Modelling residential energy savings due to Ireland's National Retrofit Programme using DEAP and LEAP

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1 Abstract

This paper quantifies the potential energy savings in the Irish residential sector due to the introduction of an ambitious national retrofit programme. This is motivated by a need to provide robust analysis to inform and underpin proposed policy measures. The stock of dwellings existing in 2008 is first classified according to their Building Energy Rating (BER), an asset rating calculated as a measure of the energy efficiency of the dwellings. The theoretical energy demand for space and water heating is calculated using the Dwelling Energy Assessment Procedure (DEAP) and aggregated for the existing housing stock as a reference scenario within LEAP_Ireland. The potential energy savings are modelled by moving dwellings from lower to higher BER bands under different scenarios, varying the profile of dwellings carrying out retrofit work and the depth of retrofit work. In the year 2020 , the estimated savings lie in the range from 6,000 GWh to 11,900 GWh, with respect to the reference scenario, or between 22% and 43%. This compares to the national retrofit programme energy savings target of 5,200 GWh for the residential sector in 2020.

2 Introduction

This paper presents a bottom up approach to modelling the portion of energy consumption due to space and water heating of the 2008 stock of residential dwellings between 2009 and 2025. It builds on previous work by the authors on a bottom up model of the energy consumption of space and water heating of dwellings that will be newly occupied from 2009 to 2025[1], as well as an estimation of the electricity consumption of lighting and appliances of all dwellings from 2008 to 2025. These three strands of work have been brought together and incorporated into a model of total residential sector energy consumption using the LEAP software tool [2]. The residential LEAP model is itself part of a wider whole economy LEAP_Ireland model being developed at the Sustainable Energy Research Group (SERG) within University College Cork, in conjunction with the Sustainable Energy Authority of Ireland (SEAI)[3, 4,].

Retrofitting of building fabric has been identified as one of the most effective and cost efficient ways to achieve energy savings in the economy, with the potential for savings in developed countries estimated to be from 60% to 80%[5, 6], and generally achieving a negative cost value on green house gas abatement cost curves, i.e. it yields a net saving over the time frame considered.[7-9]

In the Irish context, the scope for economical energy efficiency gains to be made through retrofitting of the existing building stock has been identified within the National Energy Efficiency Action Plan(NEEAP)[10]. There are two schemes currently run by Sustainable Energy Authority Ireland (SEAI) aimed at increasing the energy efficiency of the residential housing stock. These are the Warmer Homes Scheme which aims to increase the comfort level of homes experiencing fuel poverty through increased energy efficiency, and the Home Energy Savings Scheme (HESS), which provides grants to homeowners to improve the energy efficiency of their home[11]. These schemes are to be superseded in 2011 by the National Retrofit Programme (NRP) which was announced in August 2010[12]. This new scheme aims to deliver energy efficiency upgrades to 1 million residential, public and commercial buildings by 2020, and as such is potentially the most ambitious energy-related initiative ever introduced in Ireland. 75% of the available funding is to go to the residential sector, of which 40% will go to addressing energy poverty[13].

The Irish NEEAP specifies an overall energy savings target of 32,000 GWh across the whole economy to be achieved in 2020. At the time of publication of the NEEAP, 24,000 GWh of savings had been accounted for by specific measures, 10,355 GWh of these from the residential sector, with a further 8,195 GWh remaining to be realised by additional measures[10]. The NRP was not included as a specific measure at that time. A stated goal of the NRP is to achieve 8,000GWh of energy savings by 2020, with 5,200GWh from the residential sector and 2,800 from services. An intermediate target of 2,000 GWh has also been set for the period 2011-2013. A revised estimate of savings for existing and committed measures contained within the "Energy Forecasts for Ireland to 2020" 2010 report[3], indicates that including for the 8,000 GWh savings from the NRP there is still a gap to target of 2,965 GWh.

This paper quantifies the potential energy savings in the Irish residential sector due to the introduction of the NRP and compares the results with the NEEAP target savings. The methodology is outlined in section 3, which comprises a number of key steps. The housing stock is disaggregated into representative houses grouped according to energy performance. The DEAP tool is used to calculate the energy performance of these individual dwellings and this is used to estimate the annual energy demand for space and water heating for individual houses. LEAP_Ireland aggregates the energy use of individual houses within BER bands into an overall residential energy demand model. The potential energy savings are modelled by moving individual dwellings from lower to higher BER bands, under a range of scenarios based on which houses are retrofitted and the degree (depth) of retrofit. The results are then fed into the LEAP_Ireland model for scenario analysis to generate the results that are presented in section 4. Section 5 presents the conclusions.

3 Modelling Approach

3.1 Building Energy Rating and Dwelling Energy Assessment Procedure

Previous SEAI grant schemes aimed at improving residential energy efficiency allocated grants based on specific retrofit measures undertaken, for example the HESS provides a set grant for attic insulation, pumped wall insulation, boiler upgrade, etc. Table 3.1 shows the percentage of dwellings availing of the HESS that applied for and undertook each of the approved measures. Under the NRP it is proposed that grants will instead be allocated based on a calculation of the energy that would be saved by a particular measure, on a particular dwelling. This energy saving calculation will be based on the before and after Building Energy Rating (BER) of the dwelling[13]. The model will focus on the aggregate effect of moving large numbers of dwellings from one BER band to another, rather than focusing on the effect on dwelling energy efficiency of particular retrofit measures such as improved attic insulation.

	% of total	
	Applied for measure	Completed measure
External Wall Insulation	4	2
Internal Wall Insulation	8	4
Oil & Boiler Controls	17	10
Gas & Boiler Controls	19	15
Heating Controls	7	4
Cavity Wall	61	53
Roof Insulation	84	70

Table 3.1 Applications and uptake of measures in HESS

The BER scheme was introduced in Ireland in 2007 as required by the Energy Performance of Buildings Directive (EPBD)[14]. The scheme rates the energy performance of domestic dwellings, assigning each a rating from A-G based on a calculation of their primary energy consumption in kWh/m^2/annum. The energy bands for each BER label are specified in Statutory Instrument 66 of 2006[15] and are given in Table 3.2.

Label	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	E1	E2	F	G
kWh/m^2/yr	<25	>25	>50	>75	>100	>125	>150	>175	>200	>225	>260	>300	>340	>380	>450

Table 3.2 Primary energy consumption per m^2 floor area of BER bands.

The energy rating calculation is carried out using the Dwelling Energy Assessment Procedure (DEAP), developed by the Sustainable Energy Authority Ireland (SEAI) as a tool to demonstrate the compliance of new dwellings to part L of the building regulations, governing the conservation of fuel and energy, and to produce BER labels and reports. The DEAP calculation framework is based on IS EN 13790[16], and draws heavily on the calculation procedures and tabulated data of the UK Standard Assessment Procedure[17]. The procedure takes account for space heating, water heating, ventilation and lighting calculated on the basis of standard occupancy, heating patterns, internal temperature etc, as well as reduction in imported energy due to sustainable energy generation technologies[18, 19]. The calculation is performed using a software tool which requires as inputs a detailed description of the building envelope and heating system and which outputs energy consumption split into a number of end uses. A more detailed description of the inputs and outputs for the DEAP modelling procedure is provided in previous work by the authors[1].

It is a legal requirement for all dwellings being sold or rented in Ireland to have a BER. The data gathered and results of every BER survey carried out are stored by SEAI. As of 2011 this database contained details of 130,000 dwellings, out of a total dwelling stock of 1.4 million.

3.2 Modelling Approach Adopted

3.2.1 Characterisation of the stock of existing dwellings

The data from the SEAI database of BER surveys was been made available to the authors and has been used to characterise the existing housing stock. As it is most common for BERs to be carried out at the time of construction, the database was found to be weighted toward newer dwellings, which in general have better BERs than the average existing dwelling. In order to make the results better representative of the whole existing stock, the BER surveys were sorted into nine age categories. These age categories were then weighted to match the age profile observed in the existing stock according to data from the Central Statistics Office (CSO)[20], updated to 2008 using an estimate of the numbers of dwellings newly occupied in the period 2006-2008. This modified dataset was taken to be representative of the 2008 housing stock. The split of dwellings by age in both the BER database and in the whole stock according to CSO data is provided in Table 3.3.

Period in which Built	No Houses	% Houses	BER d/b	% BER d/b
1919 (pre)	155,752	10%	4,837	5%
1919-1940	108,622	7%	3,958	4%
1941-1960	143,706	9%	5,171	5%
1961-1970	113,994	7%	3,548	4%
1971-1980	214,309	14%	6,467	7%
1981-1990	167,527	11%	7,389	8%
1991-1995	93,930	6%	5,679	6%
1996-2000	156,178	10%	12,101	12%
2001-2008	395,982	26%	48,415	50%

Table 3.3: Weighting of dwellings by age in BER database and in actual housing stock.

Using this modified dataset, the 2008 dwelling stock is first split by BER category, A to G. Figure 3.1 shows the split of dwellings in each age category by BER rating according to the BER database. Within each BER category dwellings are split by dwelling type. Five dwelling types were chosen, these are one storey detached, two storey detached, two storey semi detached, terraced houses and apartments. For each of these 35 dwelling categories, i.e. 7 BER categories by 5 dwelling types, data for number of dwellings, average floor area, theoretical average energy consumption per m^2 of main and secondary space heating and main and secondary water heating was taken from the BER database.

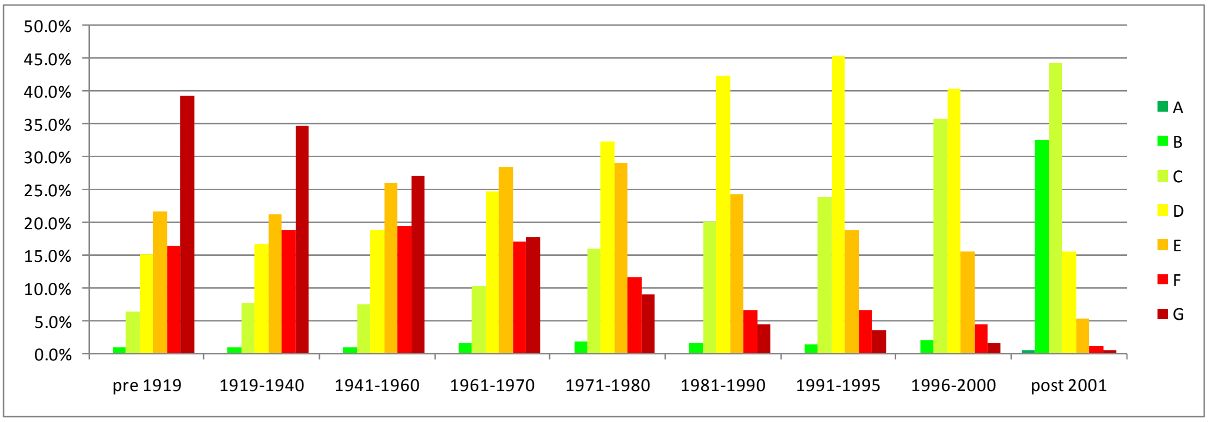

Figure 3.1: % of dwellings by BER for each age band according to BER database.

Within the LEAP_Ireland model structure, three categories of dwellings have been established. These are existing dwellings, i.e. dwellings occupied as of 2008, new dwellings, i.e. dwellings which become newly occupied between 2008 and 2020, and retrofitted dwellings, i.e. dwellings that had been occupied in 2008 and have since had improvements carried out on the building fabric. The energy consumption of dwellings that have been retrofitted is considered separately to that of "existing dwellings", therefore in this context existing dwellings refers to dwellings occupied as of 2008 that have not since been retrofitted between 2009 and 2020.

Two factors cause an annual reduction in the numbers of existing dwellings during the time period considered; obsolescence and retrofitting. Obsolescence accounts for the demolition or abandonment of dwellings. Dwellings that undertake retrofit work are reclassified as retrofitted dwellings and thus are removed from the ranks of existing dwellings.

3.2.2 Limitations of Modelling Approach

Some of the benefits of increased energy efficiency will be realised in the form of greater home comfort levels, higher internal room temperatures and less fuel poverty, rather than in the form of reduced energy consumption. This is an example of rebound or behavioural effects reducing the maximum theoretically achievable energy savings. DEAP is designed to give an asset rating to a dwelling, and so standardises factors such as occupancy and internal temperature. In reality dwellings with poorer energy efficiency standards may have lower internal temperatures than highly energy efficient dwellings. This may result in an overestimation of the energy requirement of poorer dwellings in DEAP, and a corresponding overestimation of the savings to be achieved through retrofitting.

Another important limitation of the modelling approach chosen is that although it is assumed that the energy consumption values calculated using DEAP are representative of the typical annual energy consumption of that dwelling, it has not been possible to verify this against measurements of real world energy consumption. Ideally the DEAP calculations would be calibrated to real world data and a correction factor applied to the calculated energy consumption depending on the BER grade of the dwelling. Unfortunately data relating real world metered energy consumption to predicted DEAP energy consumption is not available at this time.

SEAI produces estimates of the energy consumption of the residential sector as a whole[3]. When these figures for 2009 are compared to the estimate of overall energy consumption using the BER based model of the residential sector in 2009 the results are found to agree within 7%. This gives the authors confidence that even in the absence of real world data at the level of individual dwellings, that overall the model is capable of providing useful results and insights.

3.2.3 Obsolescence of Existing Dwellings

The rate at which dwellings in the Irish housing stock become obsolete has been quantified by the department of the Environment to be 0.73% of the total housing stock per annum[21].The total number of dwellings in the housing stock from 2009 to 2025 is taken from projections by the Economic and Social Research Institute (ESRI) provided to SEAI. This total figure is reduced by 0.73% annually from the number of dwellings in the 2008 stock. It is also necessary to split the annual number of obsolete dwellings by BER label. No real world data exists on this and so assumptions have to be made. It was assumed that dwellings being made obsolete would be older and of a poorer quality generally and would therefore be more likely to have lower BERs.

A modern dwelling built to the latest regulations should expect to achieve a B rating, as is evident from figure 3.1. It is therefore assumed that no dwellings of a B or A rating will become obsolete in the timeframe considered. The percentage split of dwellings by BER rating from C to G in the 2009 stock was first established. The split for obsolescence was then weighted toward the lower BER grades as follows: C -20%, D -10%, E +0%, F +10%, G +20%. In subsequent years the changing percentage split by BER rating was recalculated annually but the weighting towards lower BER’s was maintained until at most 95% of the number of dwellings existing in 2008 from a particular band were removed. At that point no more dwellings from this band were removed and the remaining four BER grades would be weighted from better to worse BER as follows: -20%, -10%, +10%, +20%. Further eliminations of BER bands would change the weighting of the remainders to -20%, 0%, +20% and finally -10%, +10%.

3.2.4 Number of Dwellings Retrofitted

The NRP consultation document specifies the aim of retrofitting 1,000,000 domestic, public and commercial buildings between 2011 and 2020. 5,200 GWh or 65% of the total 8,000 GWh savings for the scheme are expected to come from the residential sector, with the remaining 2,800 GWh coming from the services sector. 75% of the funding for the project is to be allocated to the residential sector. A specific number of domestic dwellings to be retrofitted is not specified but based on the above information it was assumed that 800,000 residential dwellings would be retrofitted between 2009 and 2020. The assumed annual and cumulative numbers of dwellings retrofitted are shown in Table 3.4.

Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
1000's of Annual Numbers of Retrofit	-	-	50	70	100	100	100	100	100	100	50	30
1000's of Cumulative Retrofits	-	-	50	120	220	320	420	520	620	720	770	800

Table 3.4 Numbers of dwellings retrofitted

3.2.5 Depth of Retrofit

The extent of retrofit measures adopted in an individual house (i.e. the depth of retrofit) has a significant impact on the energy savings that can be achieved. As shown in Table 3.1, those who have availed of grant support have largely undertaken the shallow measures, such as roof insulation (70% of grantees) and cavity wall insulation (53% of grantees. Very few have completed the ‘deeper’ measures such as upgrading heating controls (4%) or external wall insulation (2%). Figure 3.2 shows the impact for an individual ‘E’ rated home of the full range of measures that are supported under the NRP, illustrating the relationship between individual measure and its impact on the BER rating for the home.

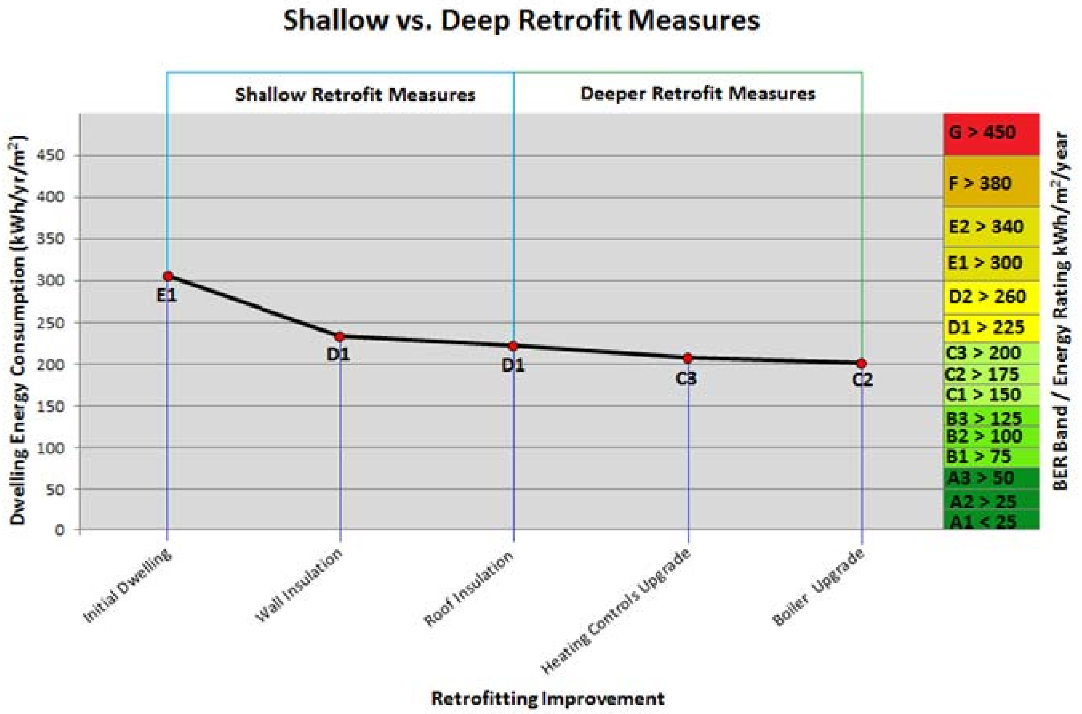

Figure 3.2: Effect of Shallow and Deep retrofit measures on an“E” Dwelling

4 Scenarios

4.1 Overview

In total seven scenarios were developed within LEAP_Ireland; A reference scenario assuming no retrofit work, a standard retrofit scenario, two scenarios investigating the effect of differing initial BER profiles for dwellings undertaking retrofit works, two scenarios investigating the effect of differing depth of retrofit work carried out, and finally a scenario investigating the maximum potential for energy savings through retrofitting work.

4.2 Reference (Ref) Scenario & Standard retrofit (RF1) Scenario

The first scenario considered is the reference scenario, abbreviated to Ref. This scenario assumes no retrofitting work is carried out on any of the 2008 stock between 2009 and 2025. This includes any retrofitting work that may be carried out autonomously, irrespective of the presence of a grant scheme or not. The reference scenario does include the effect of the natural obsolescence rate of existing dwellings.

The first scenario to consider the effect of the introduction of the NRP is the standard retrofit scenario, abbreviated to RF1 scenario. For a given annual number of retrofits carried out, there are two further variables to be considered; (a) the BER profile of dwellings taking on retrofit work and (b) the depth of retrofit work carried out.

(a) Firstly, it was assumed that dwellings with lower BERs would be more likely to be retrofitted. The same approach as was used for obsolete dwellings was adopted. It was assumed that no dwellings of a B grade or better would be retrofitted. The annual split of existing dwellings was calculated and in 2009 was weighted toward lower BER as follows: C -12.5%, D -10%, E 0%, F +10%, G +12.5%. As for obsolescence a maximum of 95% of the 2008 stock of a particular band were available for retrofit. Following this the remaining bands were weighted from better to worse BER as follows -12.5%, -10%, +10%, +12.5%; -12.5%, 0%, +12.5%.

(b) Secondly, with regards to the depth of retrofit works carried out, it was assumed that dwellings with a poorer initial BER would be in a position to make greater savings than a dwelling with a better initial BER. The following retrofit profile was assumed: Dwellings with an initial BER of C would be improved to a B grade, D to B, E to C, F to C and G to D.

4.3 Scenarios investigating the effect of the uptake profile for retrofit work (RF2 and RF3)

The next two scenarios vary the assumptions on the split by BER of dwellings undertaking retrofit work to investigate how this will influence the effectiveness of the NRP. The first of these, the RF2 scenario, assumes that the NRP will be strongly targeted towards dwellings with poor BERs, and so assumes a higher weighting factor toward low BER than the RF1 scenario. The weightings assumed in 2009 are: C -25%, D -20%, E 0%, F+20%, G +25%. Again the maximum number of dwellings from a given BER band available for retrofit is 95% of the 2008 stock, and as bands are removed the weighting changes to: -25%, -20%, +20%, +25% and subsequently to: -25%, 0%, +25%. The RF3 scenario assumes that all dwellings of a C grade or lower are equally likely to undertake retrofit work. Therefore no weightings are applied and the uptake is in the same ratio as the split of existing dwellings by BER each year. Note that in this scenario obsolescence is still assumed to be weighted towards dwellings with poorer BERs. These assumptions are summarised in Table 4.1

Uptake of Retrofit Works								
	Unweighted	Standard		Low Initial BER		High Initial BER		
BER	%	Weighting	%	Weighting	%	Weighting	%	
A	0.0%		0.0%		0.0%	0.0%	0.0%	
B	0.0%		0.0%		0.0%	0.0%	0.0%	
C	25.3%	-12.5%	12.8%	-25.0%	0.3%	0.0%	25.3%	
D	28.4%	-10.0%	18.4%	-20.0%	8.4%	0.0%	28.4%	
E	20.9%	0.0%	20.9%	0.0%	20.9%	0.0%	20.9%	
F	10.8%	10.0%	20.8%	20.0%	30.8%	0.0%	10.8%	
G	14.6%	12.5%	27.1%	25.0%	39.6%	0.0%	14.6%	

Table 4.1: Weightings for uptakes of retrofit works by BER label

4.4 Scenarios investigating the effect of the depth of retrofit work carried out (RF4 and RF5)

The terms shallow and deep retrofit are applied loosely to indicate the scale of the work carried out on and the energy efficiency improvements achieved in a particular dwelling, with a deep retrofit typically entailing costlier works and achieving greater energy savings. Two further scenarios were considered to investigate the effect of the depth of retrofit on energy savings achieved by the NRP. The first, RF4, assumes a shallower retrofit profile than the standard retrofit scenario RF1, as follows: Dwellings with an initial C grade improved to a B grade, D to a C, E to a D, F to a D, G to an E. The second, RF5, assumes a deeper retrofit profile, as follows: Dwellings with an initial C grade improved to an A grade, D to B, E to B, F to B, G to C. In both of these cases the same uptake profile by BER rating as in the RF1 scenario was used. These assumptions are summarised in Table 4.2.

Retrofit Depth								
Standard			Shallow			Deep		
Initiall	Post Retrofit	Increase in bands	Initiall	Post Retrofit	Increase in bands	Initiall	Post Retrofit	Increase in bands
B	A	+1	B	A	+1	B	A	+1
C	B	+1	C	B	+1	C	A	+2
D	B	+2	D	C	+1	D	B	+2
E	C	+2	E	D	+1	E	B	+3
F	C	+3	F	D	+2	F	B	+4
G	D	+3	G	E	+2	G	C	+4
		Total: +12			Total: +8			Total: +16

Table 4.2: Depth of retrofit measures in standard, shallow and deep retrofit scenarios.

Finally, to estimate the maximum potential for energy savings through the NRP, the RF6 scenario assumes a deep retrofit profile and also assumes an uptake profile heavily weighted toward poorer performing dwellings as per the RF3 scenario.

A summary of all scenarios giving the assumptions regarding the initial BER profile of retrofitted dwellings and the depth of retrofit works carried out is provided in Table 4.3.

	Number Dwellings Retrofitted	Pre-Retrofit BER Profile	Depth of Retrofit works
Ref	0	-	-
RF1	800,000	Standard	Standard
RF2	800,000	Low	Standard
RF3	800,000	High	Standard
RF4	800,000	Standard	Shallow
RF5	800,000	Standard	Deep
RF6	800,000	Low	Deep

Table 4.3: Summary of scenario assumptions.

5 Results

The results for the seven scenarios developed are shown in Figure 5.1 and Table 5.1. The standard retrofit scenario RF1 shows a reduction in energy consumption of 8,690 GWh or 31% in 2020 relative to the Ref scenario. Examining the effect of differing initial BER profiles, the RF2 scenario which increased the weighting in uptake toward lower BER grades shows increased savings of 809 GWh over those in the RF1 scenario, or an 9% increase. For the RF3 scenario which assumed no weighting toward dwellings with lower BER in the uptake of retrofit work, savings were 1,016 GWh or 12% lower than in the RF1 scenario.

With regard to the effect of the depth of retrofit, the shallow retrofit scenario, RF4, shows savings 2,686 GWh or 31% less than for the RF1 scenario. The deep retrofit, RF5, scenario achieved extra savings of 2,663 GWh over the RF1 scenario, an increase of 31%.

Finally, the RF6 scenario investigating the upper-bound savings potential for the NRP shows savings of 11,884 GWh or 43% with respect to the Ref scenario, a 3,194 GWh or 37% improvement on the RF1 scenario.

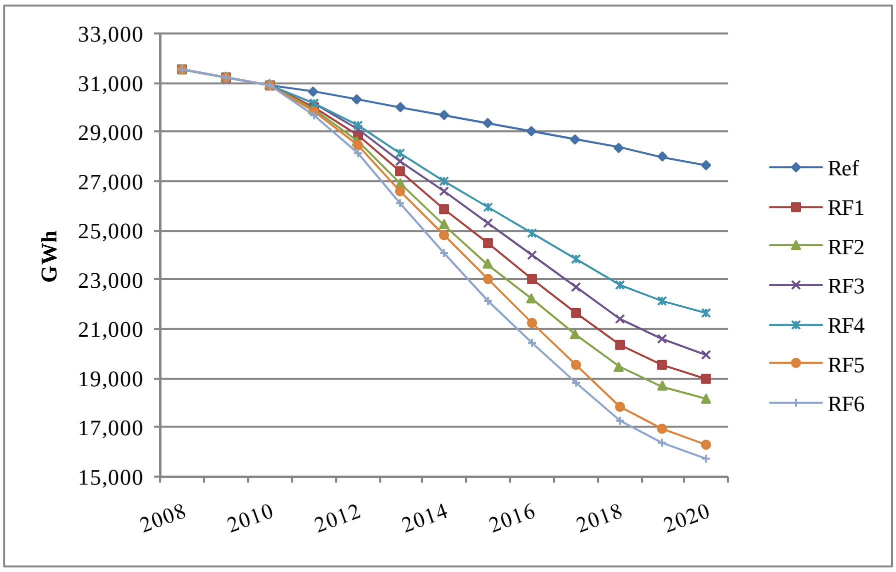

Figure 5.1: Energy for Space and Water Heating in Existing and Retrofitted Dwellings

Energy for Space and Water Heating in Existing and Retrofitted Dwellings					
	Energy Demand 2020	Savings WRT Ref		Savings WRT RF1	
	GWh	GWh	%	GWh	%
Ref	27,635				
RF1	18,945	8,690	31%		
RF2	18,136	9,499	34%	809	9%
RF3	19,962	7,673	28%	-1,016	-12%
RF4	21,631	6,003	22%	-2,686	-31%
RF5	16,283	11,352	41%	2,663	31%
RF6	15,751	11,884	43%	3,194	37%

Table 5.1: Energy for Space and Water Heating in Existing and Retrofitted Dwellings

6 Conclusions

In the year 2020 and with respect to the reference scenario, the above model estimates savings in the range from 6,000 GWh to 11,900 GWh depending on the profile of dwellings retrofitted and the depth of retrofit work undertaken. Based on continuation of the recent trends regarding uptake of measures, it is likely to be closer to 6,000 GWh. These theoretical savings do not take into account the reduction in realised savings due to increased comfort levels and other forms of behavioural and rebound effects. The objective of the NRP is to achieve savings of 5,200 GWh. The authors conclude from this analysis that this target can be reasonably achieved. It is also concluded that focusing the retrofit scheme on dwellings with lower initial BER ratings will help to reach the target, but of greater impact will be ensuring that the dwellings that do undergo retrofit have the deepest possible package of measures applied.

Additional work is required and currently underway to improve the analysis and thereby increase the robustness of the results. Empirical analysis of the data arising from the current HESS scheme will enable further precision (beyond the current approach involving a step change in energy rating for retrofitted homes) and provide insight into how much of the technical energy savings will be actually achieved in light of behavioural effects including rebound. Empirical analysis is also required to inform how actual energy usage relates to energy performance. Further analysis is required to ascertain who (according to socio-economic classification) is likely to avail of the retrofit grant support to determine free-rider[1] effects and to examine the costs and benefits of the support provided.

[1] Free riders are those who would have undertaken a retrofit in the absence of grant support but who avail of the available funding.

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