Retrofit solutions for Irish building stock: The impact of human behaviour

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Abstract

Retrofitting buildings is recognised as the most immediate, pressing, and cost effective mechanism to reduce energy consumption and carbon emissions in the building and construction sector. It is necessary to double or triple the current retrofitting rate to reach the European Union (EU) short and long term goals of 20% energy reduction by 2020, and 80-95% CO_2 reduction by 2050. Boosting confidence in retrofitting buildings to a lower energy efficiency among all different stakeholders in the building value chain is essential for uptake of energy efficiency measures in the market. However, technical interventions alone have lower impact and are more expensive to implement if carried out in isolation. Thus, it is necessary to investigate the behavioural habits and attitudes of people towards energy and carbon consumption, and if these are altered, to establish the energy savings that can be made.

This paper presents the preliminary results of the data collected in surveys carried out with tenants of retrofitted residential buildings in Ireland. The face-to-face interviews were conducted before the retrofit works were carried out on the tenants’ houses. Results based on the demographic profiles, thermal comfort and the behaviour towards energy consumption of the tenants are shown. Different groups, based on their demographic and socio-economic status, were identified in order to assess the impact retrofitting works may have on the energy consumption and greenhouse gas (GHG) emissions of the investigated buildings.

Moreover, the paper discusses how the research project nZEB-RETROFIT, on-going in the National University of Ireland (NUI), Galway aims to combine the data obtained from the surveys with the energy consumption, temperature and relative humidity data collected pre- and post-retrofit of the tenants’ houses. This will allow the most effective retrofit measures to be identified for different types of households with divergent profiles regarding key demographic, socio-economic, attitudinal and behavioural variable. Furthermore, tailored engagement actions in order to motivate changes in energy behaviour within households and communities will be developed with the aim to reduce their energy consumption.

Topics: Nearly zero energy buildings, Energy performance, Human behaviour, Energy policy, Residential housing, Building retrofit

1. Introduction

Approximately 40% of the world's energy consumption and nearly a third of GHG emissions are associated with the building sector [1]. As a consequence, the European Commission introduced the Energy Performance Building Directive (EPBD) 2002/91/EC [2] targeted at widespread reduction in building operational energy consumption and carbon emissions in EU member states. This Directive was superseded in 2013 [3]. A significant objective of EPBD 2010/31/EU (recast) [3] is the mandatory introduction, in all member states, of nearly zero energy building (NZEB) for all new buildings or those receiving significant retrofit from 2020 (from 2018 for public buildings). A NZEB is a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including those produced on-site or nearby.

The Irish housing stock is among the poorest in Europe in terms of energy efficiency [4], and the residential sector is a key area where Ireland can significantly reduce its energy consumption and carbon emissions in order to meet the mandate set out by the EU [5,6]. The Irish residential sector accounts for 27% of the country's energy use, emits 10.5 million tonnes of CO_2 annually and is expected to contribute 35% to the energy savings required by the EU [7].

Boosting confidence in retrofitting buildings to a lower energy efficiency among all different stakeholders in the building value chain is essential for uptake of energy efficiency measures in the market. Nevertheless, energy efficiency is a complex issue spanning different disciplines including engineering, architecture, economics and social sciences. The literature to date has demonstrated that there is a potential for energy savings due to measures targeting behavioural change. Technical interventions alone have lower impact and are more expensive to implement if carried out in isolation, i.e. without an accompanying programme designed to encourage behavioural change [8]. Thus it is necessary to investigate the behavioural habits and attitudes of people towards energy and carbon consumption and, if these are altered, to establish the energy savings that can be made.

2. Research Plan

The research presented is part of the nZEB-RETROFIT project: Achieving nearly zero-energy buildings – A lifecycle assessment approach to retrofitting existing buildings. nZEB-RETROFIT is an ongoing research project in the National University of Ireland (NUI), Galway, Ireland which aims at tackling the issues relating to the retrofitting of the building stock [9].

A significant part of this research project aims to monitor the actual energy usage and GHG emissions of residential refurbishment projects pre- and post- retrofitting works. This is done with data logging instrumentation for the temperature, relative humidity and energy profiles to determine the actual performance of investigated buildings. Furthermore, information in relation to the behaviour and attitude of the buildings' habitants towards energy and carbon consumption, quality of life and thermal comfort within their homes is being collected through the face-to-face qualitative interviews and a survey.

The effectiveness of the various retrofitting technologies employed in the investigated dwellings will be evaluated. The performance the technologies have on the energy consumption, GHG emissions, occupants' comfort and health will be evaluated. The data obtained from the surveys will be combined with the energy consumption, temperature and relative humidity data collected pre- and post-retrofit of the tenants' houses. This will allow the most effective retrofit measures to be identified for different types of households with divergent profiles regarding key demographic, socio-economic, attitudinal and behavioural variables. A set of renovation packages, which are based on a life cycle cost optimum approach that considers the profiles of both the households and the physical building, will be developed for Ireland's current residential building stock. The data collected from occupants' surveys and interviews will be combined with monitored energy consumption, temperature and relative humidity data to develop tailored engagement actions. This will be done in order to motivate changes in energy behaviour within households and communities with the aim of reducing their energy consumption. Furthermore, the proposed project will generate policy recommendations regarding more targeted retrofitting efforts and measures to boost public confidence in the effectiveness of retrofitting schemes.

This paper presents the preliminary results of the data collected in surveys carried out with tenants of retrofitted residential buildings in Ireland. The face-to-face interviews were conducted before the retrofit works were carried out on the tenants' houses. Results based on the demographic profiles, thermal comfort and the behaviour towards energy consumption of the tenants are shown. Different groups, based on their demographic and socio-economic status, were identified in order to assess the impact retrofitting works may have on the energy consumption and GHG emissions of the investigated buildings.

3. Methodology

The survey conducted on the tenants was developed with social science researchers based on a lifestyle survey created as part of the Environmental Protection Agency (EPA) funded Consensus project [10]. The Consensus (Consumption, Environment and Sustainability) project focused on evaluating the behaviours and attitudes of people in Ireland towards four key areas of household consumption (transport, energy, water and food) that impact the environment. A total of 1500 households across counties Dublin, Galway and Derry participated in the project. To ensure maximum comparability with CONSENSUS data, questions from the CONSENSUS Lifestyle Survey were used again. Regarding data collection, face-to-face surveys were conducted with an adult aged 18 years or older prior to the installation of data logging instrumentation in each of the houses.

The survey with the occupants of investigated houses pre- and post-retrofit works gathered information about the resident's (1) demographic profiles, (2) socio-economic status, (3) behaviour and attitude towards energy consumption and conservation, environmental responsibility and thermal comfort, (4) views of quality of life and (5) what they considered to be a luxury and necessity in their lives.

The surveys were carried out on social housing in two counties in Ireland located in the east (Dublin) and north-west (Donegal) of the country. The pre-retrofit surveys were conducted with the Donegal housing tenants in November 2012 with 15 houses involved. The refurbishment work on the Donegal housing was carried out in December 2012 and formed part of research into the environmental life cycle assessment study of Irish residential buildings [11]. The pre-retrofit surveys were conducted with the Dublin housing tenants in February and March 2015 with 23 houses involved. The Dublin housing refurbishment works were completed by October 2015.

The temperature, relative humidity and electricity usage profiles of the 23 houses in Dublin are currently being monitored using data logging instrumentation. The temperature and relative humidity profiles of these houses are being monitored at high resolution (i.e. 15 minute interval readings). Electricity usage profiles are currently being monitored at 60 minute intervals within 20 of the houses. Electricity and gas meter readings are being recorded once a month for each of the houses in the estate. Residents are asked to record if they purchase solid fuel as they have the option of using solid fuel as a secondary heating source in the living rooms.

The temperature and relative humidity profiles of 10 of the 15 houses in Donegal were monitored at high resolution (i.e. 30 minute interval readings) using data logging instrumentation. Electricity meter readings were recorded once every three months for each of the houses involved in the estate. Residents are asked to record if they purchased oil or solid fuel as they as they predominately relied on these fuels for central space and water heating purposes.

4. Case Studies

The social housing in Donegal involved in the study is located on the outskirts of a small rural town in the north-west of Ireland and was constructed in 2004. Of the 15 residences that were involved in the study, there were four two-storey mid-terrace houses, three single-storey end-terrace houses, six two-storey semi-detached houses and two single storey semi-detached houses. All houses had cavity walls constructed using concrete masonry blocks. Home heating systems in the Donegal residences comprised of an oil-fired boiler as a central heating system and solid fuel open fire acting as a secondary heating system in the living room. Two of the housing units had back-boilers installed behind the solid fuel open fire in the sitting room. This system heated water for the central heating system and domestic hot water.

The social housing in Dublin involved in the study is located in a suburb area of Dublin with 23 residences involved. The housing in the estate was constructed in two phases, 1994 and 2000. 11 residences constructed in 1994 are involved, seven end-terraced and four mid-terraced houses. Both house types are two-storey buildings with a total of six rooms in each of the buildings. Both house types were mainly solid walls constructed using concrete masonry cavity blocks with interior dry-lining using gypsum board. A section of the exterior wall on the ground floor adjacent to the living room was constructed with cavity wall construction (exterior leaf clay fired brick and interior leaf concrete masonry block).

12 residences constructed in 2000 are involved, five end-terraced, four mid-terraced and three semi-detached houses. All three house types are two-storey buildings with a total of six rooms in each of the buildings. All three house types were mainly solid walls constructed using concrete masonry cavity blocks with interior dry-lining using gypsum board. A section of the exterior wall on the ground floor adjacent to the living room was constructed with cavity wall construction (exterior leaf clay fired brick and interior leaf concrete masonry block). Home heating systems in all the 1994 and 2000 residences comprised of a gas-fired boiler as a central heating system with either a solid fuel open fire, gas fire or electric fire acting as a secondary heating system in the living room.

The houses in Donegal and Dublin are a good representation of the Irish building stock. Of the 1,649,408 permanent housing units in Ireland, single family houses (detached, semi-detached and terraced houses) represent 87% of the building stock. The percentage of Ireland's building stock which are apartments (13%) is the lowest in the EU [4]. Semi-detached houses represent 28% of the building stock, with terraced housing represent 17% according to the most recent census [12]. Of the houses constructed between 1990 and 2005 in Ireland, 31% are semi-detached and 10% are terraced [12].

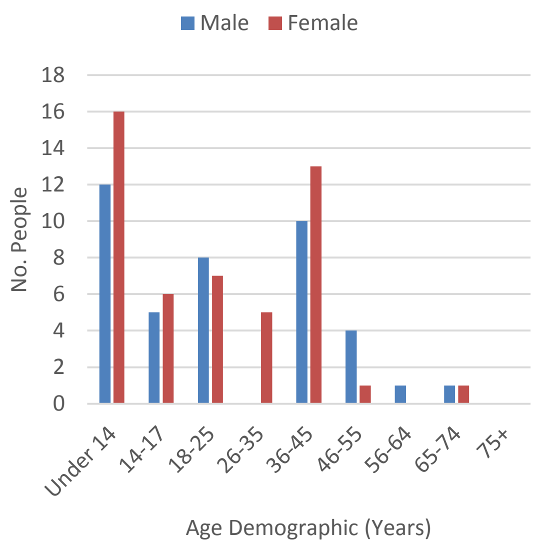
5. Results

This section presents the pre-retrofit survey data collected in the two case study residential estates (i.e. in Dublin and Donegal), with 38 houses involved. Results based on the demographic profiles, thermal comfort and behaviour towards energy consumption of the tenants are shown.

5.1 Age and Gender Profiles

Based on the collected data, there were 90 residents (49 (54.4%) being female and 41 (45.6%) being male) living in the investigated Dublin houses. The age profiles of each of the genders are shown in Figure 5.1(a). People under 14 years old represented the largest age group in Dublin, representing 31% of people residing at the estate. Six of the houses reported no person under the age of 18 in their house (27%). There were 23 people between the ages of 36-45 years old, which represented the second largest age group in the estate (25.6%). Overall, the population under 45 years of age (91.1%) represented a significant portion of the population in the investigated residential estate in Dublin.

40 people resided in the houses studied in Donegal. Their gender profiles are unavailable. The age profiles of the residents of Donegal are shown in Figure 5.1(b). People under 14 years old were the largest age group in Donegal (35%), similar to Dublin. Six surveyed houses recorded no individuals under 18 years of age residing at their home (40%). 79% of the investigated Donegal population were under 45 years of age. This represented a significant portion of the Donegal housing population.



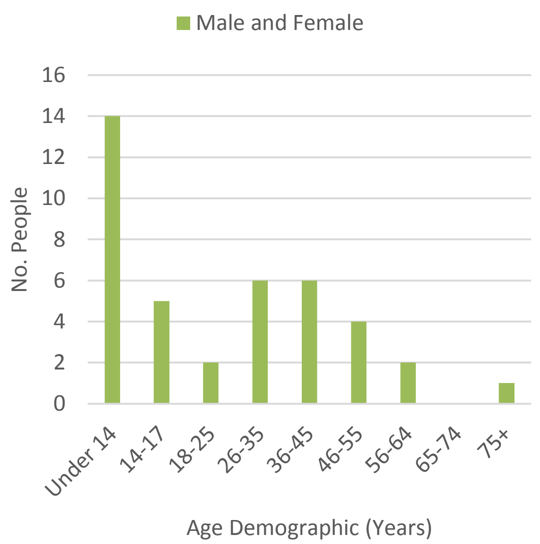


Figure 5.1 (a): Age profiles of the inhabitants of surveyed houses in Dublin (left) and **Figure 5.1 (b)**: age profiles of the inhabitants of surveyed houses in Donegal (right)

5.2 House compositions and residency duration

There were commonly two types of households represented based on the available data of the Dublin housing estate. Households which were made up of families with children in their late teens and early twenties and those with children in their late twenties and early thirties.

There was an average of 3.9 people in the 23 houses. Four to five people lived in 15 of the assessed houses, with one of the houses containing eight people. Two to three people lived in six of the houses, with one house having only a single inhabitant. The most common household composition in the Dublin estate was a house with a single adult who had three children (Table 5.1). There was an even number of households containing couples with children as there were single parents with children across the two estates.

Similar to Dublin, the investigated households in Donegal were commonly made up of families with children in their late teens and early twenties, and those with children in their late twenties and early thirties. However, only a single inhabitant was present in five of the houses. Five of the seven people aged over 46 lived alone. In Dublin, the only person that lived alone was aged between 56 and 64. 2.66 was the average number of people living in the Donegal houses compared to the 3.9 of Dublin.

The divide in the number of people living in the houses was greater in Donegal than in Dublin. In Donegal, six houses (40%) contained four to five people, four houses contained two to three people (26%), with the remaining five houses containing only one person. The most common house composition in Donegal was either a single inhabitant aged 14-64 years old or a couple with two children Table 5.1.

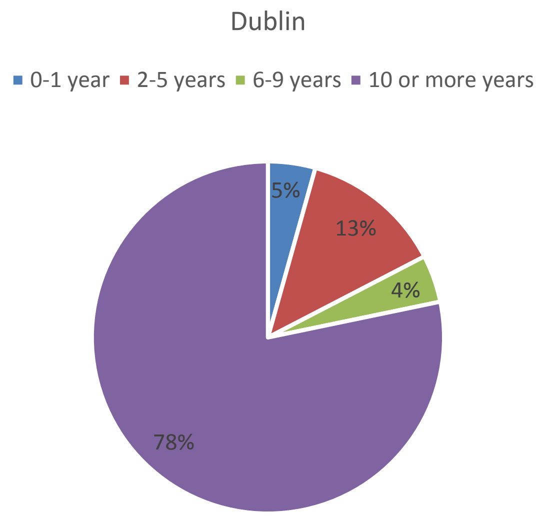
Table 5.1 Breakdown of house compositions in Dublin and Donegal

No. People	1		2		3		4		5	5 or more	6 or more
House Composition	*SA aged over 65	SA aged 46-64 years old	**CP only	SA & 1 ***CH	SA & 2 CH	CP & 1 CH	SA & 3 CH	CP & 2 CH	CP & 3 CH	SA & 4 or more CH	CP & 4 or more CH
No. Houses Dublin	-	1	2	1	-	3	7	2	5	1	1
No. Houses Donegal	1	4	-	2	2	-	1	4	-	1	-
Total	**1**	**5**	**2**	**3**	**2**	**3**	**8**	**6**	**5**	**2**	**1**

*SA=single adult, **CP=Couple, ***CH=Child/Children

18 (78%) tenants have lived in their house for 10 years or more in Dublin (Figure 5.2(a)). Three of the tenants have been living in their homes for 2-5 years, with one house indicating to be residing in their home for 6-9 years. In Donegal, 54% of the tenants had lived in their dwellings for 2-5 years, with 33% having resided for 6-9 years (Figure 5.2(b)).

The duration of residency of the houses for each estate suggested that a large portion of tenants were routinely familiar with housing heating operations. Additionally, these households were likely to have developed a daily routine which was reflected in the collected data.



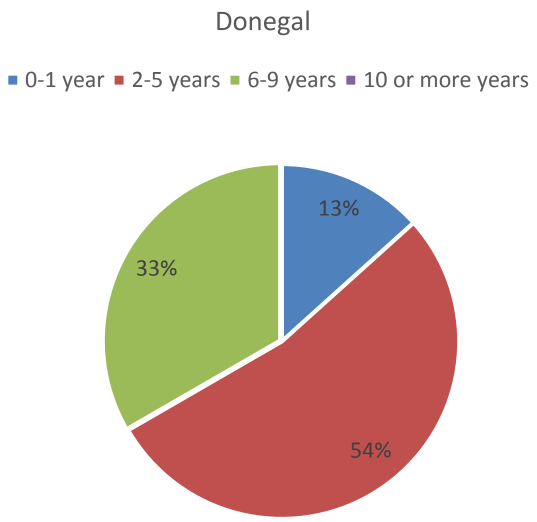


Figure 5.2(a): Years of residency of surveyed households of Dublin (left) and **Figure 5.2(b):** Years of residency of surveyed households of Donegal (right)

5.3 House Income

The annual income of the assessed homes in the Dublin estate ranged from €14,100 to €58,760. An average income of €25,569 was calculated for the 23 homes. 12 of the 23 homes assessed contained an income source from unemployment related payments. Child benefit income was recorded in 15 of the assessed homes. Housing allowance incomes were a feature in five homes. Employee income was recorded in 14 houses, old age related payments in one home and fuel allowances in ten of the surveyed houses.

The annual income of the assessed homes in the Donegal estate ranged from €10,296 to €28,960. An average amount of €17,885 was calculated for the 15 homes. 10 of the 15 homes assessed contained an income source from unemployment related payments. Child benefit income was recorded in eight assessed homes. Housing allowance incomes were a feature in five homes. Employee income was recorded in three homes, old age related payments in two homes and single parent allowance in one home. A disability benefit and pension from a private individual plan were each recorded in one home.

5.4 Amount of Time Spent at Home

In the Dublin estate, 17 houses (78%) stated that on average there was someone present in the house 24 hours a day, with two houses (9%) stating there was someone present in the house 20-22 hours a day (Figure 5.3(a)). Only three houses (13%) stated there was nobody in the house for less than 20 hours in a day. On the weekends, all houses stated there was someone present in the house 24 hours a day (Figure 5.3(b)).

In Donegal, not as many respondents reported someone present in the house 24 hours a day as in Dublin (Figure 5.4(a)). However, if taking into consideration the houses where there was a person present at least 22 hours a day, 74% of households had a person present in the house during the week for 22-24 hours a day. 87% of households had someone present in the house for 24 hours a day at the weekends (Figure 5.4(b)).

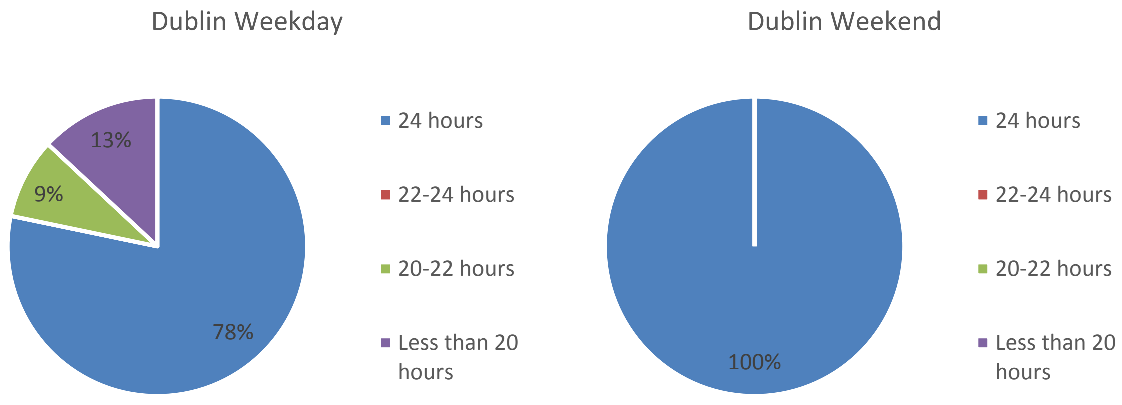


Figure 5.3(a): Average hours someone is present in house in Dublin housing on a weekday (left) and **Figure 5.3(b):** Average hours someone is present in house in Dublin housing at the weekend (right)

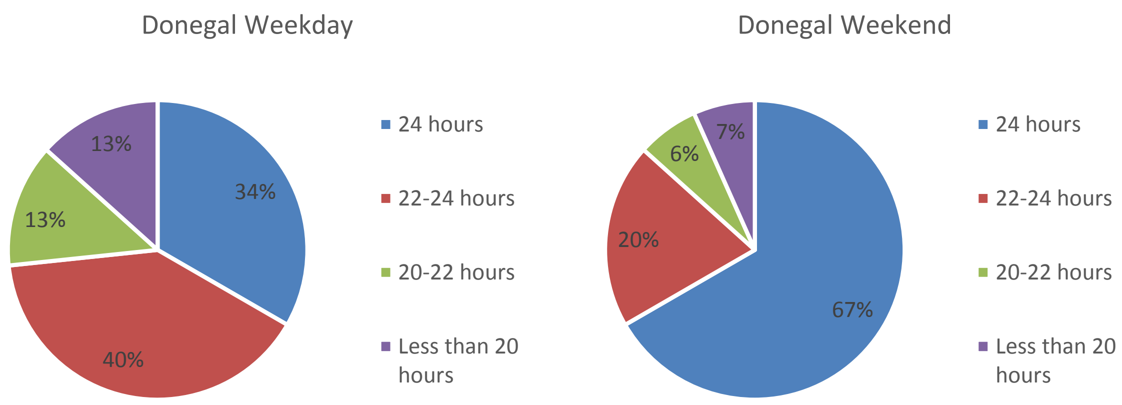


Figure 5.4(a): Average hours someone is present in house in Donegal housing on a weekday (left) and **Figure 5.4(b):** Average hours someone is present in house in Donegal housing at the weekend (right)

5.5 Electricity Usage

The electricity meter readings of each of the houses involved in the study were taken at various intervals with the average daily usage (in kWh) of the different house compositions of both housing estates given in Figure 5.5. In Donegal, the readings were taken from the start of the study to the end which lasted 272 days (22nd November 2012 to 21st August 2013). This accounts for both pre- and post- retrofit electricity usage for Donegal as there was only a month's worth of electricity usage pre- retrofit data available. Given the refurbishment works of Donegal involved only improvements to the thermal envelope, little impact was expected to be seen in the electricity usage behaviour of the residents. The study in Dublin is currently on-going. Electricity usage pre-retrofit of the houses involved in Dublin accounts for 160 days (12th February 2015 to 22nd July 2015). Data of three of the 23 houses involved in the study is missing. These houses have digital electricity meters and are unable to be read.

The number of people in the households has an impact on the electricity usage based on the data. Houses containing five people or more have the highest average energy usage. However, this is based only on two houses. The houses with the least electricity usage are houses containing only a single inhabitant. The two most common house compositions in both estates are the houses containing four people.

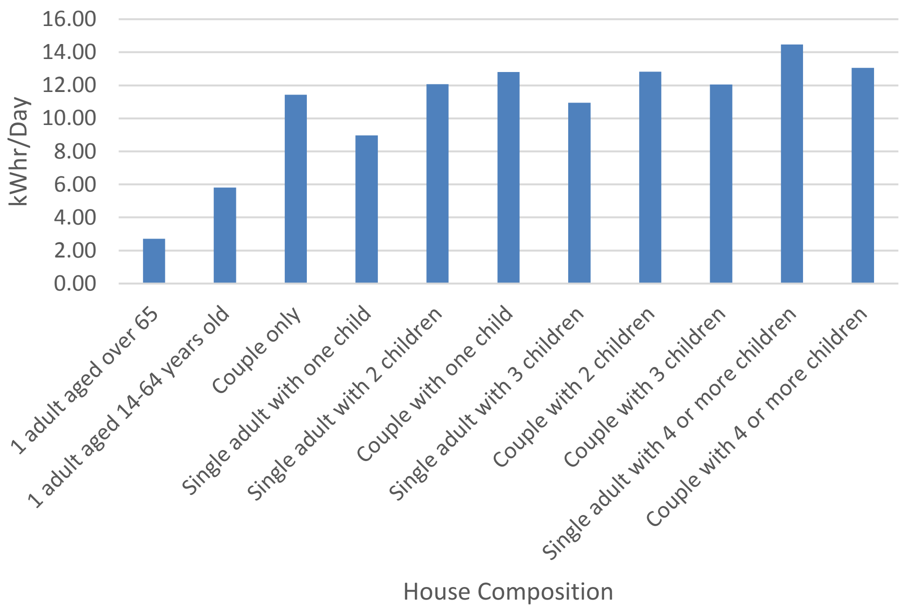


Figure 5.5: Average daily electricity usage of Dublin and Donegal housing based on house composition

5.6 Central Heating

Tenants of both estates were asked how often were the central heating devices used during the winter season (October-March) and the rest of the year (April-September). 100% of tenants in Dublin stated that pre-retrofit they had used their central heating every day during the winter heating season. This highlights the thermally poor condition the houses were pre-retrofit. 69.6% of the residents said the central heating had been used a few times a week, with 26.1% turning on the heating in the evening time only a few times a month for the summer months. This was expected given the high number of people complaining of drafts. The warm summer air would infiltrate through the house cavities during the day providing warmth, with the cooler evening temperatures and drafts causing residents to turn on the heating.

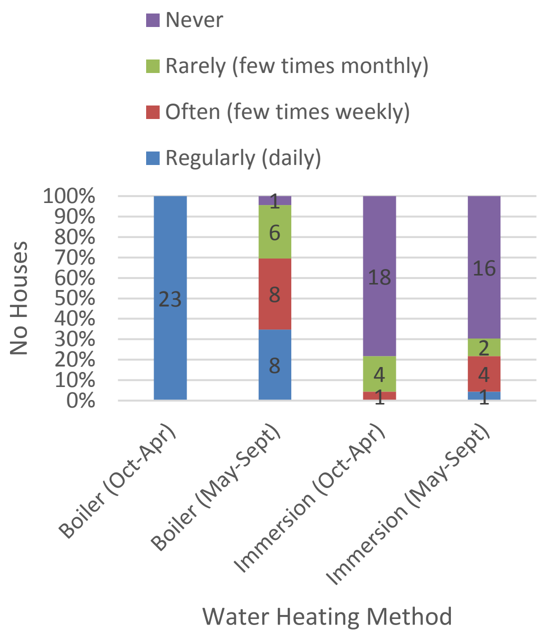
All of the Dublin houses had central heating boilers installed with a timer function. However, the residents of half of those houses preferred to manually operate their boilers either because they either did not know how the timer worked, the timer was broken or they preferred the manual mode. Almost all houses (except one) had the heating turned on for 1-2 hours in the morning time during the winter months. During the heating season those who had their heating set on a timer, the amount of hours it was scheduled to turn on during the day ranged from 4-9 hours, with the average time being 5 hours 38 minutes. Those who had used the manual mode stated that they had turned the heating on when it had been needed, resulting in the heating turned on during most of the day due to the cold.

All but one of the residences in Donegal used their central heating daily during the winter heating season. During the non-heating months, the behaviour of the residents of Donegal was different to the tenants of Dublin. 67% of the Donegal tenants rarely used their central heating, whereas 69.6% of the residents of Dublin used it a few times a week. All but two of the Donegal houses had the central heating boilers installed with a timer function. Five of these 13 houses (38.5%) used the timer function, with the remaining 8 houses preferring to operate the heating manually. The time the heating was scheduled to operate varied between 2-7 hours with the average time being 4 hours 12 minutes during the heating season.

5.7 Water Heating

100% of the investigated houses in Dublin used gas boilers to heat water during the winter months (Figure 5.6(a)). There was a discrepancy between the investigated houses on how often the gas boilers were to heat water in the summer. A significant number of people did not use the immersion boost to heat water during the summer (69.6%) and winter (78.3%) months. Those people often stated they considered it to be too expensive compared to using the gas boiler. Those who did use the immersion boost (few days a week or month), used it alongside the gas boiler.

The tenants in Donegal relied on the immersion more (Figure 5.6(b)) when compared to the Dublin tenants (Figure 5.6(a)). 60% stated they had used the immersion a few times a week all year round to heat the water. 13% and 27% of the tenants used the immersion daily during the winter and summer months, respectively.



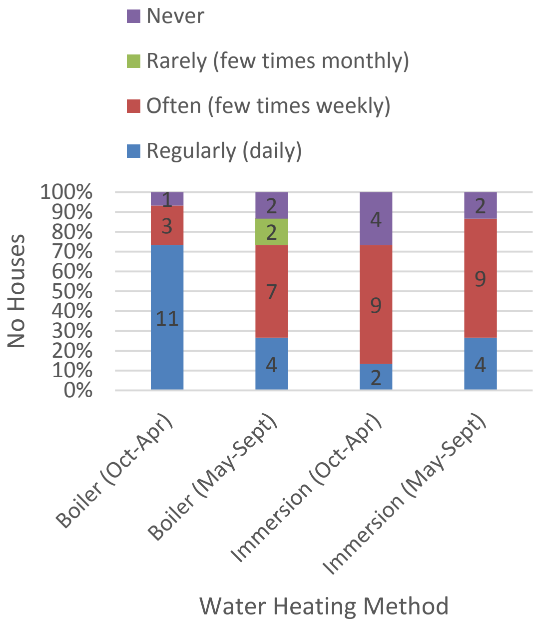


Figure 5.6(a): Residents typical water heating method of Dublin housing (left) and **Figure 5.6(b):** Residents typical water heating method of Donegal housing (right)

6. Conclusions

Retrofitting is recognised as the most immediate, pressing, and cost effective mechanism to reduce energy consumption and carbon emissions in the building and construction sectors. It is necessary to double or triple the current retrofitting rate to reach the EU short and long term goals of 20% energy reduction by 2020 and 80-95% CO_2 reduction by 2050. Boosting confidence in retrofitting buildings to a lower energy usage among all different stakeholders in the building value chain is essential for uptake of energy efficiency measures in the market. Technical interventions alone have lower impact and are more expensive to implement if carried out in isolation. Thus, it is necessary to investigate the behavioural habits and attitudes of people towards energy and carbon consumption and, if these are altered, to establish the energy savings that can be made.

There is a lack of published research into monitoring the effectiveness of case study building retrofits in order to reduce the energy consumption and GHG emissions using data logging instrumentation. Furthermore, it remains unclear whether the effectiveness of a retrofit strategy is more suitable for different habitants based on their demographic and socio-economic profiles. Moreover, an important question is whether the habitants of buildings would alter their energy consumption using tailored and effective engagement actions to motivate changes in their energy consumption behaviour. The proposed research adopts an innovative methodological design that combines engineering and social sciences expertise to address these gaps. Overall, the project will lead to the development of socio-technical innovations, including targeted action plans for households and communities to reduce their energy consumption.

With the monitoring of 20 additional buildings that will be retrofitted in the west of Ireland to begin at the beginning of 2016 along with the buildings currently monitored, this project will exploit the full-scale demonstrator retrofitted buildings, incorporating energy efficient technologies through the real-time monitoring, analysis, numerical modelling and interpretation of data. Monitoring the performance of houses with different retrofitting technologies and the impact of those technologies on the energy consumption, GHG emissions, occupancy comfort and health will help devise effective engagement actions that reduce possible rebound effects, resulting in lasting reductions in energy consumption in dwellings. Boosting confidence in the effectiveness of retrofitting efforts among various stakeholders in the building value chain, as well as altering consumers' views and practices, is essential for increasing the uptake of energy efficiency measures in the market. In order to achieve this, this project will:

- Compare predicted and observed energy consumption and GHG emissions of the buildings pre- and post- retrofit using Dwelling Energy Assessment Procedure (DEAP) software [13].
- Identify the most effective retrofitting measures, through the real-time monitoring, data analysis and numerical modelling, for various demographic and socio-economic groups with a set of renovation packages identified for the renovation of Ireland's building stock.
- Develop tailored engagement actions for different types of households to motivate lasting changes in consumers' energy consumption. This will be achieved through tailored surveys and interviews with the occupants and monitored energy consumption data to determine the effects of actions undertaken to reduce energy consumption.
- Identify key factors influencing the choice of retrofit strategies made by the house owners and propose incentives for the increased uptake in building retrofits.

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References

[1] UNEB SBCI, Buildings and Climate Change Summary for Decision Makers, United Nations Environment Programme Sustainable Buildings & Climte Initative, 2009.

[2] European Commission, Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings, Off. J. Eur. Communities. (2002) 65–71.

[3] European Commission, Directive 20/31/EC of the European Parliament and of the

Council of 19 May 2010 on the energy performance of buildings (recast), Off. J. Eur. Communities. (2010) 13–35.

[4] BPIE, Europe's Buildings Under the Microscope A Country-by Country Review of the Energy Performance of Buildings, Buildings Performance Institute Europe, 2011.

[5] European Commission, Energy Roadmap 2050 Impact assessment and scenario analysis, Brussels, 2011.

[6] Commission of European Communities, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions Limiting Global Climate Change to 2 degrees Celsius The way ahead for 2020 and beyond, Brussels, 2007.

[7] Irish Government, Better Buildings A National Renovation Strategy for Ireland, Department of Communications, Energy and Natural Resources, 2014.

[8] EEA, Achieving energy efficiency through behavioural change – what does it take ?, Luxembourg, 2013.

[9] NUIG, nZEB-RETROFIT: Achieving nearly zero-energy buildings, (2015) National University of Ireland, Galway. www.nzeb-retrofit.com (accessed October 9, 2015).

[10] Lavelle & Fahy, Consensus Lifestyle Survey: Background and methodology, Consumption, Environment and Sustainability, 2012. doi:10.1093/europace/eus256.

[11] A. Armstrong, Environmental life cycle assessment study of Irish residential buildings from an energy and carbon perspective, MEngSc thesis, College of Engineering & Informatics, National University of Ireland, Galway, 2013.

[12] CSO, Profile 4 The Roof over our Heads, Central Statistics Office, Dublin, Ireland, 2012.

[13] SEAI, Dwelling Energy Assessment Procedure (DEAP) - Irish Official Method for Calculating and Rating the Energy Performance of Dwellings., Sustainable Energy Authority of Ireland, 2007. http://www.seai.ie/Your_Building/BER/BER_Assessors/Technical/DEAP.