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Improved modelling of thermal energy savings potential in the existing residential stock using a newly available data source

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ABSTRACT

This paper presents a novel bottom up approach to modelling the energy savings potential of energy efficiency improvement measures to be applied through retrofit of the existing dwelling stock. It takes advantage of a newly available, rich dataset on the construction characteristics of the 2011 housing stock in Ireland. The methodological innovation centres on the use of wall construction type in the modelling and analysis. While Ireland is the focus, this approach is applicable to any EU member state for which data on dwelling characteristics exists from surveys carried as part of Energy Performance Certificate calculations. The model is calibrated to the national energy balance for 2011 by varying the internal temperature assumptions. Sensitivity analysis is performed on the effects of internal temperature and rebound. The paper also highlights some limitations posed by data availability on the accuracy and sophistication of models that can currently be developed, specifically in the Irish case.

1. Introduction

1.1. International and national policy context

Energy efficiency at the EU level is promoted through the ESD (Energy Services Directive) [1] and, for the built environment in particular, through the EPBD (Energy Performance in Buildings Directive) [2]. In the Irish context the SEAI (Sustainable Energy Authority of Ireland) in conjunction with the DCENR (Department of Communications Energy and Natural Resources) has run a number of schemes aimed at encouraging energy efficiency retrofit works for existing dwellings. Past examples include the HESS (Home Energy Savings Scheme) and the Warmer Homes Scheme. 2011 saw the introduction of "Better Energy: The National Upgrade Programme" [3] which superseded all previous energy retrofit programmes, both residential and non-residential, and which set the objective of delivering energy efficiency upgrades to one million residential, public and commercial buildings by 2020. The branch of Better Energy focusing on the residential sector is known as "BEH" (Better Energy: Homes).

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1.2. Bottom up modelling

Reviews of the various different types of energy models employed in the residential sector have been carried out by a number of authors [4–9]. Models are broadly classified as either top down or bottom up though the two approaches are not mutually exclusive. The modelling approach adopted here is the bottom-up engineering archetype model, which lends itself to analysing policy measures that have a technical focus such as building regulations or retrofitting. There are a number of limitations associated with this approach as identified in the literature.

Giraudet et al. [10] consider that energy consumption is the resulting product of technical factors affecting energy efficiency (the amount of energy per unit of energy service) and behavioural factors affecting energy sufficiency (the amount of energy service). They note that purely technical models fail to take account of sufficiency feedbacks, also known as the rebound effect. Similar findings are made by Cayre et al. [11], Cayla et al. [12], and Kelly [13]. Aydinalp-Koksal & Ugursal [14] point to a difficulty with the engineering method in the inclusion of consumer or occupant behaviour and other socio-economic variables that have a significant effect on the residential energy use, but note that in spite of this "because of the high level of detail and flexibility provided by engineering based models, they can be used to evaluate the impact of a wide range of scenarios for energy conservation on residential energy consumption and GHG emissions".

Natarajan et al. [9] again identify the shortcomings of deterministic, equation based, building physics models, including their inability to endogenously account for occupant behaviour and also the fact that most deterministic models do not capture uncertainty surrounding input variables. While levelling the above criticisms at building physics models Natarajan et al. also note that "*they are very useful in identifying a baseline technical potential for future emission reductions.*"

Efforts have been made to improve the accuracy of bottom up building physics models by comparing and calibrating them to metered energy data. This can be done by establishing a correction factor curve which can be applied to the results of such bottom up models [15] or by using statistical techniques to calibrate the original input parameters [16].

1.3. Previous Ireland residential sector energy modelling

Much work has been carried out for the UK residential sector with the production of many well documented residential energy consumption models. Less has been published in terms of models specific to the Irish residential sector but some significant work has been done. Clinch and Healy published a number of papers in the early 2000's investigating the potential both for energy savings and to a greater extent the potential to alleviate fuel poverty in Ireland due to retrofit of the residential dwelling stock [17–22]. Two studies have been carried out by Hull et al. [23] and Rogan et al. [24] focussing the drivers behind natural gas consumption in Ireland based on actual metered data. Ahern et al. [25] created a bottom up model of detached, oil centrally heated dwellings and used it to investigate the economic and carbon case for thermal retrofit measures. Scheer et al. [26] conducted an ex post billing analysis of 210 dwellings that had undergone retrofit work under the HESS to quantify the actual energy savings achieved. The ESRI (Economic and Social Research Institute) has carried out econometric modelling of Irish residential sector energy use, much of it focused on appliance ownership and usage [27–30].

This paper presents a bottom up approach to modelling the energy savings potential of energy efficiency improvement measures to be applied through retrofit of the existing dwelling stock. It utilises new EU energy performance certificate survey data using Ireland as a case study. This rich dataset provides detailed data on the construction characteristics of a (18%) sample of the 2011 housing stock. Using this data the authors establish a set of 175 archetype dwellings to represent the breadth of dwellings existing in the stock. We base the archetypes on three key dwelling characteristics, namely building type, energy performance and wall construction type. Data from the CSO (Central Statistics Office) 2011 national survey is used to scale this dataset up to the national level. This set of detailed data on the physical characteristics of each archetype dwelling is then used as inputs to a building physics model of the energy consumption of dwellings. The model used is the DEAP (Dwelling Energy Assessment Procedure) model, developed by SEAI to produce EPC (Energy Performance Certificates), also known in Ireland as BER (Building Energy Ratings), in accordance with the EU ESD. This is then used to model the energy savings accruing from a number of potential energy savings retrofit measures. This approach is equally applicable to any EU state for which data exists on dwelling characteristics, either as part of surveys carried for the purpose of EPC calculations as mandated by the EPBD, or through other sources.

While acknowledging the limitations typical of such models, in particular with respect to behaviour and rebound effects, the authors conclude that the bottom up engineering approach is capable of producing models which yield valuable insights, particularly in establishing the technical savings potential of energy efficiency technologies, and form a very useful basis upon which more sophisticated models can be developed. A specific limitation hampering the development of more accurate models in the Irish context is that of data availability, as is discussed later. It is hoped that this paper can from a basis for future work, can serve to highlight the stumbling blocks currently faced and encourage improvements in data collection and dissemination required for the development of more sophisticated models.

This model builds on previous work by the authors on a bottom up model of the energy consumption of space and water heating of newly occupied dwellings from 2009 to 2020 [31] as well as previous estimates of retrofit savings potential and an estimation of the electricity consumption of lighting and appliances of all dwellings from 2009 to 2020 contained within the LEAP_Ireland model [32,33].

This paper contributes to the literature on residential modelling in particular with respect to Ireland, where no such complete model of the housing stock was previously developed and bottom up analysis of this key sector has in general been poorly developed. More generally this paper contributes to the broader community in two respects. First as a demonstration of the usefulness of Energy Performance Certificate databases, which have been developed Europe wide under the EPBD, as a data rich resource for constructing such models where previously such data was unavailable. Secondly, through the use of the EPC database to take into account explicitly the wall construction type as a key variable in modelling the technical and economic feasibility of retrofitting the existing dwelling stock.

2. Methodology and data sources

2.1. Overview of methodology

The first step in developing an archetype model of the residential sector is to establish a set of dwelling archetypes that adequately characterise the entire dwelling stock. For each archetype dwelling it is necessary to estimate both the number of retrofits and the energy savings potential for a number of retrofit measures. The total energy savings equal the product of the number of dwellings retrofitted by the energy savings per retrofit, summed across all retrofit measures and across all archetypes. This is summarised by the bottom up equation:

$$E_y = \sum_{A,M} N_{A,y} \times S_{A,M},$$

E_y = Energy Savings in Year y
$N_{A,y}$ = Number of dwellings of archetype A retrofitted in year y
$S_{A,M}$ = Energy Savings per annum for retrofit measure M carried out on archetype dwelling A
A = For each archetype
M = For each retrofit measure carried out

2.2. BER certificates & DEAP

A rich dataset of the construction characteristics of each archetype was required for the analysis. The authors made use of the National BER research tool which provides detailed data on the construction characteristics of the current housing stock. BER certificates were introduced in Ireland in 2007 as required by the ESD.