Developing building archetypes for electrical load shifting assessment: Analysis of Irish residential stock

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Abstract
Appropriate use of demand side management (DSM) strategies in residential buildings, when placed in a smart grid environment, can help reduce power supply-demand mismatches by shifting electrical loads, thus leading to better integration of renewable energy sources, particularly wind and solar generation. In the current paper, detailed building energy simulation models of residential stock are developed, using an occupant focused approach. Five archetypes are considered over three construction periods, representative of about 82% of the Irish building stock. The archetype models were found to be accurate to within 10% of the Irish standards, as exemplified using the Dwelling Energy Assessment Procedure (DEAP), for space and water heating energy requirements. The proposed approach was found to be more accurate than DEAP to estimate the electricity consumption. By integrating high resolution models for occupancy and electrical equipment use, it can generate more accurate models of the housing stock and expands previous investigations to include occupant behaviour, electrical load shifting and thermal comfort issues.

Keywords Demand side management, building energy simulation, residential buildings, time-of-use, human behaviour, smart grid, thermal comfort.

1. Introduction

1.1 Policy and targets

As a result of poor building energy performance, the building sector represents the largest energy-using sector and one of the most significant emitters of CO_2 in the EU at present, with residential buildings alone accounting for just over two-thirds of this energy consumption. EU Member States have been mandated through the Energy Performance of Buildings Directive (EPBD) [***i***] to introduce a methodology to calculate the energy performance of buildings and to specify a series of reference dwellings representative of the national building stock. Through the Directive 2009/28/EC [***ii***] on the promotion of energy use from renewable sources, EU Member States have also been mandated to reach an overall European level of 20% of total energy consumption derived from renewable energy sources (RES) by 2020. In Ireland, which is taken as a case study in this paper, a target of 16% was originally required, which, in 2009 was further increased to 40% of total electricity consumption [***iii***]. As for any EU country, the Irish residential sector has a key role to play in order to meet these targets.

1.2 Response of the residential sector

The Irish direct response to the EPBD requirements is the dwelling energy assessment procedure (DEAP) methodology, which calculates the energy use intensity (EUI) and CO_2 emissions of a given dwelling, enabling the publication of building energy rating (BER) certificates. The DEAP methodology is used by the Irish government in the "Cost Optimal Calculations and Gap Analysis for recast EPBD for Residential Buildings" report [***iv***], whereby five Irish reference buildings are identified and their energy and environmental performances are assessed, as well as the performance of retrofit measures in terms of energy and cost efficiency.

Due to the variable and uncertain nature of RES, particularly wind and solar generation, the U.S. DOE [***v***] recognized that their integration requires more flexibility from the power system. One possible strategy is to utilize demand side management (DSM) strategies, altering the customer's electricity use or pattern of use. Quantification of DSM potential, especially for residential buildings, leads to several challenging issues: wide range of electricity usage patterns, variability of electrical loads, and uncertainty regarding human behaviour. Furthermore, stricter energy efficiency regulations, the integration of new load types, and the increasing electrification of space and water heating loads, as anticipated by the IEA [***vi***], challenge the assessment of the associated flexible load resource capacity.

1.3 Modelling of the residential sector

The use of simulation tools to analyse energy and electricity demand of residential buildings, in order to assess their energy performance and potential flexibility resource for the implementation of DSM strategies, provides an approach by which the aforementioned uncertainties and challenges can be addressed.

Dineen & Ó'Gallachóir [***vii***] classify building energy and electricity demand models into two categories: top-down and bottom-up approaches. The former use total energy or electricity consumption estimates to assign them to the characteristics of the building stock, while the latter calculate individual dwelling energy or electricity consumption and extrapolate these results over a target area or region. Paatero and Lund [***viii***] argue that top-down models are more suitable for demand forecasting at a utility level, as they require less detail about the electricity demand at the building level with individual end-use usually not distinguished. On the other hand, by aggregating individual end-use loads or groups of end-use loads, bottom-up approaches are capable of generating very detailed energy or electricity demand profiles. These models are complex and data intensive, but are very useful in identifying the individual end-use contribution to the overall energy or electricity consumption of the residential building stock [***ix***].

Richardson *et al.* [***x***] emphasize that analysis of DSM in the domestic sector requires detailed and accurate knowledge of household consumer loads. Accordingly, several bottom-up building energy or electricity demand models have been developed to study domestic loads with high time resolution [***xi***] [***xii***] and with high spatial resolution [***xiii***]. These models are usually based on time-of-use survey (TUS) data in order to extract the behavioural patterns of building residents, in terms of occupancy and use of electrical appliances. However, all of the above ignore the assessment of the thermal comfort of residents and each building model is representative of a single dwelling only, complicating the task of scaling outcomes to a national dwelling stock level.

The development of archetype models, being representative of a group of dwellings and dwelling loads, allows modelling and simulation of the performance of building stock as a whole. Moreover, this approach complements a power system perspective on the aggregated flexibility potential offered by residential dwellings through the implementation of DSM strategies, as emphasized by Ma *et al.* [***xiv***]. In the past decade, Johnston [***xv***], in a general context, and Corgnati *et al.* [***xvi***], in the specific context of the EPBD, have detailed the data collection requirements for the development of archetype energy models. The latter classifies such data into four categories, namely the form, envelope, system and operation of buildings, which includes the occupancy patterns and energy consumption of domestic loads related to resident behaviour, such as lighting equipment, domestic hot water (DHW) demand, ventilation needs and electrical appliances. In an Irish context, the archetypes developed by Famuyibo *et al.* [***xvii***], and the more recent set of reference dwellings proposed by the DECLG and the SEAI, have standardised the occupancy patterns themselves and the operational variables influenced by occupants, thus partially fulfilling the data collection requirements [***xvi***]. Furthermore, it has been recognised that standard assessment procedures such as DEAP have limitations, including the inability to account for occupancy variations and usage of appliances [***xviii***]. In addition, concerns have been expressed with regards to the ability of DEAP to capture the energy performance of Irish dwellings on a national scale due to standardised assumptions for electricity consumption, DHW demand, climatic data, heating periods and times, and indoor temperature setpoints.

1.4 Our contribution and approach

The set of EPBD Irish reference dwellings is modelled in detail using EnergyPlus and converted into simulated archetypes, by integrating high space and time resolution models for occupancy, electrical appliance use, lighting, DHW demand and natural ventilation, thus taking into account resident behaviour. From the four subsets described by Corgnati *et al.* [***xvi***], the form, envelope and system of the archetypes are in line with the “Cost Optimal” report [***iv***]. The operational data subset is built upon the bottom-up approach proposed by Neu *et al.* [***xix***], which specified the necessary operational data with a high space-time resolution to be used as inputs: Markov chain Monte Carlo techniques are applied to the 2005 Irish National Time-of-Use Survey [***xx***] activity data to develop activity-specific profiles for occupancy, disaggregated appliance and lighting electricity use, and is extended to DHW demand profiles. Combining that TUS activity-specific approach with the outcomes from Dutton *et al.* [***xxi***] and Peeters *et al.* [***xxii***], a domestic natural ventilation and thermal comfort model is implemented within the EnergyPlus Energy Management System (EMS) module.The models are calibrated and validated against the DEAP methodology, in terms of annual electricity, space and water heating requirements and daily DHW demand. Discrepancies are highlighted and discussed to show the limitations of the DEAP methodology. Finally, the capability of the archetypes to investigate, at national scale, issues related to electrical load shifting and thermal comfort are demonstrated by applying a load shifting strategy.

2. Development of archetypes

The set of EPBD Irish reference dwellings is modelled using EnergyPlus, developing the required operational data to convert it into a set of building archetypes.

2.1 Physical description

Table 1 summarises data describing the two building categories, further divided into five dwelling types and considered over three different construction periods, namely new dwellings and existing dwellings with either uninsulated cavity or hollow block walls. Conditioned total floor area (TFA) is also given, as well as the window to wall ratio on each façade and the share of the Irish residential building stock represented, according to the Irish 2011 census data [***xxiii***]. The set of archetypes is representative of approximately 82% of the Irish national dwelling stock. The main geometrical characteristics, construction types and materials, infiltration levels and the heating system types and control are similar to the DECLG report [***iv***], and adapted from the Irish building regulations for both new and existing buildings, as described in Table 1 [***xxiv***]. The number of rooms, layouts and floor plans are adapted from representative dwellings defined by Brophy *et al.* [***xxv***]. Figure 1 shows the SketchUp drawings of each archetype.

Table 1 – Details of the Irish archetypes

Building category	Dwelling type	TFA (m^2)	Window to Wall ratio on NWSE façades	Number of rooms	Share of national stock (%)
Single family	Bungalow	104	0 / 0.4 / 0 / 0.4	8	43.2
	Detached	160	0 / 0.5 / 0 / 0.5	13	
	Semi-detached	126	0 / 0.4 / 0 / 0.4	10	28.2
Multi-family	Mid-floor flat	54	0 / 0.5 / 0 / 0	3	10.9
	Top-floor flat	54	0 / 0.5 / 0 / 0	3	

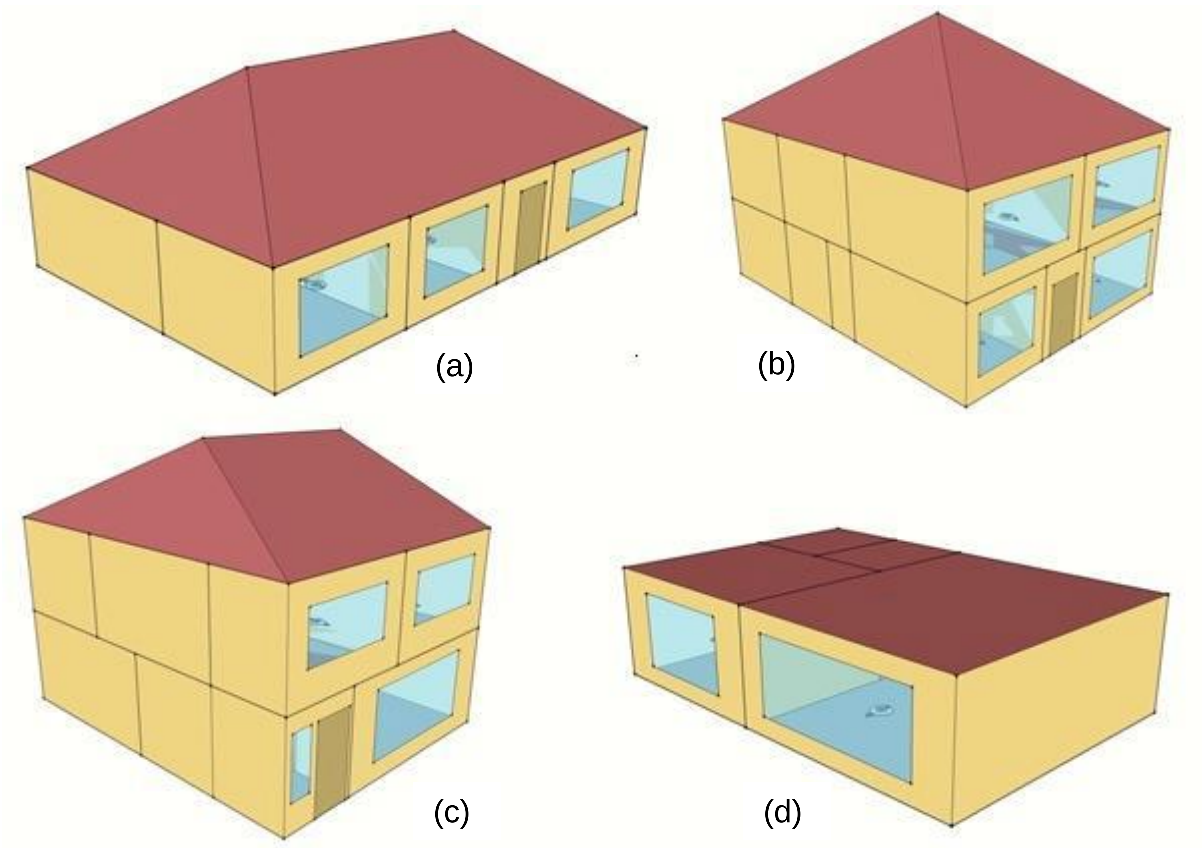

Figure 1 - SketchUp drawings of archetypes: (a) bungalow, (b) detached, (c) semi-detached, and (d) flats

2.2 Operational data

Activity-specific profiles for occupancy, electrical appliance use, lighting and DHW demand are integrated so that the archetypes capture, on a fifteen-minute basis, and at room level, the variations of internal heat gains and electricity use. As concluded by Neu *et al.* [***xix***], such space and time resolution is necessary for the investigation of issues related to thermal comfort and electrical load shifting at an aggregated level.

2.2.1 Occupancy

The occupancy profiles were developed and validated by Neu *et al.* [***xix***] for use as inputs to multi-zone residential building energy simulation archetype models. Figure 2 introduces the two types of occupancy profiles considered: normal and active profiles. A normal occupant is defined as a resident who is present in the dwelling. An active occupant is defined as a normal occupant who is not sleeping, and is thus willing to use, or to share the use of, one or more electrical appliances, depending on the level of active occupancy and on the activities performed. The difference between the modelled active occupancy and surveyed normal occupancy profiles during a weekend day, between 8-12 hours, is greater than during a weekday, as observed in Figure 2. It implies that, during the weekend, residents tend to wake-up and become active later than during the week. Surveyed TUS activity data was used to develop occupancy profiles at a fifteen-minute time resolution depending on the household size (1, 2, 3 and “4 or more” residents) and the day type (weekend or weekday).

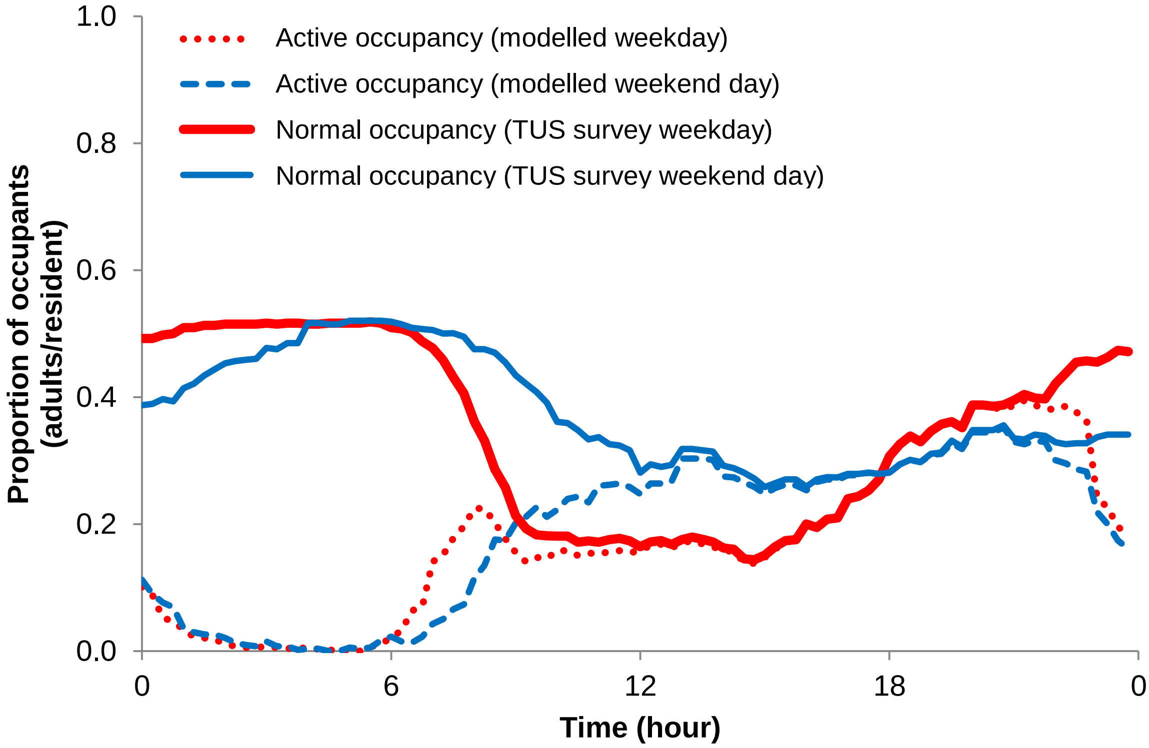

Figure 2 - Average daily modelled active occupancy and surveyed average daily normal occupancy: “4 or more” resident household

As shown in Table 2, the household size of archetypes were chosen as the closest value from the number of residents calculated by the DEAP procedure, which varies with the conditioned TFA of the building. The average household size for both the EnergyPlus and the DEAP archetypes, weighted by the share of each dwelling type within the Irish national stock, is identical but greater than the national average number of residents per household [***xxiii***]. While this might be a concern for the DEAP methodology, it is not for the household sizes considered in this work. Since only adult residents were surveyed in the Irish TUS, the resulting occupancy profiles exclude non-adult residents, with a risk of underestimating the internal heat gains associated with occupancy or even the use of equipment (DHW, electrical appliances). As shown in Table 2, the additional adult residents within the EnergyPlus households compensates for the missing national average number of children aged below eighteen, namely “0.7” residents [***xxiii***].

The activity-specific occupancy patterns (probability of at least one occupant to perform a particular activity) have a direct impact on the internal heat gains, for people and electrical appliances, and domestic hot water consumption. As per the methodology proposed by Neu *et al.* [***xix***], occupants and their internal heat gains are mapped at room level by assigning a unique, or several, thermal zones to each activity.

Table 2 – Household sizes assumed for the archetypes

Dwelling type	EnergyPlus household size (no. residents)	DEAP household size (no. residents)	National average household size (no. residents)	National average number of children <18 years old
Bungalow	3	3.0	2.7	0.7
Detached	≥4	4.4		
Semi-det.	3	3.6		
Flats	2	1.7		
Weighted average	3.4	3.4		

2.2.2 Electrical equipment

The daily power consumption profiles for domestic electrical appliances were developed and validated by Neu *et al.* [***xix***]. The average active occupancy profiles introduced previously and specific activity profiles derived from the TUS data were used in a stochastic model to develop average appliance load profiles depending on the household size, taking into account the penetration of each appliance modelled within the Irish national dwelling stock. As shown in Table 3, the model was calibrated to generate an average annual electricity consumption of 2,018 kWh for electrical appliances, representing 45% of the average annual electricity end use surveyed in the Irish households, as per SEI [***xxvi***].

Table 3 - Average annual load demand of electrical appliances

Residents per household	Surveyed average annual total consumption (kWh/yr)	Objective average annual appliance consumption (kWh/yr)	Modelled average annual appliance consumption (kWh/yr)
1	2,660		1,607
2	3,734		1,926
3	4,004		2,093
≥4	5,650		2,119
Total	4,484	2,018	2,005

Annual quantitative results suggest a greater sharing of electrical appliances, within the same dwelling, as the household size increases. The electrical appliance load profiles given in Figure 3 were validated qualitatively against the surveyed total household average daily load profiles based on data from the Irish Smart Metering Project (SMP) Electricity Customer Behaviour Trials (ECBT) [***xxvii***]. By assigning a unique, or several, thermal zones to each electrical appliance and by considering the fraction of electrical power consumed which is converted into latent, radiant, convected heat or heat lost to the outdoor environment, appliances and their internal heat gains are spatially mapped at room level.

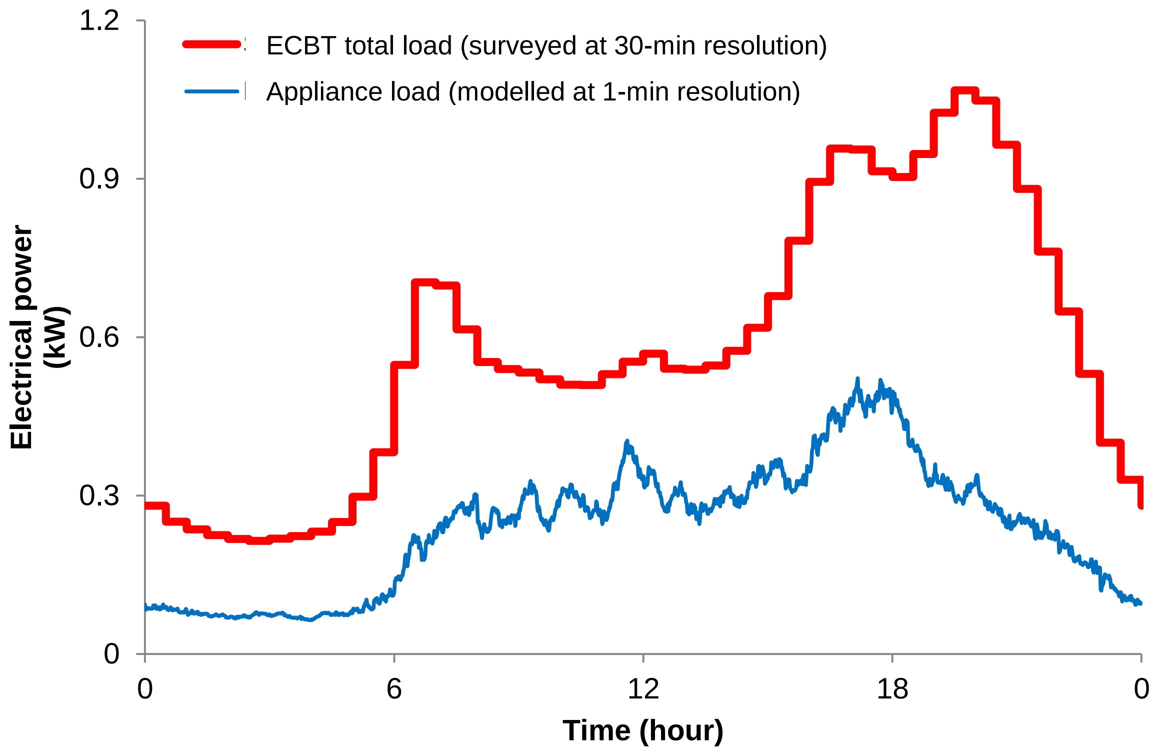

Figure 3 - Average daily electrical appliances load demand and surveyed average daily total load demand: "4 or more" resident household, weekday

A noticeable underestimation of power consumption can be seen from electrical appliances and associated internal heat gains, especially during the late evening time (18-22 hrs). This difference can be mainly attributed to the surveyed load (Irish TUS dataset), which excluded activity performed by occupants less than eighteen years of age. The household sizes chosen for the archetypes used in this research compensate for this underestimation.

2.2.3 Lighting

As detailed by Neu *et al.* [***xix***], the lighting electricity demand and associated internal heat gains are also activity-specific, varying with the occupancy level, activity level and type, illuminance requirement, light bulb efficacy of the lighting technology installed, and daylight level. For new dwellings, a 100% penetration of compact fluorescent technology within the Irish national stock was assumed, with a light source efficacy of 50 lm/W. For existing dwellings, a composite light bulb efficacy of 18 lm/W was assumed, based on IESNA standards [***xxviii***] and the breakdown of lighting technologies surveyed in UK residential building stock [***xxix***]. The lighting internal heat gains are spatially mapped at room level, by attributing an illuminance requirement level to each activity detailed in the Irish TUS dataset and by considering the fraction of electrical power consumed by lights which is converted into visible radiation, radiant and convected heat transfer.

2.2.4 Domestic Hot Water

Without any water meters installed at scale in the Irish residential sector, insufficient data is available to support the development of DHW consumption patterns in an Irish domestic context. Instead, a standard assessment methodology analogous to the EPBD is used, which provides an estimation of the average daily DHW consumption per household. While the DEAP methodology is based on the assumed household size only, which in turn is based on the dwelling TFA, the UK equivalent of the DEAP methodology, namely the 2009 Standard Assessment Procedure [***xxx***], also takes into account the seasonal variation of the average daily DHW demand and is considered to be more accurate. As a result, it is used to estimate the average daily volume water draw. The annual average daily DHW consumption assumed for the archetypes are shown in Table 4. Correcting for occupancy, using the household sizes set out in Table 2, there is a strong correlation for each archetype across each methodology.

Table 4 – Average daily DHW consumption assumed for the archetypes

Dwelling type	DHW consumption (L/day)		DHW consumption (L/day-resident)	
	DEAP	EnergyPlus	DEAP	EnergyPlus
Bungalow	107.1	111.0	35.2	37.0
Detached	141.3	159.6	32.4	32.3
Semi-detached	121.2	111.0	33.8	37.0
Flats	71.6	86.0	42.7	43.0

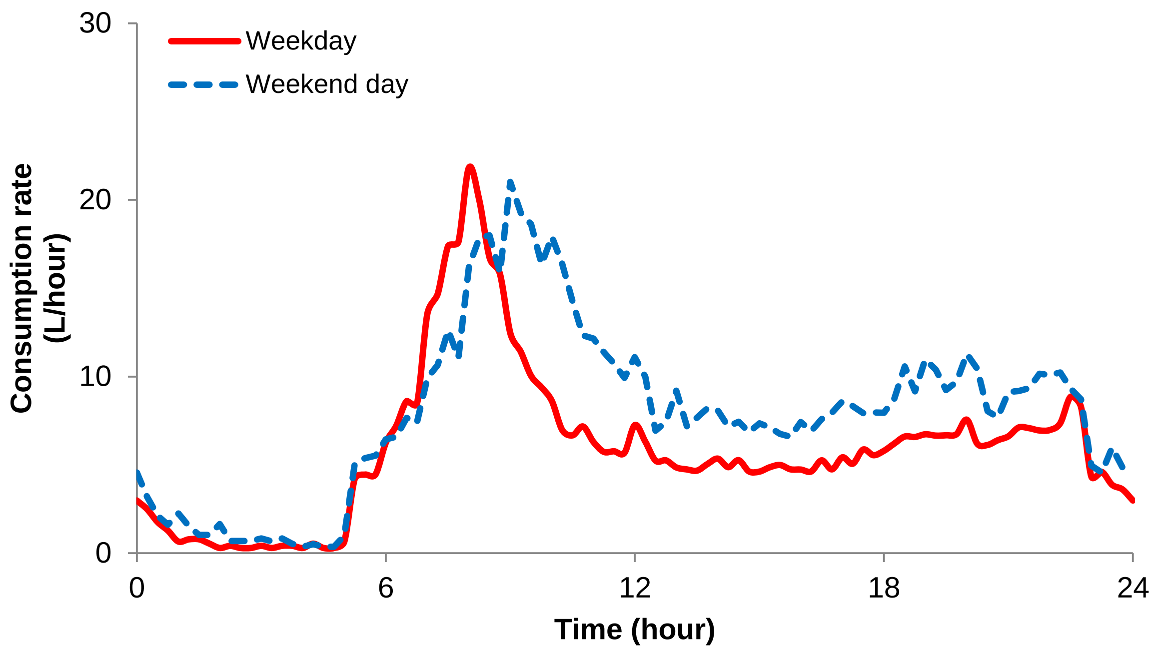

Figure 4 - Daily DHW consumption profiles: “4 or more” resident household

The resulting monthly average daily DHW consumptions are the basis for developing activity-specific daily DHW consumption profiles at a fifteen-minute resolution, depending on the household size, season and day type. The load profiles for the DHW demand, developed by Jordan and Vajen [***xxxi***], display the DHW flow rate, drawn at a sub-hourly scale. Four categories of DHW draws are defined: short draw (e.g. hand wash), medium draw (e.g. laundry), shower, and bath. Each category is responsible for 14%, 36%, 40% and 10% of the total volume of water drawn per day, respectively. The Irish TUS [***xx***] “washing” activity profile is found to be representative, in terms of load duration, peak times and peak amplitudes, of the bath and shower DHW draw categories. As a result, the sub-hourly probability distributions of these two load categories are substituted by the unique TUS “washing” activity profile, assumed to be responsible for 50% of the total volume of water drawn per day. By fitting the monthly average daily volumes of DHW calculated within the final draw-off probability distribution, the average daily DHW consumption rate profiles are generated at a fifteen-minute time resolution, Figure 4.

2.3 Climatic data

Different weather data files are used depending on the issue being addressed:

- To compare the energy performance of the Irish archetypes between the DEAP and EnergyPlus methodologies, the International Weather for Energy Calculation (IWEC) weather data for Dublin is used [***xxxii***], which is similar to the DEAP weather data, with only a 1% difference between the average monthly outdoor temperature and the heating degree days.
- To investigate the suitability of the methodologies in predicting the energy performance of dwellings on a national scale, IWEC weather files for locations distributed across Ireland are used.
- To investigate issues related to the shifting of electrical loads and the thermal comfort of occupants, data measured in 2009 in Dublin and produced by the Real-Time Weather Converter (RTWC) software developed by Lundström [***xxxiii***] is used, which is more relevant when comparing the modelled electrical load profiles with the ECBT metered data [***xxvii***].

2.4 Natural ventilation and adaptive thermal comfort algorithms

As houses become more energy efficient and air tight due to highly thermal resistant fabrics and stricter building regulations, the impact of natural ventilation on indoor comfort and on transient heating and cooling loads increases. In order to assess the DSM potential in residential buildings, as a mechanism for electricity peak load management, these two constraints, namely indoor thermal comfort and transient heating loads, must be considered in the analysis of archetype dwellings. To that end, a natural ventilation and adaptive thermal comfort model is developed, based on occupant behaviour, and implemented at room level. In brief, a stochastic approach determines whether to open or close the windows, depending on the room occupancy state, the type of activity performed and the thermal comfort experienced. This approach is consistent with the recommendations of Dutton *et al.* [***xxi***], who recognise that stochastic probability-based models are more suitable for describing natural ventilation because human behaviour is not deterministic. The main drivers proposed [***xxi***] for window operation are listed below:

- Environmental conditions, especially outdoor temperature during the heating season and indoor temperature during the off-heating season.
- Indoor thermal comfort and air quality, such that window operation is driven by a temporary discomfort in order to re-establish acceptable conditions.
- Temporal events, such that window operation is related to a particular event (e.g. entering a room, cooking, cleaning or waking-up).

Generally, building occupants tend not to interact that often with windows [***xxi***]. While this might be true for a commercial or office building, it is expected that residential building occupants would operate windows more dynamically in order to reach or to restore optimal comfort conditions [***xxii***]. Indeed, the domestic environment is characterised by high variations, at a sub-hourly timescale, of internal heat gains associated with occupancy level, activity level and types, and electrical equipment use. As opposed to commercial or office buildings, such an environment also offers many ways for occupants to adapt, including the adjustment of natural ventilation rates by operating windows. This justifies the choice of an adaptive thermal comfort model to estimate the acceptable indoor temperature range, rather than a model based on Fanger's approach, which is more appropriate for commercial and office buildings [***xxii***]. The model behaviour complies with the recommendations drawn from similar modelling studies performed in commercial and small office buildings [***xxi***]. The proposed approach considers the main drivers governing window operation, and adapts them to the residential sector context.

3. Results and discussion

3.1 Comparison between the DEAP and EnergyPlus methodologies

The energy performance of the Irish EPBD archetypes is introduced in this section and the results calculated through EnergyPlus are compared to those from the DEAP assessment.

3.1.1 Total energy performance

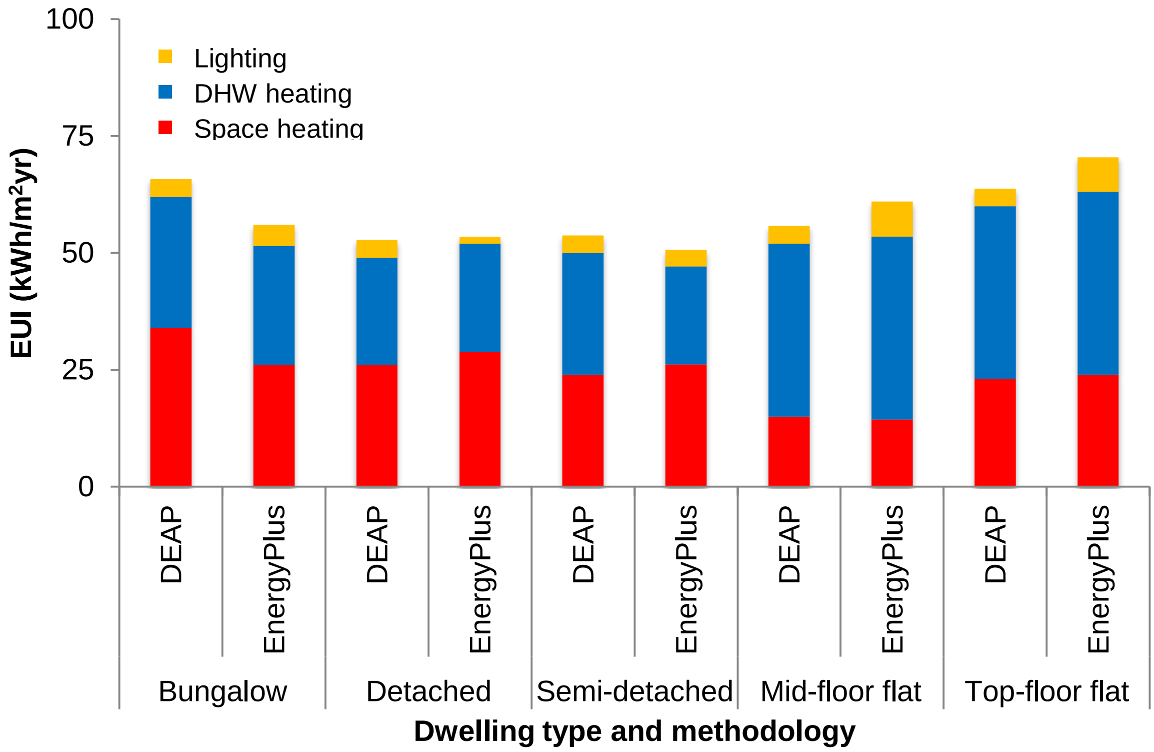

Figure 5 - Breakdown of average annual EUI: new dwelling archetypes

Figure 5 considers new dwelling archetypes, at an aggregated level, and excluding the electrical equipment which was not considered in the DECLG report [***iv***]. It can be seen that there is a good correlation between the results calculated through EnergyPlus and those predicted by DEAP, with a variation of 7.9% observed. Considering Figure 6 for existing dwelling archetypes, a better correlation is evident, with variations of 0.5% and 7.3% observed for cavity and hollow block wall dwellings, respectively. By dwelling type, a general underestimation trend is seen for single family dwellings, while a general overestimation trend is observed for flats. In all cases, the EnergyPlus approach is found to be accurate to within 8% of the Irish standards, as specified by DEAP, for the total energy performance of archetypes.

At an aggregated level, and excluding electrical equipment, the annual EUI associated with existing dwellings is increased by a factor of 4.6, approximately, compared to new dwellings, according to DEAP and EnergyPlus. The impact of the latest Irish building regulations on the energy performance of dwellings is significant, similar with both approaches, and differs from one dwelling type to another. It is thus primordial to consider the share of both and existing dwellings when assessing the energy performance or the DSM potential of Irish dwellings on a national scale.

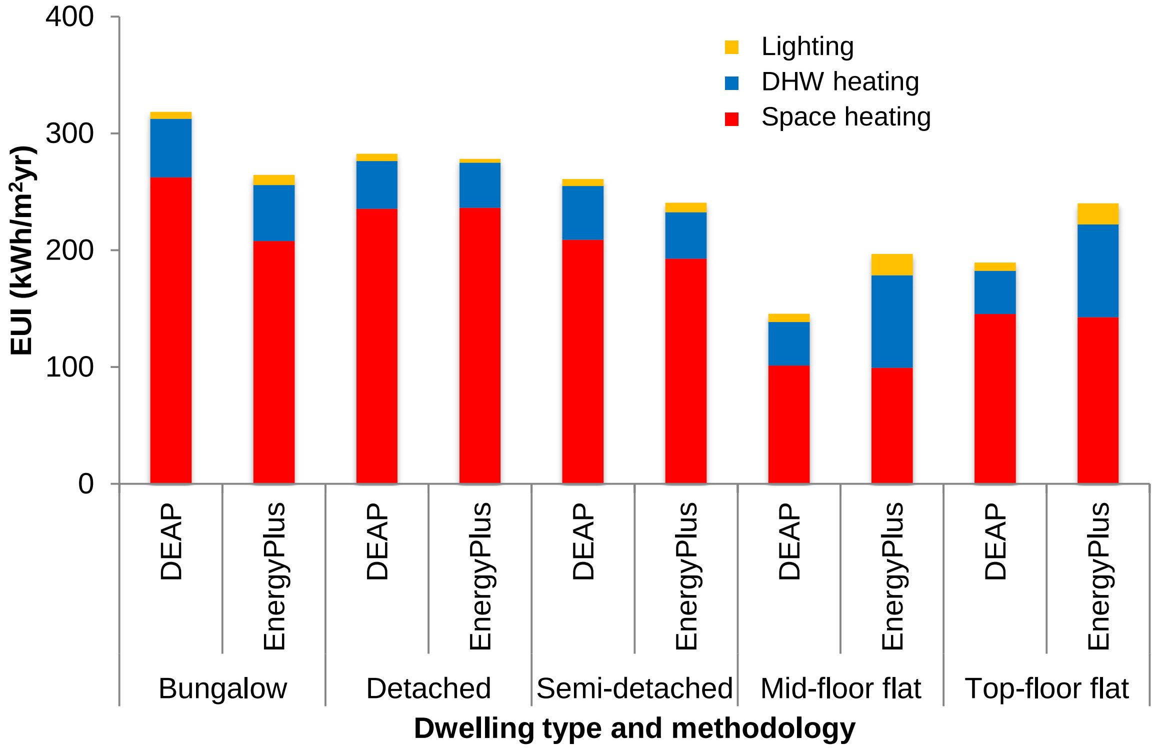

Figure 6- Breakdown of average annual EUI: existing dwelling archetypes

3.1.2 Space heating

Considering Figure 7 and Figure 8, excepting for the bungalow, a strong correlation is clear between the two approaches, independent of the construction period. However, even with this strong outlier, average underestimations of 0.3%, 4% and 12.2% are observed for the EnergyPlus predictions compared to DEAP for new, existing cavity and hollow block wall dwellings, respectively, at an aggregated level.

Sources of discrepancy include: the differing approach for considering internal heat gains, which is standardised for all DEAP dwellings while dynamically modelled within EnergyPlus based on occupant behaviour; or the lack of detail provided from DEAP regarding the heating water temperature setpoint; or the ventilation needs, amongst others. Furthermore, the DEAP methodology assumes constant infiltration rates and does not account for variability due to outdoor weather conditions.

The average underestimation observed for existing dwellings using EnergyPlus can possibly be attributed to the assumptions of a single primary heating system and an adiabatic system pipe network. Petersen *et al.* [***xxxiv***] found that the DEAP methodology overestimates the space heating energy requirements for buildings with poorer BER ratings, which is also captured by EnergyPlus for hollow blocked wall archetypes, as evident in Figure 8.

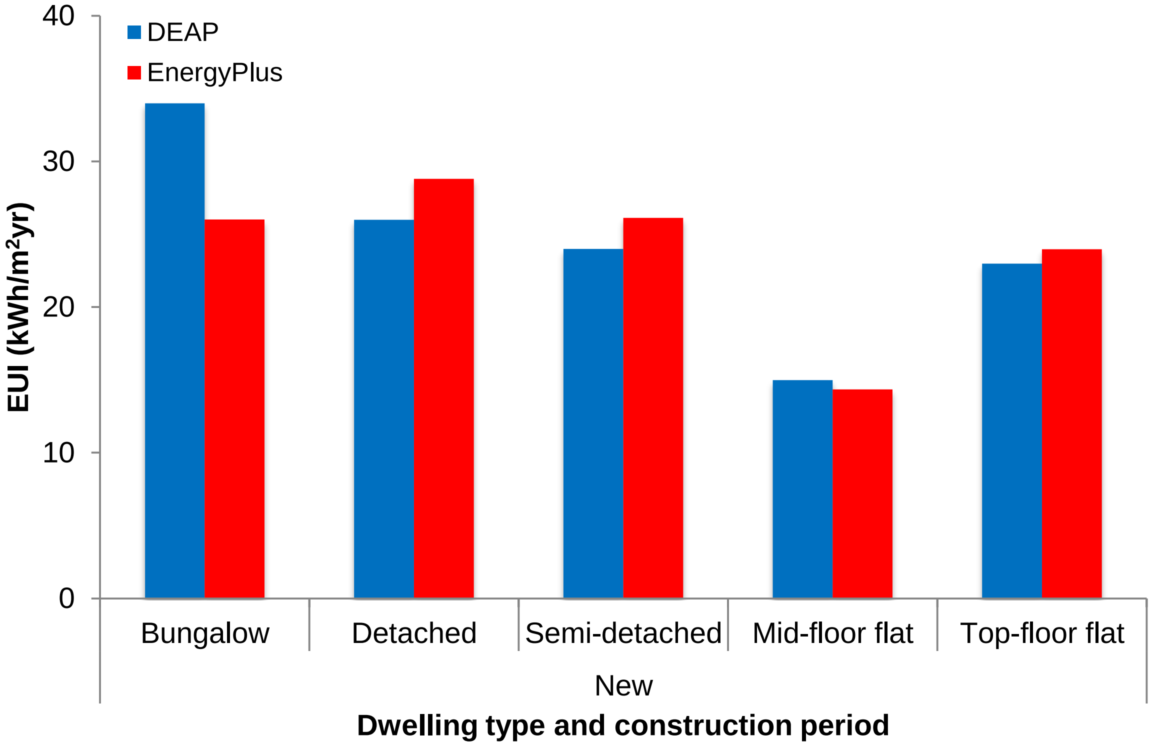

Figure 7 - Annual space heating EUI: new dwelling archetypes

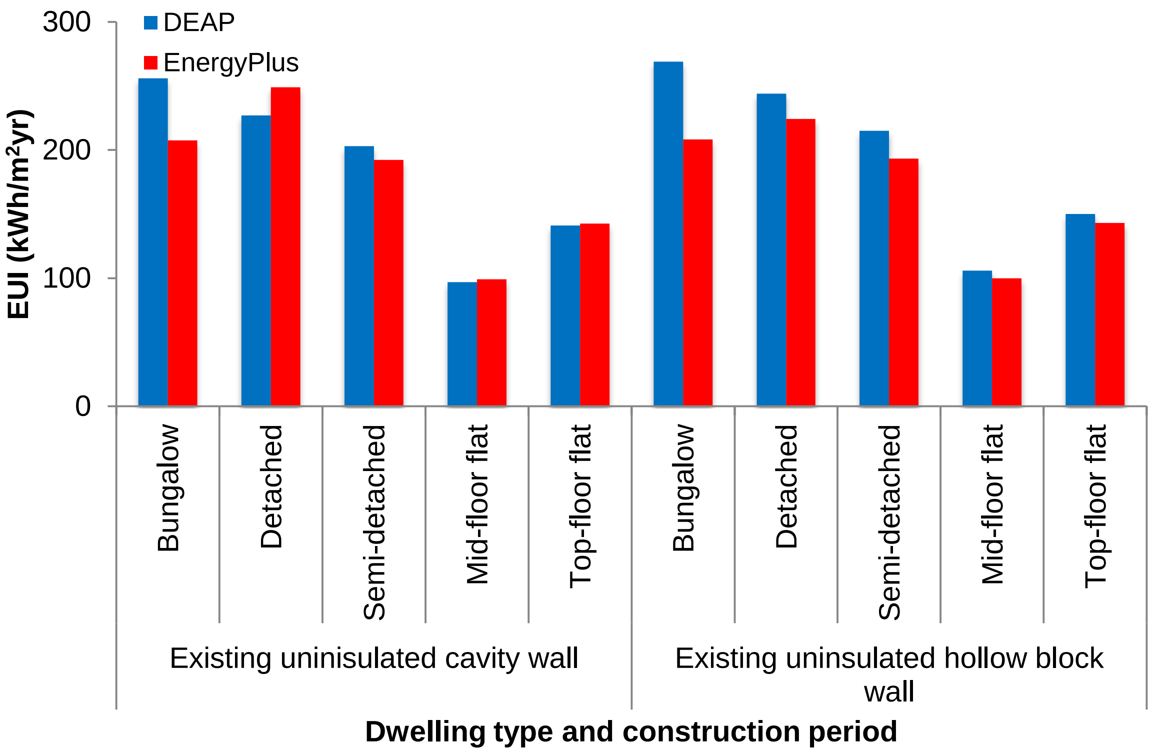

Figure 8 - Annual space heating EUI: existing dwelling archetypes

3.1.3 DHW heating

Figure 9 and Figure 10 show annual DHW heating EUI for new and existing dwellings, respectively. Except for the semi-detached and the existing multi-family dwelling types, a strong correlation is seen between the approaches, especially for existing dwellings. However, even with these outliers, an underestimation of 8% is observed at an aggregated level for new dwellings, as per Figure 9, while an overestimation of 7.9% is seen for existing dwellings in Figure 10.

Sources of discrepancy include the differing approach for considering DHW consumption, which is standardised by DEAP while dynamically modelled within EnergyPlus based on occupant behaviour. Furthermore, the DEAP methodology accounts for distribution circuit heat losses but does not detail how they are calculated, while EnergyPlus assumes an adiabatic distribution pipe network, and heat losses are estimated by reducing the DHW tank insulation to compensate for this assumption.

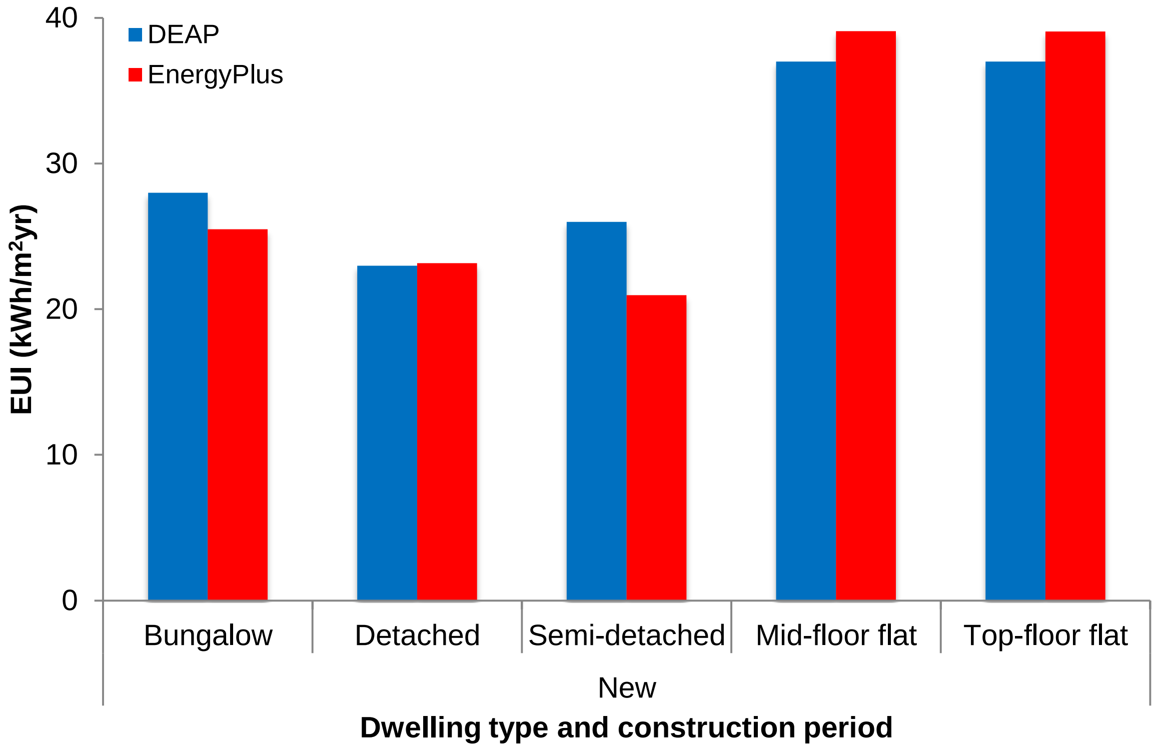

Figure 9 - Annual DHW heating EUI: new dwelling archetypes

Despite the difference in DHW heating EUI for the semi-detached dwelling type (Figure 9), strong correlations are observed for the other new dwelling types, and the EnergyPlus semi-detached model behaves consistently for each construction period, with a similar error observed for each of them. The significant overestimation of DHW heating EUI for the existing flats, Figure 10, directly relates to the DEAP approach, which assumes that for flats, there is no difference in DHW heating energy demand between the new and old construction periods, despite significant differences in heating system efficiency, whereas an increase by an average factor of 1.7 is estimated for all other dwelling types. EnergyPlus predicts an increase by an average factor of 1.8 for all dwelling types.

Considering Figure 10, the overall underestimation of DHW heating energy demand estimated by EnergyPlus is mainly caused by the assumption of a single primary heating system, with an approximated lower combined nominal efficiency to compensate for this assumption. While this approximation is valid for estimating space heating requirements, it is less valid for DHW heating since, in reality, the DHW heating energy demand is not affected by a secondary heating system.

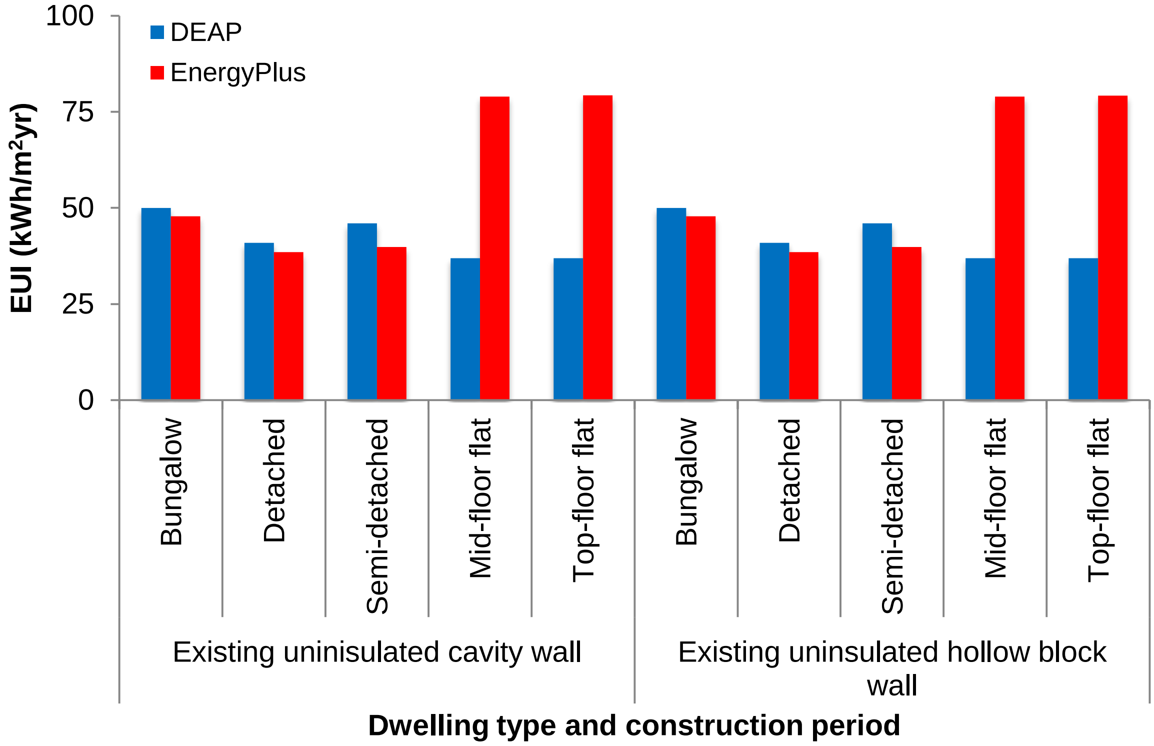

Figure 10 - Annual DHW heating EUI: existing dwelling archetypes

3.1.4 Electricity demand

Figure 11 shows electricity demand for different electrical equipment types as estimated by EnergyPlus and DEAP.

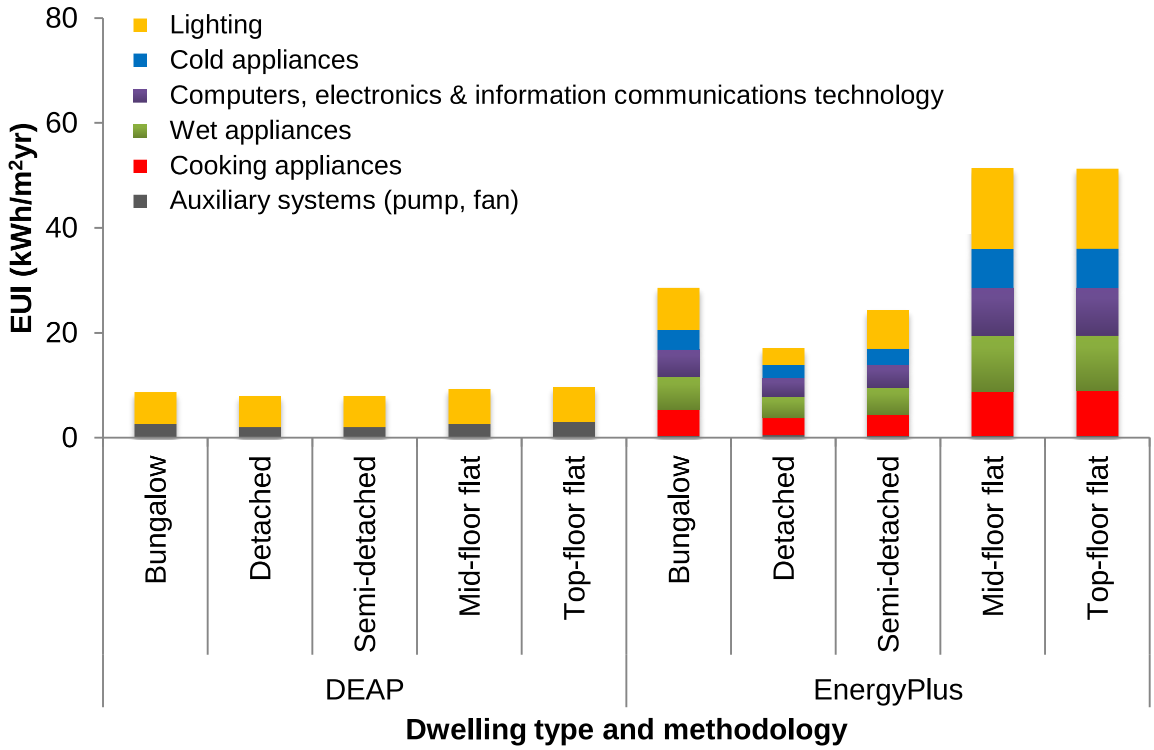

Figure 11 - Average annual EUI for lighting and electrical equipment

A poor correlation is observed between the two approaches. The EnergyPlus approach is believed to be more accurate than DEAP because, for DEAP, the same demand load for lighting is assumed for all dwellings of the same construction period. Moreover, excepting for auxiliary systems, demand load for electrical equipment is noticeably not considered in the DECLG report [***iv***]. On the other hand, by accounting for variations in daylight, occupancy, occupant activity level and type, with high space and time resolutions, the EnergyPlus archetypes capture the variations of lighting and electrical equipment loads at room level within a 15 minute timescale.

3.2 Scalability to national level

The development of archetype models is motivated by their capability to create results that may be scaled up to national level when considering the number of dwellings that are represented by each archetype class. Concerns have arisen with regards to the ability of DEAP to capture the energy performance of Irish dwellings on a national scale because of the use of standardised assumptions for climatic data. Indeed, the DECLG methodology [***iv***] uses only one set of climatic data, representative of weather conditions seen in the Dublin area. In order to investigate the suitability of the DEAP and EnergyPlus methodologies in predicting the energy performance of dwellings on a national scale, the EnergyPlus archetypes are simulated using a selection of IWEC database files for six locations distributed across Ireland. The detached dwelling type, over two construction periods (new and existing dwellings with uninsulated cavity walls), is considered because it is most representative of Irish dwelling stock, with a share of 43.2%, as seen in Table 1. It also showed strong correlation with the DEAP methodology in terms of space and water heating energy requirements.

Table 5 - Variation of space heating EUI with location

Construction period	Location in Ireland	Change of space heating EUI with respect to Dublin	
		Absolute change (kWh/m^2yr)	Percentage change (%)
New insulated cavity wall	Belmullet	-3.7	-12.8
	Birr	-0.8	-2.7
	Clones	2.0	7.0
	Kilkenny	-2.3	-7.9
	Malin	-2.5	-8.5
	Valentia	-6.2	-21.5
Existing uninsulated cavity wall	Belmullet	-7.1	-2.8
	Birr	0.1	0.1
	Clones	10.0	4.0
	Kilkenny	-6.1	-2.5
	Malin	0.3	0.1
	Valentia	-25.8	-10.3

The results demonstrate that significant variations of energy requirements were only observed for space heating. The absolute change and the percentage change with respect to those predicted for archetypes located in Dublin are shown in Table 5. The greatest absolute changes are observed for existing dwellings, due to low thermal resistant fabrics. Perhaps unexpectedly, the greatest percentage changes with respect to Dublin are observed for new dwellings. Considering that the layout and the exposed surface area of new and existing archetypes are identical, timecontrolled space heating for existing dwellings explains why they are less responsive to outdoor environmental variations than new dwellings, which are equipped with room thermostats.

3.3 Load shifting and thermal comfort

In order to demonstrate the capability of the archetypes to investigate issues related to electrical load shifting and thermal comfort, a load shifting strategy is applied to the new detached building archetype. The electrical load from the kitchen refrigeration appliances is brought to its minimum level for thirty minutes, during the evening peak period on a weekday (17:30-18:00 hrs), followed by fifteen minutes at its maximum level to simulate the load rebound effect. Such a DSM strategy is assumed to respect food quality requirements, making use of the thermal inertia offered by these appliances. From a power system perspective, it reduces the system peak load demand, which might not be met with RES and would thus require an expensive fossil fuel-based electricity generation unit to turn on otherwise. The load demand from cold appliances and electrical equipment are shown in Figure 12, as well as the impact on the kitchen indoor operative temperature. At the peak time, a load reduction of 22 W per detached dwelling archetype is observed with an insignificant reduction of 0.1°C on the indoor operative temperature. By considering the total number of dwellings in the Irish national stock [***xxiii***], i.e. 1654208, and the maximum share of dwellings that could represented by this new detached house archetype, i.e. 43.2% as shown in Table 1, the potential load reduction is estimated at 16 MW at an aggregated national level, for this archetype category, without impacting on the thermal comfort of occupants. While these figures might be insignificant when compared to the national electrical demand, significant results might be obtained when applying load shifting strategies on electrical loads such as space and water heating systems.

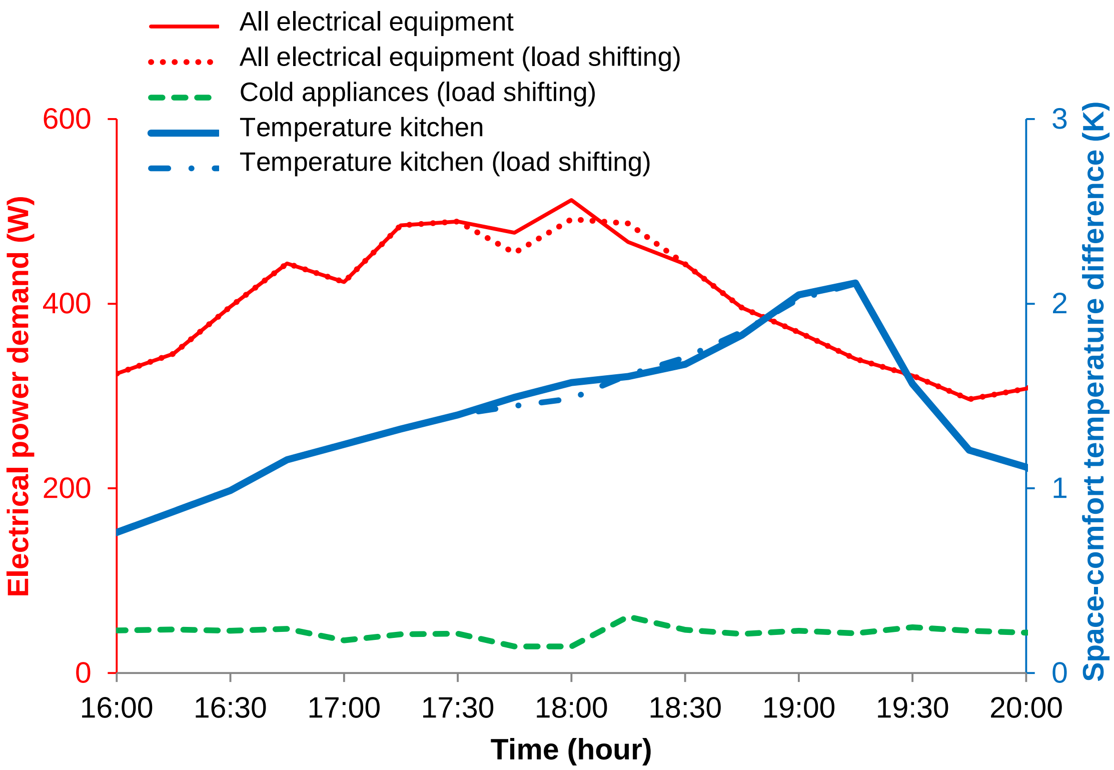

Figure 12 - Load shifting of refrigeration appliances and kitchen thermal comfort: "4 or more" resident household, weekday

4. Conclusion and further work

The EnergyPlus archetype building energy simulation models are found to be accurate to within 10% of the Irish standards, as exemplified using the DEAP methodology, for space and water heating energy requirements. The proposed approach is believed to be more accurate than DEAP to estimate the electricity consumption for lighting and electrical equipment. According to the variations in energy performance observed in different locations, there are concerns about the DEAP standard assessment approach regarding its ability to capture the energy performance of dwellings on a national scale. This might also be true for other standard assessment methodologies developed in the EU in response to the EPBD directive. The EnergyPlus archetypes can however capture these variations, making it more scalable than the EPBD reference buildings. While it would be unnecessary and counterproductive to base the delivery of energy rating certificates on the dynamic simulation approach introduced, discrepancies between the DECLG reference dwellings and the EnergyPlus archetypes could be resolved by a number of measures. These include: an increase in DEAP modelling resolution with respect to building form, an improved internal heat gain calculation approach and an improved electricity consumption metric. In summary, by integrating high resolution models for occupancy and equipment use, as well as increasing the time resolution of the EPBD archetypes from a yearly level to a sub-hourly level, the proposed approach can generate more accurate models of the housing stock. Moreover, it allows additional questions such as electrical load shifting to be assessed, thus expanding on previous investigations.

Further features of the archetype models may include the electrification of space and water heating systems and the development of a methodology for the assessment of the flexibility embedded within Irish archetypes through the implementation of load shifting strategies constrained by thermal comfort. Also, the archetypes modelled will facilitate analysis of the scale up of the potential flexibility resource from individual representative buildings to a national scale.

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