 | **AR2** | 1113 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| 7705 | **AR3** | 1121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| 11065 | **AR4** | 1122 | 2050 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| 7705 | **AR5** | 1123 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| 8215 | **AR6** | 1131 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| 9755 | **AR7** | 1132 | 0 | 2050 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |

We have developed a methodology to undertake the spatial analysis of the energy performance of the housing stock pre-retrofit and post-retrofit, using GIS tools. The spatial analysis uses a combination of output from the baseline tool and geographical data from CSO Census 2016. We have prototyped this approach using fuel cost and primary energy usage per dwelling as KPIs for the county Kerry housing stock, but the GIS model can be applied for any KPI outputs from the baseline or retrofit scenario analyses. The following maps present the result of the spatial analysis of average fuel cost per dwelling and BER rating (on the basis primary energy usage) at small area level for County Kerry:


Average fuel
cost per dwelling
< €1500
€1501 - €1700
€1701 - €1900
€1901 - €2100
€2101 - €2300
> €2301
No Information
Tralee
Killarney


Average BER Rating
KWh/m2/yr
A1 (< 25)
A2 (26 - 50)
A3 (51 - 75)
B1 (76 - 100)
B2 (101 - 125)
B3 (126 - 150)
C1 (151 - 175)
C2 (176 - 200)
C3 (201 - 225)
D1 (226 - 260)
D2 (261 - 300)
E1 (301 - 340)
No information
Tralee
Killarney

# V. Case Studies to Test the Prototype

We have undertaken two case studies to test the alfa version of the RetroKit software tools and present the results as proof of concept:

1) The full housing stock of county Kerry (55,300 permanent housing units)
2) The social housing stock of Cork City Council (8130 units).

The results of the case studies analysis are presented separately in case study reports, available on request. The case studies were conducted to test the RetroKit tools extensively with real life examples of large-scale datasets, continue develop the prototype and showcase the functionalities of RetroKit and the nature of the results obtained. The case studies, and the feedback from our local authority partners, will inform our plans for future research & development activities for RetroKit.

# VI. RetroKit's next phase of R&D

An ideation workshop was undertaken to brainstorm on potential future developments for RetroKit, looking at software engineering solutions, new toolkit functionalities and potential markets. Each expert in the team carried out additional research and analysis individually, to contribute to framing 3 key development areas and assessing their feasibility at a high level. The first one concerned software engineering and key recommendations were to evolve all the functionalities of RetroKit to a common programming language in order to improve the data processing efficiency and improve user experience. We also aim at introducing machine learning in the modelling process to improve and accelerate the scenario optimisation process, as well as the interactivity of RetroKit.

Secondly, we envisage migrating RetroKit to a Client/Server application, web-based and accessible via a user's web browser (the client) and a GUI. This will provide all the computational resources required, improve development turn around, facilitate administrative tasks and improve the user experience. In addition, we want to reinforce Software Quality Management as a key to the success of RetroKit commercial development and user experience.

Finally, we are planning a number of additional functionalities in terms of spatial analysis (WebGIS solutions), integrating environmental and socio-economic externalities of housing energy retrofit in the cost-benefit analysis and widening the services offered by RetroKit into retrofit project management.

To capitalise on the above, we intend to undertake the following research and development activities:

a) Market research with key stakeholders in Ireland to identify important market segments and quantify their value;
b) Analyse the policy-framework governing energy retrofit in housing in Ireland and in selected EU countries, as well as the data sets on building energy performance available, both for housing and non-residential buildings.
c) Develop a business plan for RetroKit's development and commercialisation over the next 5 years.

# VII. Conclusions and Thanks

This report, and accompanying case study reports, provide a detailed account of the RDD project undertaken by XD Sustainable Energy Consulting Ltd to develop a software toolkit to support the planning of energy retrofit in large housing stock. The results of this project have exceeded our expectations, and the outcomes have surpassed what we had set out to do at proposal stage. We have made a strong dent into developments we had anticipated to be part of a phase II R&D effort, opening the door for further development that will increase the quality and extent of RetroKit capabilities. This achievement is in no small part due to the dedication and talent of the partners who have joined XD

Sustainable Energy Consulting Ltd to deliver the project. I look forward to continuing this innovation journey with them.

I would like to take this opportunity to thank both Cork City Council and Kerry County Council staff who have generously shared their time, knowledge and data underlying the case studies. Thank you also to a number of people who have been kind with their advice, information and data, at SEAI and its BER Helpdesk, UCC and the CSO, as well as contractors who have shared energy retrofit cost data. Finally, I would like to thank SEAI RDD programme team for granting funding to this project and being supportive during its execution.

Xavier Dubuisson, on behalf of XD Sustainable Energy Consulting Ltd. 13/10/2017.