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Albert Famuyibo
Technological University Dublin, sojarchi@yahoo.ie

Aidan Duffy
Technological University Dublin, aidan.duffy@tudublin.ie

Paul Strachan
University of Strathclyde

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A LIFE CYCLE ASSESSMENT OF EMISSIONS REDUCTION POTENTIAL IN THE EXISTING IRISH HOUSING STOCK: A PERSPECTIVE OF INTERNATIONAL AND DOMESTIC SOURCES

A.A. Famuyibo[1], A. Aidan[2] and P. Strachan[3]

1. [1 and 2]School of Civil and Building Services Engineering and the Dublin Energy Lab - Dublin Institute of Technology, Dublin. Ireland. emails: albert.famuyibo@dit.ie and aidan.duffy@dit.ie
2. [3]Energy Systems Research Unit, University of Strathclyde, Glasgow, UK. email: paul@esru.strath.ac.uk

ABSTRACT

As the volume of imported materials increases, the magnitude of the imported environmental impacts becomes a greater factor in the energy demand and related CO_2 emissions from the residential sector. As supply chains of goods within the global arena expands across country and region, domestic consumption of imported goods results in CO_2 emissions in countries of production. Given that these emissions are attributable to countries of import, directing information towards environmental policy experts on a complete view of total emissions of retrofitting along international and domestic sources will have an impact on decision making, and for the first time in Ireland a study of the shares (%) of these sources is the primary aim of this paper. The housing stock has been categorised into thirteen representative archetypes to statistically reflect the mix of key energy related characteristics within the stock of Irish dwellings. Detailed life cycle inventories were prepared for each these archetypes to identify their impacts and then a suite of energy efficient retrofit technologies were applied under 'meet current building regulations'(current standard) and 'meet anticipated future regulations' (passive house standard) to identify the impact of retrofitting on life cycle performance of the housing stock. Results show that although for the average dwelling, operational phase consumption and emissions is much greater than any other phase across all options, there is a wide variation in the shares (%) of international and domestic sources on this balance across the retrofit options.

Keywords: Decision making, residential sector, emissions, archetypes.

1 INTRODUCTION

Ireland and the EU are both fossil fuel import dependent, and it has been predicted for the EU that the dependency on fossil fuels will attain around 67% by 2020 [1]. Carbon dioxide is the most significant anthropogenic greenhouse gas from the consumption of fossil fuels. In 2009, the existing Irish housing stock was responsible for 26% and 27% of the country's primary energy and primary energy-related CO_2 emissions, respectively. As the residential sector is a predominant element of energy consumption and emissions, significant change in approach to fossil fuel import dependency will be required to achieve Ireland's 20% energy reduction target by 2020.

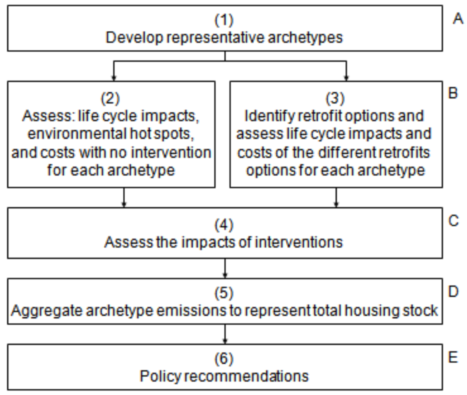
To allow a complete view of all energy and emissions of retrofitting to be evaluated a bottom-up (archetype) model of the existing Irish housing stock incorporating a process-based LCA hybrid method has been developed. Such a view will indicate emissions reduction potential along international and domestic sources. The case study presented here indicates the model applied to the existing Irish housing stock. It involves: estimation of the primary energy and primary energy-related emissions under 'no-intervention, 'meet current building regulations' (current standard) and 'meet anticipated future regulations' (passive house standard); performing an analysis of the identified retrofit options; and determining the shares of imported emissions.

Several studies have been performed using bottom-up (archetype) techniques, from: studies at regional levels by Nemry et al., [2] and Lechtenbohmer and Schüring [3] to studies at national scales by the BREHOMES model [4] , the 40% house project [5] and the model developed by Johnston et al., [6] (Henceforth referred to as the Johnston model); and studies at urban scales by Firth et al. [7], and Shimoda et al. [8]. See inter alia, Swan et al [9] and Kavgic [10] for complementary literature reviews of the different archetype bottom-up modelling techniques.

The remaining part of this paper is presented as follows: Section 2 accounts for the methodology used in study. Section 3 presents the results and discussion of the LCA. In Section 4 conclusions and recommendations are made.

2 METHODOLOGY

The methodology used in study was split into two sections. First, the entire housing stock was developed into representative archetype houses. Subsequently, the life cycle impacts of the different archetype houses were assessed. Retrofit measures were identified for the individual unit archetypes along their respective options and their new impacts assessed. Figure 2.1 below illustrates the overall methodology used in study.



2.1 Development of representative archetypes

Representativeness of the housing database: In this paper the Energy Performance Survey of Irish Housing (EPSIH) [11] and the Irish National Survey of Housing Quality (INSHQ) [12] have been useful in the development of archetypes. While the EPSIH represents the housing database used in current study, the INSHQ was used to check the representativeness of the EPSIH. The comparative analysis that was performed indicates that the variables of both databases demonstrate evidence of significant consistency.

Archetype development: the development of representative archetypes was carried out as follows. First, in order to identify the importance of household variables of energy use in Irish housing, a multiple linear regression analysis was carried out involving all 23 variables recorded in the housing database including those considered important based on literature as independent variables and Total Primary Energy Use as a dependent variable.

Second, as the results of the MLRA could not provide the necessary parameter inputs to adequately define representative archetypes and perform energy analysis, supplementary variables which are undisputedly important based on literature/or theory were obtained. Overall, a total of nine variables impacting energy use were finally selected in the development of archetypes as described below.

Third, using the identified most important variables which explain energy use in Irish housing, a statistical analysis of the distributions for each key variable was then used to identify representative parameters and corresponding construction details based on a knowledge of housing construction details and thermal characteristics for the sample.

Fourth, and finally, clustering analysis was used to identify coincident groups of parameters and construction details; this led to the identification of 13 representative archetypes.

2.2 Process-based hybrid LCA

The methodology has been carried out in accordance with: ISO 14040 (2006) - Environmental Management-life cycle assessment-Principles and framework; and ISO 14044 (2006) - Environmental Management- life cycle assessment- Requirements and Guidelines.

Environmental impact categories: In this study the environmental impacts are presented in impact categories. These environmental impact categories are selected based on literature; international agreements; feasibility; the most significant impact category attributed to the building sector; and regional and national policies, and in particular as most environmental indicators published by Irish government agencies focus mainly on greenhouse gas emissions. These include primary energy (PE) and global warming.

Service life of products and of complete buildings: the residual service lives of the buildings have been estimated based on technical factors that affect embodied energy, operation energy and life cycle energy of a building. However, a maximum residual service life of 50 years has been estimated for most dwellings [Nemry et al, 2010]. Older representative archetype dwellings (i.e. with representative periods of construction of pre 60, 1960-1980 and 1981-1990) with insulated and un-insulated partial fill cavity and solid walls, insulated roof, draught-proofed single glazed/double glazed windows and mainly un-insulated solid floor/suspended timber floor, are assumed to have an estimated residual service life of 30 years.

Life cycle inventory data sources: Two categories of data have been primarily useful in this study: process analysis data and input-out analysis data.

Input –output analysis data include: Data on costs of materials, products, labour, etc and were obtained from Spon's Irish construction price book [13] and adjusted to 2005 baseline year of study; and the sub-sector embodied energy/CO_2-eq energy intensities of Irish construction from a previous study, Acquaye A., (2010) [14], calculated based on the 2005 baseline year (the most recent year in which the Central Statistics Office has published Supply and Use Input-Output Tables for Ireland [14]).

Process analysis data was obtained from both the housing database and GaBi software tool - datasets. Other process analysis data include percentage shares of domestic (national) arising and International arising embodied CO_2-eq intensities of Irish construction [14]. This equivalent was also assumed for percentage shares of domestic (national) arising and International arising embodied energy intensities of Irish construction. Other assumptions regarding process data include: (1) As the above data on sub-sector energy and emissions intensities of Irish construction was based on Dublin new apartment buildings constructed in concrete, it was assumed that construction details were similar for the existing Irish housing stock which was also largely constructed in masonry including the use of 'Dublin concrete blocks'; (2) The 2005 baseline year of Acquaye A., (2010) [14] was also assumed to support the 2005 baseline year of this study; and (3) Equivalent percentage shares of domestic arising and international arising energy intensities of Irish construction were assumed.

Life Cycle Inventories (LCI) of construction materials and products: Using the detailed technical descriptions of representative archetype houses, life cycle inventories for the needed materials for the refurbishment work were generated. Also useful in generating these inventories are the residual service lives of the buildings and the corresponding life expectancy of the products/materials including their corresponding rate of replacement. The rate of replacement yields the number of replacements of products (e.g. replacing PV systems every 30 years) and number of upgrade actions (e.g. external redecoration every 7 years, etc) for each construction detail over the residual life of the building.

Hybrid-LCA energy and emissions calculations: As both input –output analysis and process analysis are limited in their capacity to adequately estimate the emissions associated with retrofitting over the whole life cycle, the two methods were combined. Process analysis was used for materials quantities for which process emissions intensities can be applied. On the other hand, input output analysis was used for materials quantities for which input-output emissions intensities can be applied. The total hybrid energy requirement of a given life cycle phase of a unit archetype is derived as the summation of the process energy requirement of the given life cycle phase and the corresponding input-output energy requirement.

Process energy calculations: Process life cycle energy calculation was categorised into two - process energy due to maintenance, retrofitting and disassembly phases; and process energy due to operation of the building. Using GaBi software tool, predictions were made across life cycle phases for the unit archetype. On the basis of the data on percentage shares of domestic arising and International arising embodied energy/CO_2 intensities of Irish construction these predictions were separated into international and domestic sources. Similarly, operation phase energy predictions were separated into international and domestic sources using the percentage of energy for fuel supply chains.

The procedure of calculating input-output energy requirement along life cycle phases is as follows. A bill of quantities was prepared for the refurbishment work and then every entry in terms of Euro was classified into one of the sub-sectors of Irish construction (with units in kWh/Euro) (see section on data sources). The energy requirement for a given life cycle phase was then derived as the summation of the multiplications of each entry. These predictions were considered domestic.

Then the average energy requirement for a given life cycle phase across international and domestic sources was derived as the summation of the multiplication of the predictions for the individual life cycle phases and the corresponding number of houses for which the unit archetype is representative in Irish housing divided by total number of houses in Irish housing stock. The average energy requirement of a given life cycle phase across international and domestic sources can be represented by equation 2.1 below.

$$E_{lcp,avg} = \frac{\sum_{i=1}^{n} E_{lcp,i} * N_i}{\sum_{i=1}^{n} N_i} \qquad \text{Equation (2.1)}$$

Where, $E_{lpc,\,i}$ is the life cycle phase predictions of archetype i, across international and domestic sources, N_i is the total number of dwellings in Irish housing stock which it is representative.

The above procedures were also performed to derive the total process primary energy-related emissions ($kgCO_2$-eq.), but this time by: applying emissions intensities of Irish construction instead of energy intensities; and fuel supply and fuel production impacts instead of energy for fuel supply chains.

2.3 Life cycle assessment results discussion

Table 1 indicates the average dwelling primary energy contribution across life cycle phases and retrofit options. The average dwelling operational contribution to primary energy is generally consistent with the Irish national statistics which was 21,755kWh in 2005 [15], especially when upstream and horizontal activities for domestic energy production and distribution (e.g. power station operation and maintenance, transmission network maintenance and operation diesel road transport, etc), are considered. It should also be noted that study incorporates impacts of services associated with refurbishment.

Table 1: Dwelling primary energy consumption across life cycle phases for each of the retrofit options

Life cycle phase	No-intervention			Current standard			Passive house standard		
	Domestic	International		Domestic	International		Domestic	International	
	kWh/yr		%	kWh/yr		%	kWh/yr		%
Retrofit	0	0	0	162	778	83	205	1010	83
Maintenance	38	57	60	69	199	74	84	244	74
Operation	39,360	6,117	13	19,787	2,577	12	10,780	869	7
Disassembly	21	41	67	29	52	64	24	52	68
Total	39,419	6,216	14	20,048	3,605	15	11,094	2,175	16

Similarly, Table 2 indicates the average dwelling contribution to global warming potential ($kgCO_2$-eq) across life cycle phases and retrofit options. The direct correlation between resource consumption and GHG emissions is emphasized as this table directly reflects that of the primary energy.

Table 2: Average dwelling global warming potential ($kgCO_2$-eq./yr) across life cycle phases for each of the retrofit options

Life cycle phase	No-intervention			Current standard			Passive house standard		
	Domestic	International		Domestic	International		Domestic	International	
	$kgCO_2$-eq./yr		%	$kgCO_2$-eq./yr		%	$kgCO_2$-eq./yr		%
Retrofit	0	0	0	173	1,120	87	182	1,122	86
Maintenance	66	362	85	84	517	86	58	517	90
Operation	9,805	1,445	13	4,754	819	15	2,595	411	14
Disassembly	9	10	53	8	14	65	8	13	62
Total	9,881	1,818	16	5,019	2,470	33	2,843	2,063	42

Improvement measures: Improvement measures applied to the no-intervention house option include those specified in the current 2010 Irish building regulations, and those independently identified for the passive house option.

For each of the 13 archetypes and the selected retrofit options, calculation of life cycle energy and life cycle emissions were repeated based on the same procedures as earlier discussed above. The life cycle energy and emissions were then compared to the no-intervention option.

Improving the no-intervention option to the current standard option significantly reduced operation energy by around 50%, mainly a result of the use of low-emissions solutions. These benefits offset the additional materials of retrofitting. Although, the passive house option provided the lowest operation phase energy and emissions (i.e. almost 4 times lower than the no-intervention option) due mainly to the use of zero-emissions technologies, but also incurred increased use of materials of retrofitting. Thus the option recorded the highest embodied energy, but still provides the optimal life cycle environmental benefits.

The shares (%) of international sources of energy and emissions across life cycle phases indicate that in addition to fossil fuels dependency earlier discussed above, emphasis is also on the use of imported construction materials. For example, the shares (%) of international sources of emissions of retrofitting represents 87 and 86 for the current standard and the passive house options, respectively. On the other hand those of the operation phase appear low because the impacts of energy production are mainly domestic.

2.4 *Conclusions:*

Given that Ireland is an open economy with around 90% of its energy requirement sourced from abroad, had the building regulations prescribed greater proportions of energy provision from renewable energy technologies, then average dwelling emissions of retrofitting to the current standard option would have been further significantly reduced (see Tables 1 and 2).

2.5 *Recommendations*

This study supports national and international policies aimed at reducing the proportion of emissions due to imports which focus mainly on reducing operational emissions from existing dwellings through: on the domestic front - greater uptake of renewable sources and scheduled retrofitting of the stock; and on the international side – there is a need for sustainable production patterns to lead to reduction of environmental impacts in Ireland (i.e. greater improvements of production processes), especially as relates to goods meant for export to Ireland.

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