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How accurate are Energy Performance Certificates indicated energy savings of building retrofits?

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ABSTRACT: With the impending nearly zero energy building (NZEB) regulations for residential new builds and retrofits for the European Union (EU) housing stock and the percentage of new buildings relative to existing buildings is increasing at a rate of only 1% per year, retrofitting is recognised as the most immediate, pressing and cost effective mechanism to reduce energy consumption and carbon emissions in the building and construction sector. Currently, an Irish residential building Energy Performance Certificates (EPC) indicates the estimation of a buildings' annual energy usage that is assessed by the Dwelling Energy Assessment Procedure (DEAP). DEAP is the standard method for assessing the energy savings that are made by a residential building through retrofitting its technical characteristics to greater energy efficiency standards. This paper presents the pre-retrofit DEAP results of a sample set of urban social houses in Ireland and compares them to the actual energy usage of the houses highlighting the limitations of DEAP in estimating the pre-retrofit energy usage of the sample set of urban social housing. As many Irish government policies promoting the uptake in residential buildings base their energy savings on DEAP, the need for a more robust assessment procedure for determining the impacts retrofitting a building to a higher energy standard is discussed in addition to the need for engineers to start understanding the behaviour and attitudes towards energy consumption of the people living inside them in order to develop a holistic retrofit design that incorporates both technical and behavioural interventions.

KEYWORDS: Energy performance, Energy Performance Certificate, energy demand, occupant behaviour

1   INTRODUCTION

The Energy Performance Building Directive (EPBD) introduced legislation whereby all EU member states were required to introduce a standard assessment procedure for the energy performance certification of new and existing buildings in their respective countries [1]. The assessment procedure generally includes an analysis of the buildings (i) form, (ii) thermal, solar and daylight properties of the building envelope, (iii) air permeability, (iv) space, water heating and ventilation systems, (v) fixed lighting and (vi) fuel and renewable energy sources. These variables are assessed under standard occupancy and climatic conditions of the respective country [2]. As such, the assessment procedure does not capture the impact of human behaviour, including the consumption of household appliances.

The Energy Performance Certificates (EPCs) are seen as a tool for providing clear and reliable information to homeowners and tenants to compare and assess the energy performance of buildings [3], encourage owners to invest in improving the energy efficiency of the building through the provision of cost effect retrofit measures [3] and assist governments in developing policies to achieve national energy reduction targets in the building sector [2].

The Sustainable Energy Authority of Ireland (SEAI) maintains a register of Irish residential building EPCs, termed BERs [4]. The energy performance of a building is rated on a simple scale of A1 to G. An A1 rated dwelling equates to the most operational energy efficient building. The primary energy consumption in a building of A1 and G ratings are 25 kWh/m^2/year and 450 kWh/m^2/year, respectively. In total 633,972 BER's have been completed on Ireland's residential building stock [5]. The most common BER rating of Irish residential houses is a D1 for which the energy usage requirement ranges from 200 to 225 kWh/m^2/year. The Dwelling Energy Assessment Procedure (DEAP) software is used to produce a BER [4]. DEAP is based on the European Standard IS EN 13790:2004 [6] and draws heavily on the UK's Standard Assessment Procedure (SAP) [7]. Further details can be found in [4].

The accuracy of EPCs for indicating the energy usage of residential buildings has been questioned in several studies in EU countries [8]–[13]. A Greek study found there to be on average a 44% lower energy usage in 8500 residential buildings compared to the theoretical energy usage according to these buildings EPCs [8]. A Dutch study of around 200,000 dwellings comparing the theoretical energy usage of their EPCs and actual energy usage found houses with higher energy performance ratings to be more accurate compared to houses with lower ratings for estimating their space and water heating requirements [10]. The houses with the poorest energy rating (G) used theoretically twice as much energy compared to what they actually consumed.

Similar to the findings of the Dutch study [10], an Irish study on the oil consumption of 142 houses pre-retrofit found that houses with a lower EPC were poorer predictors of the households oil consumption. This study found the houses on average to use 41% less energy compared to the theoretical usage estimated by the buildings DEAP [12]. Based upon the

post-retrofit data collected in this study, some of the main reasons for this difference is believed to be due to the estimated internal temperatures of the houses using DEAP compared to the actual temperatures and the underestimation on the usage of the secondary heating systems in the households.

With the impending nearly zero energy building (NZEB) regulations for residential new builds and retrofits for the European Union (EU) housing stock [14] and the percentage of new buildings relative to existing buildings is increasing at a rate of only 1% per year [15], retrofitting is recognised as the most immediate, pressing and cost effective mechanism to reduce energy consumption and carbon emissions in the building and construction sector [16].

There are currently many Irish governmental policies/schemes focused on promoting the uptake in residential building retrofits [17]. Currently DEAP, which produces a BER, is the standard method for assessing the energy savings that are made by a residential building through retrofitting its technical characteristics to greater energy efficiency standards and forms the basis for assessing the savings of various Irish government policies/schemes for promoting the uptake in residential building retrofits [17].

One of these schemes is known as Better Energy Homes. The scheme provides householders who want to make their homes more energy-efficient by providing incentives for the installation of energy efficiency measures [17]. An analysis on the effectiveness of 256 houses who received a grant through this scheme showed an estimated 21% reduction in their gas demand. However, the results estimate a shortfall of between 28-44% in the actual energy savings compared to the theoretical results based on their BER information [13].

As current policies are aimed at promoting the upgrade of houses for the most vulnerable (low-income households, social housing tenants, old people) [17], this paper aims to assess how accurate is DEAP for estimating the energy usage of urban social housing. This paper presents the pre-retrofit DEAP results of a sample set of urban social houses in Dublin and compares them to the actual energy usage of the houses. The limitations of DEAP in estimating the pre-retrofit energy usage of the sample set of social housing and the need for a more robust assessment procedure for determining the impacts retrofitting a building to a higher energy standard are discussed in addition to the need for engineers to start understanding the behaviour and attitudes towards energy consumption of the people living inside them in order to develop a holistic retrofit design that incorporates both technical and behavioural interventions.

This forms part of a research study whereby the temperature, relative humidity and energy usage profiles of 23 social houses in Dublin are being monitored pre- and post-retrofit using data logging instrumentation at high resolution in addition to examining the demonstrator buildings tenant (1) demographic profiles, (2) socio-economic status, (3) behaviour and attitudes towards energy consumption, energy conservation, the environment, environmental responsibility, thermal comfort, (4) views of quality of life and (5) what they consider to be a luxury and necessity in their life.

2 METHODOLOGY

The aim of this research project is to monitor the actual energy usage and greenhouse gas emissions of residential retrofit projects pre- and post- retrofitting works using data logging instrumentation for the temperature, relative humidity and energy usage profiles to determine the actual improvements achieved by retrofit works. Furthermore, information in relation to the behaviour and attitude of the building's habitants towards energy and greenhouse gas emissions, quality of life and thermal comfort within their homes is collected through face-to-face qualitative interviews and a questionnaire survey. Combining the data collected on energy consumption, temperature profiles of individual rooms, thermal comfort surveys and findings from occupant surveys will allow the most effective measures to be identified that consider the profiles of both the physical building and its occupants.

2.1 Survey Design

The questionnaire survey used in this study built on an existing lifestyle survey developed by researchers as part of the CONSENSUS Project [18]. CONSENSUS (Consumption, Environment and Sustainability) was a seven-year collaboration (2009-2015) between the National University of Ireland, Galway and Trinity College Dublin that investigated behaviours and attitudes in four key areas of household consumption (transport, energy, water and food). The CONSENSUS Lifestyle Survey, a key element of CONSENSUS, involved the collection and analysis of data from 1,500 households in Counties Derry/Londonderry, Dublin and Galway. To ensure maximum comparability with CONSENSUS data, questions from the CONSENSUS Lifestyle Survey are being used again in this project.

2.2 Data Instrumentation

In order to monitor the influence retrofitting works have on the energy use and thermal comfort of the residents, temperature and relative humidity data logging instrumentation is installed in each of the participating buildings. There are four/five temperature and relative humidity data loggers installed in each house with data recorded at 15 minute intervals. One data logger is installed in the kitchen and living areas and in two/three separate bedrooms. Electricity usage profiles are monitored using data logging instrumentation with data recorded at 1-60 minute intervals. Oil usage profiles are monitored using data logging instrumentation with data recorded at 60 minute intervals. Household electricity and gas meters are read once a month in addition to oil levels in oil tanks. Tenants are also asked to keep a diary record of their solid fuel usage.

2.3 BER Survey

Information is gathered with regards to the building's dimensions, orientation, thermal envelope characteristics, space, water heating and ventilation systems, internal lighting, renewable energy sources and fuel sources. Using the DEAP software [4], this information is used to determine a BER rating for a residential building under standard occupancy conditions and typical Irish climate conditions to estimate the

annual energy consumption and carbon emissions required to operate the building.

3   CASE STUDY

The social housing estate in Dublin involved in the study is located in a suburb area of Dublin, Ireland. The estate was constructed in two phases. The first phase in 1994 which consisted of 16 end-terraced (ET) houses, 16 mid-terraced (MT) houses and 14 apartments. The ET and MT houses are two-storey buildings with a total of six rooms in each of the buildings. These six rooms are divided into three bedrooms and individual kitchen, living and bathroom spaces. The apartments are not involved in the study.

An additional 30 residences – 12 ET houses, 12 MT houses and 6 semi-detached (SD) houses were constructed in 2000. Each building has two storeys with a total of seven rooms: three bedrooms, two bathrooms and individual kitchen and living spaces. 23 of the 62 households contacted in the estate agreed to participate in the study. Each of the different house construction types encountered in the Dublin study are shown in Figure 1(a)-(c).

Figure 1(a) MT and ET houses constructed in 1994, Figure 1(b) MT and ET houses constructed in 2000 and Figure 1(c) SD houses constructed in 2000

In the houses constructed in 1994, the walls of the buildings were mainly solid walls constructed using cavity blocks with interior timber battens and dry-lining plasterboard (u-value: 1.28 W/m^{2}K). A section of the exterior wall on the ground floor adjacent to the living room was constructed with cavity wall construction. This cavity was empty (u-value: 1.65 W/m^{2}K). The windows of the houses were PVC framed (u-value: 3.1 W/m^{2}K) with mineral wool insulation in between the joists of the attic (u-value: 0.4 W/m^{2}K).

The exterior walls of the houses constructed in 2000 were built using cavity wall construction with an exterior façade of either red brick or blockwork, plaster and paint. The cavity of these houses was partially filled with 60mm expanded polystyrene insulation (u-value: 0.45-0.46 W/m^{2}K). The windows of the houses were wooden framed (u-value: 3.1 W/m^{2}K) with mineral wool insulation in between the joists of the attic (u-value: 0.4 W/m^{2}K).

Table 1 details the year of construction, house type and u-values of the building elements assumed in the DEAP analysis of the participating residences in the study. The u-values of the wall construction types were determined using the wall u-value calculation method given in the current Irish building regulations with the typical u-values of the materials taken from the current Irish building regulations [19] and DEAP [4]. The default u-values from DEAP for double glazed PVC and wooden frame windows are used for the windows. The default u-values for the floor and roof (100mm of mineral wool) are also taken from DEAP.

Table 1 Breakdown of the houses involved in terms of their year of construction, house type and u-values of the building elements assumed in the DEAP analysis

Construction Year	House Type	U-Value (W/m^{2}K)					Total
		Wall	Wall	Window	Roof	Floor	
1994	MT	1.28	1.65	3.1	0.4	0.44	4
	ET	1.28	1.65	3.1	0.4	0.44	7
2000	MT	0.46	0.45	3.1	0.4	0.44	4
	ET	0.46	0.45	3.1	0.4	0.44	5
	SD	0.46	0.45	3.1	0.4	0.44	3

The main space heating systems in all the Dublin residences comprised of a gas-fired boiler as a central heating system with radiators in each of the rooms of the house. The boiler types in the households varied as some of the original boilers installed had been replaced over time. The efficiency of the different gas boiler types (main space heating) are given in Table 2 for the different construction types examined in this analysis. Also included in Table 2 are the efficiencies of the different secondary space heating systems employed in the buildings. Either a solid fuel open fire (30% efficiency), solid fuel stove (65% efficiency), gas fire (76% efficiency) or electric fire (100% efficiency) acted as a secondary heating system in the living room. The efficiencies of the secondary heating system are the default values used in DEAP.

Table 2 Efficiencies of the different main space heating (gas boiler types) and secondary space heating systems for the different house types examined in the DEAP analysis.

Space Heating Efficiency (%)		House Type					
Main	Secondary	MT 1994	ET 1994	MT 2000	ET 2000	SD 2000	Total
77	30	0	0	2	1	0	3
77	65	0	0	0	0	1	1
77	76	0	0	1	0	0	1
77	100	0	0	1	1	1	3
78.8	0	1	0	0	0	0	1
78.8	30	1	0	0	0	0	1
78.8	76	1	1	0	0	0	2
78.8	100	1	1	0	0	0	2
90.3	30	0	2	0	0	1	3
91.3	100	0	0	0	1	0	1
	Total	4	4	4	3	3	18

The gas-fired boiler was also the main system used for providing hot water heating in the houses. The hot water was stored in a hot water tank after being heated by the gas-fired

boiler. There is also an electrical immersion available to heat the water in the hot water tank. The study in Dublin is currently on-going with the monitoring of the buildings beginning in February 2015. The buildings underwent retrofitting works to improve their thermal envelopes and heating systems. The works were complete in October 2015.

3.1 DEAP Scenarios

DEAP assessments of each of the houses involved in the study were carried out before and after the retrofitting upgrade works. Two different pre-retrofit DEAP scenarios are evaluated for 18 of the houses in this analysis. The first scenario is where each house is evaluated as if it were being evaluated as standard. Thus in this scenario, the solid fuel and gas secondary space heating systems are assumed to account for 10% of the houses space heating requirements and the electrical secondary space heating systems are assumed to account for 20% of the houses space heating requirements, as assumed in DEAP. The gas-fired boiler acts as the primary space and water heating system and is assumed to provide the remaining space and water heating requirements for the building. The second scenario takes into account the actions of the people living inside the buildings. Therefore, if the residents reported in the survey carried out that they never use their secondary space heating system, it is assumed to account for 0% of the space heating requirement of the building. If it was reported that they use their secondary space heating system, the same percentages for the different heating systems as described for scenario one are applied. Also, if they reported that they use their electrical immersion for water heating, it is assumed that 33% of the energy required to provide hot water was provided by the immersion, as assumed in DEAP. The gas-fired boiler acts as the primary space and water heating system and is assumed to provide the remaining space and water heating requirements for the building.

3.2 Gas and Electricity Meter Data and Estimations

As there is only data available from February 2015 to July 2015 of the houses electricity and gas usage pre-retrofit, estimations are made based on this data in order to compare to the results of the DEAP evaluations.

The gas and electricity meter readings were recorded at seven different intervals from the 12th of February to the 22nd July at least once a month. As the main space and water heating system of the houses use gas, the gas usage of the houses is assumed to be related to the external temperature. The average daily gas usages between the dates the meters were read are normalized using the average external daily temperatures recorded at Dublin Airport [20] (located with 11km of the estate) between the meter read dates. Linear interpolation is then used to estimate the average daily gas usage for each of the 12 months of the year based on the average external daily temperature recorded at Dublin Airport during each of the months. Using the number of days each month of the year has together with the estimated average daily usages for each of the months, the total yearly gas usages of the houses are calculated.

Unlike the gas usage of the houses, the electricity usage cannot be linked to the average daily temperature for the months with unknown data. Apart from February, each of the

intervals the electricity meter readings were taken at accounted for at least two thirds of the month's electricity usage. Thus, the average daily electricity usage during these intervals, including February, is assumed for the entire month and multiplied by the number of days of each month to give the total electricity consumption. For the remaining days of the year with no electricity usage data (1st January to the 31st January and 1st August to the 31st December), the average daily usage of the respective houses from the 12th February to the 22nd of July is determined and used as the electricity consumption for the remaining days of the year with no available data.

4 RESULTS AND DISCUSSION

The total annual primary energy consumption results of the two DEAP scenarios evaluated and BER rating for the 18 different houses are given in Table 3 together with the total primary energy consumption based on the collected meter data from the houses and the estimations made based on this data as described in section 3.2. The average of the two DEAP scenarios are within 9% of the estimates based on the gas and electricity meter readings for the MT and ET houses constructed in 1994 and 2000. The DEAP assessments of the SD houses are on average the least accurate in comparison to the meter data and estimates data. The standard deviation of the total consumption for each of the house types is larger for the meter readings and estimates compared to the two DEAP scenarios. This highlights the variability that the behaviour of the people in the households can have on the energy consumption that DEAP does not account for.

The house with the highest energy consumption difference between the DEAP scenarios and the meter readings and estimates is a SD house constructed in 2000. Based on the one on one surveys conducted within each of the households, there is a couple and three children (two under 14 years old and one between 18-25 years old) who live in this house and have the second highest annual income of the houses involved. This house also has the overall highest energy consumption based on the meter readings and estimates. This is despite having one of the most efficient gas boilers of all the houses (90.3%) and achieving the sixth best DEAP result in DEAP scenario one and two. Based on the measured annual consumption of this household (384 kWh/m^2/yr.), it would achieve a BER of F which is the second worst rating a house can achieve. This however includes the impact that household appliances have on the energy consumption of the house which is not included in a DEAP.

The house with the lowest energy consumption based on the meter readings and estimates is a house with a single mother and one child who live in an ET house constructed in 2000 and have the lowest annual income of the houses involved in the study. This is despite achieving the tenth and seventh best DEAP result in DEAP scenario one and two. Based on the measured annual consumption of this household (157 kWh/m^2/yr.), it would need to reduce its energy consumption by only 7 kWh/m^2/yr. to be considered a NZEB building for existing buildings even before it has been retrofitted [21].

On average, the second DEAP analysis is more accurate in estimating the overall energy consumption of the houses constructed in 1994 compared to the meter data whereas the

Table 3 Total annual primary energy consumption results and BER ratings of DEAP scenario one and two and the collected meter data and estimations made for the 18 houses

	DEAP Assessment (Scenario 1)		DEAP Assessment (Scenario 2)		Meter Data and Estimations
	Total (kWh/ m²/yr.)	BER Rating	Total (kWh/ m²/yr.)	BER Rating	Total (kWh/m²/yr.)
House Type	Mid Terrace 1994				
	239	D1	239	D1	247
	266	D2	247	D1	200
	237	D1	237	D1	271
	257	D1	246	D1	311
Avg.	**249**		**242**		**257**
Std Dev.	**14**		**5**		**46**
House Type	End Terrace 1994				
	287	D2	253	D1	193
	292	D2	259	D1	320
	303	E1	288	D2	363
	282	D2	282	D2	222
Avg.	**291**		**270**		**274**
Std Dev.	**9**		**17**		**80**
House Type	Mid Terrace 2000				
	198	C2	198	C2	172
	187	C2	192	C2	170
	208	C3	208	C3	257
	198	C2	183	C2	258
Avg.	**198**		**195**		**214**
Std Dev.	**8**		**10**		**50**
House Type	End Terrace 2000				
	195	C2	179	C2	340
	225	D1	207	C3	157
	222	C3	214	C3	198
Avg.	**214**		**200**		**232**
Std Dev.	**17**		**19**		**96**
House Type	Semi-Detached 2000				
	202	C3	202	C3	384
	197	C3	202	C3	208
	223	C3	210	C3	175
Avg.	**207**		**205**		**256**
Std Dev.	**13**		**5**		**112**
	All Houses				
Avg.	**234**		**225**		**247**
Std Dev.	**38**		**33**		**71**

first DEAP analysis is more efficient in estimating the overall energy consumption of the houses constructed in 2000 compared consumption to the meter data.

Based on the average energy consumption of all the houses, one could say that DEAP is accurate in estimating the annual energy consumption of the houses. However, when examining the estimated gas, electricity and solid fuel usage of the households in both the DEAP scenarios in comparison to the meter data and estimations, one can see that this statement does not hold true. The over estimation of DEAP in relation to the gas usage of the buildings compensates for its underestimation in electricity usage by not accounting for the appliance usage by the households and assuming standard electricity requirements for the building's lighting, heating system pumps and ventilation fans.

In terms of gas usage, the house type which has the smallest difference between the two DEAP scenarios and the meter data is the SD households. On average, DEAP scenario one uses 28% more gas per annum compared to what the house type actually uses. This however increases to 41% when comparing it to scenario two. The least accurate of the house types analysed are the MT houses constructed in 1994. DEAP scenario one and two estimates the house type uses 69% and 70% more gas per annum compared to the meter data and estimations annual usage. Based on the averages of all the houses, DEAP scenario one and two estimates the house types use 41% and 45% more gas per annum, respectively, compared to the meter data and estimations annual usage. Both houses with the highest and lowest total yearly energy consumption based on the meter data also have the highest and lowest total yearly gas consumption.

As expected the total electricity consumption based on the meter data is significantly larger compared to what both the DEAP scenarios estimate as a DEAP does not account for the energy consumption of household appliances. The house type with the largest difference is the SD houses constructed in 2000. DEAP scenario one and two estimate the houses use 25% and 21% of what the houses actually use according to the meter readings and estimations, respectively. The house with the lowest electricity consumption is an ET house constructed in 1994. A retired couple lives in this household. Both DEAP scenario one and two estimate 21% of what the house actually uses based on the meter data.

Based on the averages of all the houses, DEAP scenario one and two estimates the house types use 31% and 28% of the electricity that the houses actually use according to the meter data and estimations, respectively. Thus, assuming that the electricity accounted for by DEAP for the building's lighting, heating system pumps and ventilation fans is accurate, a DEAP may not account for up to 72% of its electricity use which is more than twice the 30% which has been previously estimated [12].

However, as stated only 6 months of monitored electricity data is available in this analysis. For the remaining days of the year with no electricity usage data (1st January-31st January and 1st August-31st December), the average daily usage of the respective houses from the 12th February to the 22nd of July is determined and used as the electricity consumption for the remaining days of the year with no available data. There are obvious limits associated with this method as electricity usage habits of people generally alter between the winter and summer months. Internal lighting is used more during the winter months due to less daylight. Also during the summer

Table 4 Average and standard deviation gas, electricity and solid fuel primary energy usage of the house types for DEAP scenario one and two and the meter data and estimations

	DEAP Scenario 1 (kWh/yr.)				DEAP Scenario 2 (kWh/yr.)				Meter Data and Estimations (kWh/yr.)			
	Gas	Electricity	Solid Fuel	Total	Gas	Electricity	Solid Fuel	Total	Gas	Electricity	Solid Fuel	Total
House Type	Mid Terrace 1994											
Avg.	15339	2608	734	18680	15471	2671	0	18143	9050	10236	0	19286
Std Dev.	1179	1889	1467	1054	923	1314	0	394	1893	1880	0	3459
House Type	End Terrace 1994											
Avg.	17174	2688	1945	21806	18237	2026	0	20263	12502	8055	0	20557
Std Dev.	1831	1999	2246	581	1158	876	0	1107	3276	3450	0	6027
House Type	Mid Terrace 2000											
Avg.	13248	2762	1139	17149	12893	3430	589	16911	9366	9199	0	18565
Std Dev.	794	1424	1317	727	1045	1719	1179	901	2594	2182	0	4314
House Type	End Terrace 2000											
Avg.	13418	4238	881	18536	14610	2721	0	17331	10527	9543	0	20070
Std Dev.	1625	1768	1525	1442	1143	1006	0	1616	4901	3527	0	8313
House Type	Semi-Detached 2000											
Avg.	13760	2889	1321	17969	13971	2452	1321	17744	10698	11471	0	22168
Std Dev.	805	2100	1389	1169	1982	899	1389	431	8718	1405	0	9731
House Type	All Houses											
Avg.	14699	2978	1215	18892	15119	2668	351	18138	10408	9611	0	20019
Std Dev.	1953	1777	1510	6281	2226	1210	855	6719	4150	2564	0	5516

months, certain appliances which use a large amount of electricity, for example a tumble dryer, may be used less due to the warmer weather.

With regards to DEAPs underestimation of the building gas requirements, one has to account for the limitations associated with some of the assumptions used in the DEAP analysis. Default values for the building's window, floor, and roof u-values and secondary space heating systems are taken from DEAP. The airtightness of the buildings involved in the analysis are assessed using the DEAP software and may not reflect the real air tightness of each of the buildings analysed. A default thermal bridging factor of 0.15 W/m²k is also assumed in the analysis. These assumptions can have a large impact on the space heating requirements of a building with some recommending the revision of current default u-values for better accuracy [22]. These are also common assumptions taken when evaluating an existing building's BER due to the unavailability of information on the buildings technical characteristics. The standard occupancy of a household is assumed to be 2.27 in the DEAP analysis. The average occupancy of the 18 houses is 3.94 with only five of the 18 houses containing three people or less. Due to the small sample size, it is not possible to determine whether having less people in the household effects the actual energy usage of the household.

5 CONCLUSIONS

The DEAP assessed as standard (scenario 1) and DEAP taking into account occupant actions (scenario 2) for a sample set of urban social housing in Dublin on average underestimates the gas usage of the houses by 41% and 45%, respectively, compared to actual gas consumption. Currently DEAP, which produces an Irish residential EPC that indicates an estimation of a residential buildings' annual energy usage, is the standard method for assessing the energy savings that can be made by a residential building through retrofitting its technical characteristics to greater energy standards. DEAP forms the basis for assessing the savings of various Irish government policies/schemes for promoting the uptake in residential building retrofits [17]. While current retrofits schemes for low-income households assume a 70% take back for comfort/rebound effect [17], the inaccuracies of DEAP in estimating energy usage of pre-retrofit social housing highlighted in this paper and the inaccuracies of EPCs in indicating the actual energy savings highlighted in other studies discussed, suggests estimated energy savings made by Irish government policies using DEAP may not come to pass and also prohibit homeowners from investing in more energy efficiency measures.

Thus, there is an urgent need to develop a more robust standard assessment procedure for assessing the energy savings that can be made through retrofitting the technical characteristics of a residential building to greater energy standards. However, monitoring the energy usage profiles of a household pre- and post-retrofit is not sufficient in determining the overall improvements that have been made.

For instance, based on the currently limited available post retrofit gas usage data of the Dublin social housing, no energy

savings were made in the household with the lowest gas usage. This house had temperatures of 18°C or less during February and March of 2015 before the retrofitting works. As the tenants were living in poor thermal conditions, they probably experienced a benefit of improved thermal conditions rather than energy reductions. This phenomenon, known as the rebound effect, has been estimated to offset energy savings by 30% [23].

With the number of retrofit measures homeowners have applied for grant aid in Ireland falling steadily since 2009 [24], homeowners may be more enticed to invest in retrofit measures if given more of a net benefit feedback on how their homes have improved due to a retrofit upgrade. This net benefit feedback could include information on not only the energy cost savings made by their retrofit upgrade but also the improvements to their internal environment and health benefits associated with these improvements.

The high variability of actual energy consumption, based on the collected readings from the electricity and gas meters, highlights the influence the people living in households have on energy consumption. Engineers need to start understanding the behaviour and attitudes towards energy consumption of the people living inside them. Once the main social norms and energy practices influencing their energy consumption behaviour, such as what people perceive to be a comfortable internal environment, typical indoor choice of clothing, people's attitudes regarding luxuries and necessities of housing items/appliances are understood, the feedback given to the tenants on the net benefits the technical interventions have can be complimented by behavioural interventions which focus on negating the impact the tenant's behavioural consumption habits are having on their energy consumption

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