APPLICATION OF A BUILDING ENEGRY PERFORMANCE SYSTEM TO ASSESS DOMESTIC SECTOR UPGRADING STRATEGIES FOR SCOTLAND

Clarke J A, Johnstone C M, McElroy L and Strachan P A
Energy Systems Research Unit, University of Strathclyde, Scotland

McKenzie F* and Peart G#
* Scottish Executive, Edinburgh, Scotland
#Scottish Building Standards Agency, Livingstone, Scotland

Corresponding author:
Cameron Johnstone, ESRU, Department of Mechanical Engineering, University of Strathclyde, 75 Montrose Street, Glasgow G1 1XJ
cameron@esru.strath.ac.uk

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Abstract
This paper describes the application of a decision-support tool for use by policy makers addressing the needs of the Scottish domestic energy sector. It is argued that the generic nature of the tool renders it suitable to support the cumulative roll-out of upgrade measures in the long term, both within and outwith the UK. The tool is then used to appraise the impact of the upgrade measures that might be applied to the Scottish housing stock.

Introduction

The housing sector within the UK is resposible for a large proportion of the overall energy consumption [1]. For this reason, and because housing impacts greatly on the health and wellbeing of citizens, most national governments have substantial policy instruments focused on the sector. In Scotland, for example, there are 2,278,000 dwellings of which 4% are vacant and 2.5% due for demolition. The majority of dwellings are houses (62%) and flats (38%). Over 40% (905,000) of all dwellings were built within the last 37 years, with 24% (531,000) constructed between 1945 and 1965. In constructional terms, the breakdown is as given in Table 1. The 2002 House Condition Survey established a mean NHER rating of 4.5 (on a scale of 0 poor to 10 good) for the Scottish housing stock, with an associated mean SAP rating of 46.5. The associated CO_2 emissions are around 16.2 million tonnes per year. By comparison, the 1996 House Condition Survey established that a mean NHER rating of 4.1 and a mean SAP rating of 43. These data indicate a 10% improvement since 1997, with only 12% of all dwellings achieving an NHER rating of 7 - 9 and no dwellings attaining a rating of 10.

Table 1: Construction types.

Construction system	%
Cavity wall	74
Solid wall	25
Material	**%**
Brick/block	67
Sandstone	18
Whin/granite	5
Non-traditional	10
External finish	**%**
Rendered	61
Stone	18
Brick	9
Non-traditional	12

From these data it is clear that there is an urgent need for energy efficiency improvements:

- From the 2002 survey, around 86% (1,902,000) of dwellings have whole house central heating, with a further 8% (169,000) having partial central heating. This represents a 6% improvement on the corresponding 1996 survey, with the number of dwellings with no central heating down from 13% to 5.5% (i.e. 271,000 to 116,000 dwellings). This small but significant change gives rise to concerns about fuel poverty and the health-related problems associated with hypothermia, condensation and mould growth.

A review of the Scottish housing stock concluded that existing information is diverse in nature, making it difficult to apply to the present problem: how best to assess and compare the energy reduction impacts of the different possible improvements to the housing stock. The review indicated that the existing housing stock could be classified into 7 architectural types and 13 construction systems. As shown in Table 2, this resulted in over 50 permutations as not all construction systems apply to all house types

Table 2: Construction categories of Scottish house types.

Category	%	Sub-category	Related house type
Cavity Wall brick/block	67	1. Cavity throughout – plastered on hard. 2. Hybrid - cavity dividing walls with single skin in-fill (brick, block or cladding system) to front and rear – part plaster on hard/part lined.	Detached Semi-detached Terraced Tenement Four-in-a-block Conversion
Solid Wall brick/block sandstone whin/granite	23	3. Sandstone/whin/granite – strapped and lined. 4. Concrete block – plaster on hard. 5. Concrete block – strapped and lined.	Detached Semi-detached Terraced Tenement Conversion
Non-traditional timber concrete metal	10	6. Hollow concrete block – plastered on hard. 7. As above – strapped and lined. 8. Swedish timber or steel frame - not insulated. 9. Swedish timber or steel frame - insulated. 10. No Fines concrete – plaster on hard. 11. As above – strapped and lined. 12. Solid/insitu concrete – plaster on hard. 13. As above – strapped and lined.	Detached Semi-detached Terraced Tenement Four-in-a-block Tower/slab block

A number of upgrading measures may be applied to these house/construction type combinations depending on the particular case. Examples of upgrades include wall, floor, loft, tank and pipe insulation, draught-proofing, heating system and control improvements, double glazing, and low energy consumption lights and appliances. In addition, it is possible to consider local means of supply in the form of solar thermal, solar electric, wind energy and recovered heat.

The response by the Scottish Executive (SE) to the present need is to use regulatory means to bring about energy efficiency improvements over time. The impetus for the present project was to assist this process while ensuring compatibility with the new EU Energy Performance of Buildings (EPD) Directive [3]. In enacting such legislation, the key questions to be addressed are: 1) what changes offer best value?, 2) what deployment combinations are suited to the different house/construction types? and 3) how should the deployments be phased over time? The SE sought to establish a project that would identify best value approaches to the incremental improvement of the energy efficiency of the existing housing stock up to 2020 [4]. From the data of the foregoing tables, it is evident that the problem is complex, largely because of the many permutations of the observable house types, constructional systems and energy efficiency measures. While a simulation-based approach was adopted within the project, for reasons explained in the following section, it was not deemed necessary to simulate directly the many possible permutations.

Project Outline

Contemporary simulation tools are powerful, with features that allow them to quantify the integrated performance of a building when operating under realistic weather and user influences. That said, these tools have not yet reached a stage of refinement where users with different conceptual outlooks can easily apply them. This is especially the case in the present context: the evaluation of housing retrofit options by decision-makers in support of policy formulation. While simplified programs do exist—e.g. the EPIQR system, which has been designed for the German market to enable the rapid assessment of retrofit options for specific apartment buildings [5] these require building specific inputs and are therefore not well tailored to the needs of policy makers.

Even if the interface dilemma can be overcome, there remains another application difficulty: the identification of representative house designs for simulation. While it is a straightforward task to identify house types from an architecture and construction (A/C) viewpoint, the task becomes intractable when viewed thermodynamically. Two houses, each belonging to the same A/C group, may have substantially different energy consumption patterns as a result of dissimilar energy efficiency measures having been previously applied. (The effects of occupant behaviour are not considered at this point.) Likewise, two houses corresponding to different A/C groups may have the same energy consumption because the governing design parameters are essentially the same.

The approach adopted in the present project was to operate only in terms of thermodynamic classes (TC) so that different A/C types may belong to the same TC. A representative model was then formed for each TC and its energy performance determined by simulation. Any real house may then be related to a TC via the present level of its governing design parameters. Should any of these parameters be changed as part of an upgrade then that house would be deemed to have moved to another TC. Within the present study, the design parameters considered as determinants of energy use are window size, insulation level, thermal capacity level, capacity position and air permeability.

The simulation results for the set of representative models then define the possible performance of the entire housing stock, present and future, for the climate, exposure, occupancy and control assumptions made within the simulations. By varying these assumptions and re-simulating, scenarios such as future climate change and improved standard of living may be incorporated.

The performance predictions, in the form of regression equations defining monthly energy requirements as a function of the prevailing weather parameters, were then encapsulated within a Web-based decision-support tool. The intention is that this tool will be used by housing managers and policy developers engaged in the development of building regulations in response to need and national policy drivers.

The impact of technologies that may largely be considered independent of house type, such as solar thermal collection, heat recovery, low energy lamp replacement and the like, were separately analysed and the results encapsulated within a second decision-support tool.

The evaluation of any given upgrading scenario is therefore a two-stage process. First, the contribution of a proposed building upgrade is quantified by assigning the house in question to a TC based on an estimate of the levels of its governing parameters. The energy reduction brought about by its relocation to any other TC may then be 'read off' as shown later. Because each TC corresponds to a different combination of the governing design parameters, the required upgrade is immediately apparent from the TC relocation. Second, the contribution of generic energy efficiency measures (e.g. heat recovery) and possible local source of energy supply (e.g. solar thermal) are quantified. This is done by applying house-specific parameter values to the technology in question (e.g. available roof area in the case of a solar thermal installation). The user is then able to accept or discard these contributions as a function of their applicability to the case in hand and likely cost. By making the decision-support tool interactive, such trade-offs may be immediately assessed.

The impact of future climate change or enhanced standard of living is assessed by substituting the TC energy consumption data by a set corresponding to the new scenario. In the former case, an assumed temperature increase is applied to the energy regression equations; in the latter case the regression equation set is substituted by one corresponding to a control regime definition that reflects a higher comfort expectation.

The development and verification processes used for the Housing Upgrade Planning Support (HUPS) tool-set has been reported extensively [6][7] giving confidence in the application of the decision support system to develop a potential upgrading strategy for the Scottish domestic stock.

HUPS Application

The HUPS tool-set comprises Java Applets for upgrade impact assessment and the evaluation of technology options. Figure 1 shows the user interface of the Applet relating to the space heating requirements of Scotland's domestic dwellings. Typically, a user might proceed as follows. First, the property to be upgraded is selected from a list using the 'Property Type' entity, or defined in terms of its governing parameters using the 'Property Characteristics' entity. It is envisaged that the parameter levels for a given house would be determined as a function of the age of the property. This is because the building standards in force at the time may be regarded as a proxy for the construction from which the level and distribution of insulation and capacity may be inferred. The infiltration category may be established via visual inspection of the potential leakage paths around windows, doors and other envelope penetrations.

In either case, menu selection or property definition, the TC is automatically identified within the 'Current House Type' entity (say TC 2). The horizontal slider located near the top of the Applet may then be used to read off the corresponding heating energy demand (approx. 87 kWh/m^2.y^r for TC 2). The house properties and energy demand data are automatically transferred to the 'Action Planner' entity. The slider may then be moved to another position (say TC 23 as shown here). The design properties and energy demand estimate (56 kWh/m^2.yr) of the target house are then transferred to the 'Action Planner'. After the initial and target properties are accepted by the user, the saving expressed in energy, monetary and CO_2 terms is computed and displayed. A site inspection would then typically be arranged to determine the feasibility of implementing the upgrades as implied by the parameter differences indicated in the 'Action Planner'.

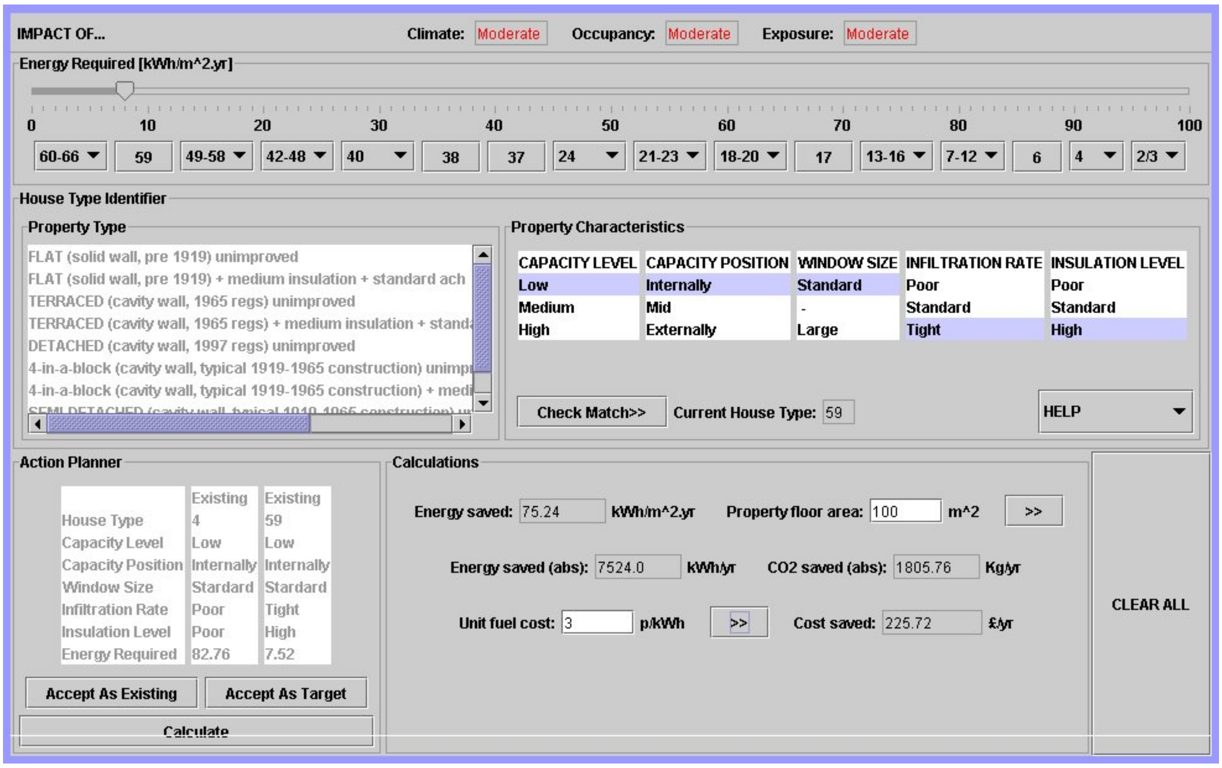

Figure 1: Assessing the impact of housing upgrades.

Finally, the cost of implementation may be established as a function of the planned replication extent, in order to ensure best value. In practice, the tool may be used strategically to explore alternative upgrade strategies in order to select the most cost-effective options. In some circumstances, it may be desirable to implement upgrades piecemeal over time. For example, a property corresponding to TC 2 might be upgraded to one corresponding to TC 23 in the first instance and then to one corresponding to TC 27 thereafter. In this way, the tool supports action planning over extended time periods.

Application of the tool to the Scottish housing stock.

A digest of the 2002 Scottish house condition survey data has shown that the 2,278,000 dwellings in Scotland translate to a total annual space heating demand of 14.5 TWh and CO_2 emissions of 5.5 MT. The energy demands for space heating account for 17% of the total Scottish demand. The mapping of the Scottish housing stock to thermodynamic types was undertaken based on house architectural type and year of construction. From the mapping process it can be shown that the entire Scottish housing stock can be represented and classified into 8 thermodynamic classes as listed in Table 3. As can be seen, the largest housing sector is contained within thermodynamic category TC6, representing 42% of the Scottish housing stock or approximately 956,000 units. This is followed by TC2 and TC1 representing 16.5% and 11.5% respectively. TC6 represents dwellings constructed over the periods 1919-65 and 1966-97 using an un-insulated cavity wall, which accounts for a space heating demand of 6.3 TWh/yr. TC2 represents dwellings constructed over a similar period but with a solid wall and no insulation, and accounts for an annual space heating demand of 2.8 TWh. TC1 represents a traditional pre-1919-65 construction using a solid wall of high thermal mass and accounts for an annual space heating demand of 2 TWh.

Proposed upgrading strategy for existing dwellings

Practical considerations dictate that any upgrading strategy should focus on low cost technologies initially to maximise the return on any investment and be phased over time thereafter to accommodate technical advances. Reducing fabric and ventilation heat loss are the most effective measures to improve the thermal performance of dwellings. In the former case, higher levels of insulation will be required. In the latter case both draught proofing and ventilation heat recovery may be utilized, with draught proofing being the better cost effective option for the Scottish housing stock. The addition of insulation and draught proofing to varying levels was assessed in this study.

When attempting to decide which houses should be tackled first within an upgrading programme, it is necessary to consider the product of the population size within a specific TC and the heating energy demands associated with the TC. The greater this value, the greater the energy saving potential and hence the higher the priority for upgrade. The data of Table 3 indicates that to achieve maximum impact, an upgrade programme should initially target TC6 category dwellings, followed by TC2 and TC1. Targeting of these three TCs will cover 70% of the Scottish housing stock. A second phase of upgrading should then target TC7, which covers 7% of the housing stock and corresponds to 8% of the total heating demand. TC7 represents houses constructed in the period 1965–97 consisting of a cavity wall with thermal mass on the interior, standard insulation and excessive air infiltration rate. The third phase should target TC17 and TC18 representing 8% and 11% of the Scottish housing stock respectively. These TCs represent dwellings built during 1965-19 that have a cavity wall with standard levels of insulation and air tightness. The main difference is the location of the thermal mass: in TC18 the position of the thermal mass is on the outside of the cavity, while TC17 has the thermal mass located on the inside. The final phase should target TC19, which represents non-traditional construction types built during the period1965-97. This represents 2.5% of the housing stock. Construction primarily consists of an insulated thermal mass wall with standard levels of insulation and air tightness.

Table 3: Digest of existing Scottish dwellings.

TC Number	Thermodynamic classification	% of Scottish housing stock	Number of dwellings	Floor area (m^2)	Annual heating demand (kWh/m^2)
1	Solid wall, high thermal mass, large windows, poor insulation and large air change rate	11.5	261,970	22,461,000	90
2	Solid wall, high thermal mass, standard windows, poor insulation and large air change rate	16.5	375,870	31,778,000	87
6	Cavity wall, outer thermal mass, standard windows, poor insulation and large air change rate	42	956,760	83,283,000	75
7	Cavity wall, inner thermal mass, large windows, standard insulation and large air change rate	7.25	165,155	15,934,000	73
17	Cavity wall, inner thermal mass, standard windows, standard insulation and standard air change rate	8.25	187,935	18,087,000	47
18	Cavity wall, outer thermal mass, standard windows, standard insulation and standard air change rate	11	250,580	23,810,000	47
19	Solid wall, standard thermal mass, standard windows, standard insulation and standard air change rate	2.5	56,950	5,159,000	46
26	Timber wall, outer thermal mass, standard windows, high insulation and standard air change rate	1	22,780	2,596,000	26

Quantification of energy savings associated with upgrading

The proposed upgrading schedule features draught proofing and insulation because these measures are cost effective and relatively easy to implement. The initial upgrading phase should target type TC6 dwellings by improving their air tightness. This will result in a change of the thermodynamic class to TC11 and give rise to an 8 kWh/m^2 (from 75 kWh/m^2) reduction in the annual heating energy demand (i.e. a saving of 0.67 TWh or 4.6% relative to the present national annual heating energy demand). The addition of insulation to TC11 moves it to TC18, resulting in a further reduction of 20 kWh/m^2 corresponding to a saving of 2.2 TWh/yr or 15.5% of the national space heating demand.

When targeting type TC2, simultaneously improving air tightness and insulation level will change it to a type TC19 with a saving of 41 kWh/m^2 (from 87 kWh/m^2). This corresponds to a saving of 1.3 TWh/yr (or 9% of the annual national heating energy demand). In the case of TC1, the addition of insulation to a high standard alters the thermodynamic class to TC16, giving a saving of 43 kWh/m^2 (from 91 kWh/m^2) or 0.9

TWh per year (6.5%). Where draught proofing and an insulation upgrade is applied to TC1 the thermodynamic class would shift to TC21, giving a saving of 35 kWh/m^2 or 1.2 TWh annually (8.7%).

Within the second phase of an upgrade programme, targeting thermodynamic class TC7, by improving both air tightness and insulation, changes the class to TC28. This would reduce the annual space heating demand by 62 kWh/m^2 (from 73 kWh/m^2) giving an annual energy saving of 1 TWh (7%).

The third phase of the programme should focus on TC18 and TC17, both of which may be upgraded in increments. Initially, improving air tightness will change the class to TC22, giving an annual saving of 17 kWh/m^2 (from 47 kWh/m^2) or 0.7 TWh annually (5%). Only upgrading the insulation level for TC17 and TC18 changes the thermodynamic type to TC24, resulting in an energy demand reduction of 21 kWh/m^2, equating to an annual energy saving of just under 0.9 TWh (6%). Applying both measures to TC17 and TC18 changes the type to TC30, which reduces demand by 38 kWh/m^2 or 1.6 TWh annually (11%).

The final phase of an upgrading programme should focus on thermodynamic type TC19 by improving air tightness. This will result in a saving of 35 kWh/m^2 (from 46 kWh/m^2) or 0.06 TWh (0.4%).

Table 4 identifies the range of annual space heating savings that can be achieved by the phased upgrading of the Scottish housing stock.

Table 4: Summary of improvement measures.

TC	Quantity relative to housing stock (%)	Percentage of annual heating demand (%)	Suggested improvement	New TC	Reduction in national heating demands (TWh)	(%)
6	42	43	Air tightness to high standards	**11**	0.67	4.6
11			Insulation to standard levels	**18**	2.2	15.5
2	16.5	19	Standard levels of draught proofing and insulation	**19**	1.3	9
1	11.5	14	High levels of draught proofing and standard levels of insulation	**21**	1.2	8.7
7	7.25	8	High levels of draught proofing and insulation	**28**	1	7
17 & 18	19.25	13.5	High levels of draught proofing	**22**	0.7	5
			High levels of insulation	**24**	0.9	6
			High levels of draught proofing and insulation	**30**	1.6	11
19	2.5	1.5	High levels of draught proofing and standard levels of insulation	**21**	0.06	0.4

Impact of proposed Scottish housing upgrading strategy

The implementation of the improvement measures in a phased programme will result in savings in the annual space heating energy demand of 4.7 TWh (or 33.2% of the national energy demand) by the end of the first phase. This may be achieved by focusing solely on buildings of type TC6, TC2 and TC1. These savings would rise to 5.7 TWh (40.2%) by the end of phase 2 through the inclusion of type TC7. By the end of phase 3, the savings would have increased to 7.3 TWh (51.2%) by the inclusion of types TC17 and TC18. In the final phase of the programme, the annual space heating energy savings would rise to 7.36 TWh (51.6%) by targeting type TC19 dwellings.

Overall, such a phased programme would reduce the annual energy demand of the Scottish housing stock from 14.5 TWh to 7.14 TWh (or 51.6% of current demand).

Conclusions and Future Work

An integrated simulation program has been applied to a set of house designs corresponding to distinct thermodynamic classes established to represent the spectrum of possible house thermal responses. Existing Scottish dwellings have been categorisation into eight representative thermodynamic classes and the energy performance of each established. Cost effective energy performance improvent measures have been identified and a phased implimentation programme established. Implimentation of energy performance improvements measures result in Scottish dwellings being represented by 3 thermodynamic classes, achieving a national energy saving of up to ~7,300 GWh/yr, equating to a CO_2 emissions reduction of 2.1 million tonnes. The tool-set is available under an Open Source licence [8][9].

Future intentions are to deepen the tool-set by extending the underlying model of occupancy interaction and the number of technologies that may be applied (e.g. μCHP) and make it compatible with SAP energy performance rating of dwellings in order to implement the EU EPB certification scheme for existing dwellings where SAP ratings have/ cannot not be produced. It is envisaged that to be effective the HUPS procedure will require substantial inputs from site inspections. These will be required to assist with the process of parameter setting for the houses comprising a targeted estate and the translation of indicated upgrade measures to action on the ground. These end user site inspection procedures are currently under development in order to make the tool fully functional in the implementation of the EU EPB directive.

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