SDAR* Journal of Sustainable Design & Applied Research

Volume 2 | Issue 1 Article 5

9-12-2014

A Cost-Optimal Assessment of Buildings in Ireland Using Directive 2010/31/EU of the Energy Performance of Buildings Recast

Christopher Pountney
AECOM, UK, CHRISTOPHER.POUNTNEY@AECOM.COM

David Ross
Aecom UK, david.ross@aecom.com

Sean Armstrong
Environ, sean.armstrong@environ.ie

Recommended Citation

Pountney, Christopher; Ross, David; and Armstrong, Sean (2014) "A Cost-Optimal Assessment of Buildings in Ireland Using Directive 2010/31/EU of the Energy Performance of Buildings Recast," *SDAR* Journal of Sustainable Design & Applied Research*: Vol. 2: Iss. 1, Article 5.
doi:https://doi.org/10.21427/D7S16Z
Available at: https://arrow.tudublin.ie/sdar/vol2/iss1/5

A Cost-Optimal Assessment of Buildings in Ireland Using Directive 2010/31/EU of the Energy Performance of Buildings Recast

Cover Page Footnote

Mr Sean Armstrong DEPARTMENT OF THE ENVIRONMENT, COMMUNITIES AND LOCAL GOVERNMENT, IRELAND Acknowledgements This paper contains material taken from the full cost-optimal calculations report [DECLG, 2014] and is reproduced with the consent of the Department of Environment, Community and Local Government.

A Cost-Optimal Assessment of Buildings in Ireland Using Directive 2010/31/EU of the Energy Performance of Buildings Recast

Christopher Pountney
CHRISTOPHER.POUNTNEY@AECOM.COM

David Ross
AECOM, UK

Sean Armstrong
Department of the Environment,
Communities and Local Government, Ireland

SCHOOL OF
ELECTRICAL AND
ELECTRONIC
ENGINEERING

School of
Multidisciplinary
Technologies

Building Services news

CIBSE

Abstract

This paper describes the first cost-optimal assessment of national energy performance standards for buildings in Ireland undertaken in accordance with Article 5 of the Energy Performance of Buildings Directive (EPBD) Recast [Council Directive 2010/31/EU]. This paper focuses on new-build standards which are set out in Part L of the Building Regulations in Ireland. A set of representative residential and non-residential building models were selected. The impact on primary energy demand of a wide range of energy efficiency measures and renewable technologies was evaluated for each building model and the corresponding lifecycle costs were calculated. The results show that the new-build residential standards in Ireland are in the cost-optimal range, while the new-build non-residential standards deliver a greater primary energy demand than the cost-optimal range.

Key Words:

Cost-optimal, Part L, Lifecycle cost

1. Introduction

In Ireland energy use and CO2 emissions associated with the built environment continue to be significant and measures to reduce their impact in both new and existing buildings will continue to be an important component of Government energy and climate change policies. The latest data in respect of CO_2 emissions estimated that a total of 12.6 million tonnes of CO_2 equivalent was generated by the buildings sector in Ireland in 2010 [DECLG, 2012]. In 2010, this accounted for 28.8% of emissions in Ireland that were not included in the EU Emissions Trading System.

Against this background, improvements in energy efficiency within the buildings sector, in tandem with the increased use of renewable energy technologies, constitute important policy measures needed to facilitate a reduction in Ireland's energy dependency on fossil fuels and associated greenhouse gas emissions over the period to 2020 and beyond. A key policy is Part L of the Building Regulations which sets standards for primary energy use and CO_2 emissions for new buildings (as well as setting standards for the energy efficiency of building works on existing buildings). The domestic and non-domestic standards were last updated in 2011 and 2008 respectively.

Article 5 of the Energy Performance of Buildings Directive (EPBD) Recast assesses the suitability of national building energy performance standards. It requires all EU member states to determine cost-optimal standards for building energy performance and to compare these with their national standards. This assessment should be conducted using the comparative methodology framework, which is defined in the Cost-optimal Regulations (the "Regulations") [Commission Regulation (EU) 244/2012] and expanded upon in the associated Cost-optimal Guidelines [Guidelines accompanying (EU) 244/2012]. The methodology stipulates how various building measures should be evaluated, including both energy efficiency options and renewable technologies, based on the primary energy benefits and the associated lifecycle costs. Applying these rules to a range of typical reference buildings gives an indication of the cost-optimal, minimum energy performance which should be compared against that of the national standards applied to the same reference buildings. This paper presents the first cost-optimal assessment of buildings and building elements in Ireland undertaken in accordance with the framework.

For each reference building, the various building measures are plotted with primary energy on the horizontal axis and lifecycle costs on the vertical axis. Figure 1 gives a typical example. For each level of primary energy, there are likely to be many options with different lifecycle costs. For any particular primary energy consumption, the points plotted in red are those which have the lowest lifecycle cost. These are used to determine the cost-optimal curve. Since the cost-optimal curve may reasonably be expected to vary based on uncertainties in the input data, a range of sensitivity analyses are undertaken. The range of minimum points from each of these cost-optimal curves forms the cost-optimal range. The

https://arrow.tudublin.ie/sdar/vol2/iss1/5
DOI: https://doi.org/10.21427/D7S16Z

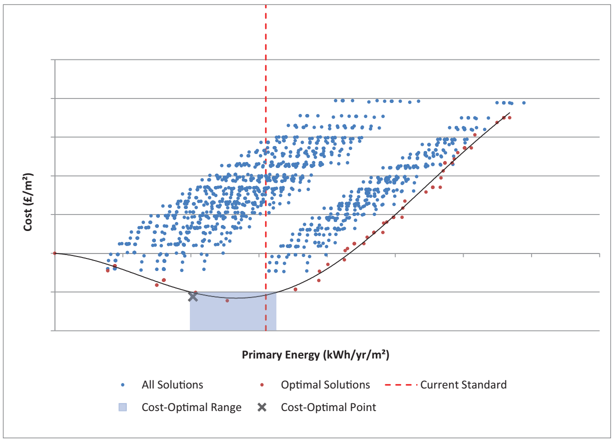

Figure 1: Example cost-optimal curve for a reference building.

cost-optimal point is the point within the cost-optimal range with the lowest primary energy. Applying the Part L standard to the example reference building is also shown in Figure 1.

The final part of the assessment is a comparison of the cost-optimal point with the current national standards. The primary energies of both the cost-optimal points and the national standards are averaged over the reference buildings. The average of the national standards should be no greater than 15% above the average of the cost-optimal points. The member state should either give a justification for any exceedance or outline a plan of action to reduce the deficit.

2. Methodology

This section describes the application of the cost-optimal methodology in Ireland. Although the analyses of residential and non-residential buildings were undertaken separately, most of the methodology is consistent. Both parts are presented together.

2.1 Reference buildings

For the purpose of this work, it has been assumed that the reference buildings are constructed in Dublin. The greater Dublin region contributes to a significant proportion of newly-constructed dwellings and is also the focus of current non-residential construction activities. Hence, we have used climate data for Dublin, as defined within the Irish building energy assessment procedures, as well as initial investment cost data for Dublin as provided by AECOM cost experts.

2.1.1 Residential buildings

The regulation stipulates that member states should define reference buildings for both single-family dwellings and either apartment blocks or multi-family dwellings. In this case, reference buildings were selected for five different dwelling types –

- Bungalow
- Detached house (2-storey)
- Semi-detached house (2-storey)
- Mid-floor flat
- Top-floor flat

The reference buildings were based upon typical building models (not actual buildings) provided by the Department of the Environment, Community and Local Government (DECLG). These dwellings were based on a review undertaken of new-build dwelling construction between 2003 and 2006. Sources included the DECLG Annual Housing Statistics Bulletin, the Central Statistics Office Construction and Housing Statistics, DKM Economic Consultants Ltd Annual Review of the Construction Industry, and Sustainable Energy Authority of Ireland's Energy Consumption and CO2 Emissions in the Residential Sector. Further details of current new-build dwellings were supplied by OMP Architects, DTA Architects and MosArt to confirm typical area, form, glazing ratios, and construction methods [DEHLG, 2007].

A summary of the floor areas for these buildings is shown in Table 1, where the floor areas were calculated by taking linear measurements between the finished internal faces of the walls. New buildings are assumed to be of cavity wall construction as DECLG advised that this is the most common new-build construction type in Ireland.

Table 1 – Selected residential reference building models

Building Category	Reference Building	Floor Area
Single-family buildings	Bungalow	104m²
	Detached house	160m²
	Semi-detached house	126m²
Apartment blocks	Mid-floor flat	54m²
	Top-floor flat	54m²

2.1.2 Non-residential buildings

According to Annex 1 of the regulation, member states should establish at least one reference building for office buildings, as well as for certain other non-residential buildings for which specific energy performance requirements exist. In Ireland, energy performance requirements are set for all non-residential buildings. Reference buildings based on the following four building categories were selected –

- Office buildings
- Educational buildings
- Hotels and restaurants
- Wholesale and retail services buildings

A summary of the buildings, construction type and servicing strategy is shown in Table 2. The office building, hotel and restaurant building, and wholesale and retail services building, were based on

Table 2 – Selected non-residential reference building models

Building Category	Construction type	
	Cavity Wall	Steel Frame
Retail (Air Conditioned)	–	1250 m²
Office (Natural Ventilation)	1500 m²	–
Office (Air Conditioned)	–	1500 m²
School (Primary – Natural Ventilation)	2300 m²	–
Hotel (Air Conditioned)	2500 m²	–

building models used to develop building regulations for energy performance requirements within the UK. The floor areas of these models were amended to reflect the mean area of the planning permissions granted in Ireland in 2010. The school building was based on an exemplar primary school building provided by the Department of Education and Skills [DES, 2013].

2.2 Building energy measures

A list of potential measures was compiled using the cost-optimal guidelines and design experience for both residential and non-residential buildings. Since it is impractical to evaluate every permutation of the selected measures, the measures were grouped into packages.

For residential buildings, three sets of packages were created (see Table 3), representing three different components of a dwelling design (fabric, heating, photovoltaics (PV)). PV is selected here as the primary renewable energy technology, since it is often one of the lowest-cost alternatives, is usually independent of building features and is applicable to a wide range of building forms. Selecting one package from each component forms a complete dwelling design. Taking account of all of the permutations, 80 alternative dwelling designs have been modelled in each reference dwelling.

In non-residential buildings, building services measures were explicitly included as a fourth component (see Table 4). In total, 225 alternative building designs have been modelled in each reference building, with the exception of air conditioned offices where that number was doubled due to the inclusion of optional free-cooling as a fifth component.

The values selected for each of the measures (e.g. the fabric U-values and building services efficiencies) within the packages have been chosen to give a large spread of primary energies and lifecycle costs. This helps to obtain a clear cost-optimal curve, making it easier to identify the cost-optimum range. Some packages include solutions that, taken together, might comprise a building design that performs more poorly than the primary energy standard set by the current Part L regulations. This is necessary to show whether the current standards are already at, or beyond, cost-optimal.

It should be noted that some possible measures have been omitted from these packages. There are a number of reasons for this –

- Site specific measures: Various measures are particularly dependant on site constraints. For example, building orientation and the feasibility of wind turbines are likely to depend on the site and the surrounding context. Our assumption is that the cost-optimal point should be based on measures that any designer can typically adopt. If not, achieving the cost-optimal point may be unrealistic in many real cases.

Table 3 – Measures included in residential analysis

Fabric	**F1**	**F2**	**F3**	**F4**	
Wall U-value (W/m²K)	0.27	0.20	0.13	0.13	
Roof U-value (W/m²K)	0.16	0.14	0.11	0.11	
Floor U-value (W/m²K)	0.20	0.18	0.13	0.13	
Window U-value (W/m²K)	1.6	1.4	0.9	0.9	
Thermal Bridging (y-value)	0.15	0.08	0.04	0.04	
Air Tightness (m³/m².hr @ 50 Pa)	10	7	5	2	
Ventilation Strategy	Natural Ventilation			MVHR	

Heating	**H1**	**H2**	**H3**	**H4**	**H5**
Space Heating Source	Condensing Gas		Biomass	GSHP	ASHP
Space Heating Efficiency	91%		80%	396%	374%
Communal option for flats?	No	Yes (all houses have individual heating systems)			
Controls	Full time and temperature zone control, weather compensation, modulating boiler with interlock			Full time and temperature zone control	
Emitters	Radiators			Underfloor Heating	
Electric Immersion Heater	NO	NO	NO	YES	YES
Solar Hot Water	NO	YES	NO	NO	NO

PV	**PV1**	**PV2**	**PV3**	**PV4**	
PV Installation (% foundation area)`	0%	10%	20%	30%	

Table 4 – Measures included in non-residential analysis

Fabric	**F1**	**F2**	**F3**		
Wall U-value (W/m²K)	0.3	0.25	0.2		
Roof U-value (W/m²K)	0.25	0.2	0.15		
Floor U-value (W/m²K)	0.25	0.2	0.15		
Window U-value (W/m²K)	1.8	1.4	0.9		
Improved Thermal Bridging	NO	YES	YES		
Air Tightness (m³/m².hr @ 50 Pa)	7	5	3		

Services	**S1**	**S2**	**S3**		
Lighting (llm/cW)	55	60	65		
Daylight Lighting Control	NO	YES	YES		
Occupancy Lighting Control	NO	YES	YES		
Heat Recovery	NO	NO	65%		
Chiller Efficiency (SEER)	3.5	4.5	5.5		
AHU SFP	2.2	2	1.8		
FCU SFP	0.6	0.3	0.3		
Demand Control Ventilation	NO	NO	YES		

Additional Services	**FC1**	**FC2**			
Free Cooling (FC)	NO	YES			

Heating	**H1**	**H2**	**H3**	**H4**	**H5**
Heating Source	Gas boiler		CHP	GSHP	GSHP
Space Heating Efficiency	86%	91%	45%	400%	400%
Solar Hot Water	NO	YES	NO	NO	NO

PV	**PV1**	**PV2**	**PV3**	**PV4**	**PV5**
PV Installation (% foundation area)	0%	10%	20%	30%	40%

- Design measures: Some measures impact on design constraints that do not affect the building primary energy demand. For example, modifying the percentage of glazing or introducing shading to optimise the primary energy demand may result in inadequate daylight levels. Furthermore, this is building-dependent – a particular percentage of glazing may provide appropriate day lighting in one building design but not another. Therefore, such measures have not been considered in the list of packages.
- Default measures: There are other measures that are likely to be included in new buildings by default, for example in non-residential buildings, monitoring and metering, variable speed pumps and power factor correction. These have not been treated as options; they are simply added to the base building models where appropriate. Since these measures do not vary, there is no need to separately identify costs for them.

2.3 Energy performance assessment

The EPBD Recast requires member states to develop a methodology for calculating the energy performance of buildings. There are a range of European standards recommended for the calculation of various loads and energies in buildings, including EN ISO 13790 for heating and cooling. In Ireland, this methodology has been implemented in the Domestic Energy Assessment Procedure (DEAP) and the Non-domestic Energy Assessment Procedure (NEAP). Both DEAP and NEAP reflect the additional requirements regarding conservation of fuel and energy in Part L.

The Irish Government publishes a software implementation of DEAP, which is available as a standalone tool and as a spreadsheet tool. For this analysis, the reference dwellings were constructed in the spreadsheet tool, so that evaluating the various packages of measures could be automated.

Similarly, the NEAP is implemented in the Simplified Building Energy Model (SBEM) calculation engine. To undertake this analysis, a custom modelling environment was developed using VB.NET to automatically edit the SBEM building model input files to reflect each package of measures. The energy end uses (i.e. heating, cooling, lighting, domestic hot water and auxiliary energy) were recorded directly from the SBEM output files.

In both cases, the end-use energies were then summed for each energy carrier to find the delivered energy requirement. Any on-site generated energy was also determined at this stage. The associated primary energy for each package of measures was calculated by multiplying the delivered energies by the appropriate primary energy factor. The projected primary energy factors (PEFs) were averaged over the calculation period (see section 2.4).

2.4 Lifecycle calculations

The calculation of lifecycle costs was undertaken according to the detailed procedures laid down in Annex 1 of the Regulations. The lifecycle cost (C_L) is defined in the equation below.

$$C_L(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) R_d(i) + C_{c,i}(j) \right) - V_{f,\tau}(j) \right] \tag{1}$$

where:

τ	calculation period
C_I	initial investment cost
$C_{a,i}(j)$	annual cost for package of measures j during year i
$C_{c,i}(j)$	cost of carbon for package of measures j during year i
$V_{f,\tau}(j)$	residual value of package of measures j at the end of the calculation period (discounted to starting year τ_0)

$R_d(i)$ is the discount rate in year i and is calculated as follows:

$$R_d(p) = \left(\frac{1}{1 + {}^{r}/_{100}} \right)^p \tag{2}$$

where:

p	number of years from starting year
r	the real discount rate

Following the Regulations, the calculation period was set to 30 years for the residential and public buildings (i.e. the primary school) and 20 years for all other non-residential buildings.

The initial investment costs were provided by AECOM cost experts based on industry data. Similarly, they provided the maintenance and replacement costs for inclusion as part of the annual costs. Asset lives were taken from IS EN 15459 [NSAI, 2007]. However, since the calculation periods are similar to or less than many of the component asset lives, few replacements were required.

The annual costs also include the annual energy cost. The baseline energy costs were taken from the Energy Trends 2009 document [European Commission, 2010] referenced in the Regulation. The cost of biomass in the residential analysis was taken from the BioEnergy Supply Curves for Ireland report [SEAI, 2012]. Similarly, solid multi-fuel (coal assumed) costs were taken from the DECC Interdepartmental Analyst Group tables [DECC, 2013], converted to Euros and 2013 prices.

For the societal calculation, the cost of carbon was calculated using carbon emission factor projections provided by DECLG. The baseline cost of traded carbon emissions were taken from Annex 2 of the Regulation. This projection assumes the implementation of existing legislation, but does not account for any further future decarbonisation.

The residual value at the end of the calculation period was calculated assuming a linear depreciation over the component asset life.

The lifecycle costs were evaluated from both the private investor perspective and the societal perspective. In practice, this requires a slight modification to the equation above for the private investor calculation, since the cost of carbon is not included. Furthermore, for the private investor calculation, Value Added Tax (VAT) is also applied as appropriate. From the societal perspective, taxes are not included in the lifecycle cost calculation.

The discount rate varied depending on the lifecycle perspective. For the private investor, the baseline discount rate was set at 7% and was based on an assessment of the current financial landscape. The societal baseline discount rate was set at 4%, the value used by the Irish Government in policy-impact assessments.

A series of sensitivity analyses were undertaken on the initial investment cost, discount rates, energy prices and primary emission factors to assess the potential variation depending on reasonable uncertainty in input data.

3. Results

This section presents the results of the cost-optimal assessment of the various packages applied to each reference building.

3.1 Residential results

Figure 2 provides an example Residential result. It is a societal analysis for the Semi-Detached House. The red dashed line marks the current standard, which intersects the cost-optimal curve at a lower primary energy than the cost-optimal point.

Table 5 summarises the results for each of the residential buildings, including the range of cost-optimal energies based on the various sensitivities. For most building types, the national standard is within the cost-optimal range. Over the build mix, the national standard meets the requirement of being less than 15% above the average cost-optimal primary energy.

An analysis was also undertaken of the technology solutions on the cost-optimal curve:

- Heating technology: The solutions were segregated with typically the lowest primary energies achieved using gas heating with solar hot water. Gas heating solutions appeared at greater energies, while some biomass heating solutions were towards the right hand side of the cost-optimal curve.
- Fabric and PV: On the curve, there were several solutions for each heating technology with differing fabric and PV packages. The solutions with the lowest primary energy pushed the fabric to package F4 and the PV to 30%.
- Cost-optimal: From a societal perspective, the cost-optimal solution was fabric package F2, no PV and either biomass for homes and gas for flats. From a private investor perspective, gas heating was the preferred technology for all dwelling types.

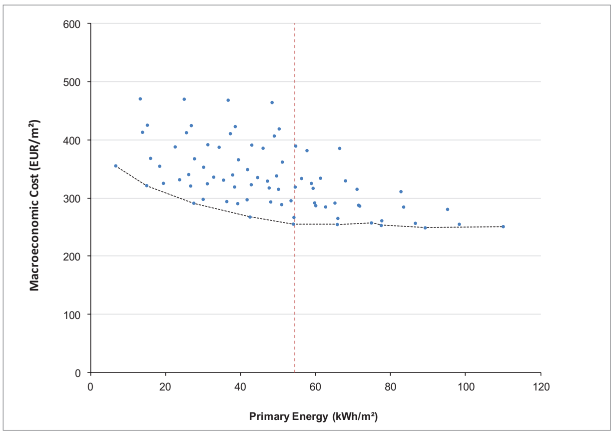

Figure 2: Semi-Detached House (Societal Perspective, 4% Discount Rate).

Table 5 – Residential cost-optimal primary energy values

Building Category	National Standard (kWh/m2/yr)	Cost Optimal (kWh/m2/yr)	Sensitivity Range (kWh/m2/yr)
Bungalow	67	110	33-139
Detached house	55	90	45-113
Semi-detached house	54	89	49-110
Mid-floor flat	57	79	57-94
Top-floor flat	65	92	68-105

3.2 Non-residential results

Figure 3 shows the results of the societal perspective analysis, using the baseline discount rate and costs, for the Naturally-Ventilated Office. The red dashed line marks the current standard, which is greater than the cost-optimal primary energy.

Table 6 summarises the results for each of the non-residential buildings, including the range of cost-optimal energies based on the various sensitivities. For all building types, the national standard is above the cost-optimal range. Over the build mix, the national standard is greater than 15% above the average cost-optimal primary energy.

An analysis was also undertaken of the technology solutions on the cost-optimal curve. This was more complex for non-residential buildings given the greater range of building types.

- Heating technology: Typically, the heating technology with the lowest primary energies was GSHP heating. In the Hotel, this included the addition of solar hot water also. The solutions with the highest primary energies always used gas heating. CHP did not feature in the cost-optimal solutions in any of the reference buildings.

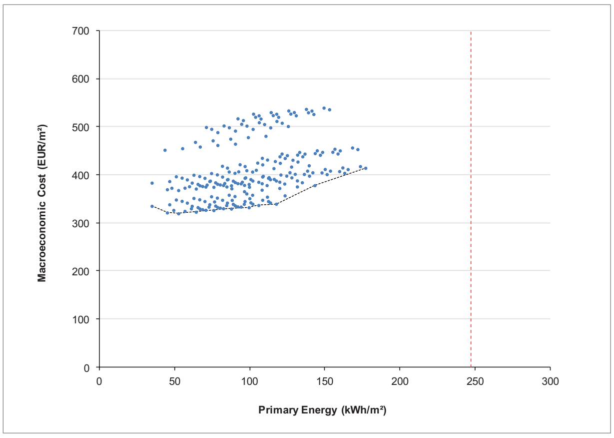

Figure 3: Office (NV) (Societal Perspective, 4% Discount Rate).

Table 6 – Non-residential cost-optimal primary energy values

Building Category	National Standard (kWh/m2/yr)	Cost Optimal (kWh/m2/yr)	Sensitivity Range (kWh/m2/yr)
Retail (Air Conditioned)	726	239	227-338
Office (Natural Ventilation)	247	52	35-103
Office (Air Conditioned)	366	102	101-179
School (Primary – Natural Ventilation)	111	55	8-80
Hotel (Air Conditioned)	507	284	243-330

- Fabric, Services and PV: On the curve, there were several solutions for each heating technology with differing fabric, services and PV packages. The solutions with the lowest primary energy pushed the fabric to package F3, the services to package S3 and the PV to 40%.
- Cost-optimal: At the cost-optimal point, GSHP was the selected heating technology in most cases, although the School used gas heating. The fabric varied from F1 to F3 and similarly the services varied from S1 to S3. In all cases the maximum-sized PV array was selected, except for the School where no PV was used.

3.3 Sensitivity analysis

It is useful to review in more detail the results of the sensitivity analysis.

Both reducing the energy prices and increasing the discount rate reduced the cost of energy over the calculation period. This tended to have two impacts.

- It made solutions with higher primary energy demand relatively more attractive with the cost of energy consumption over the calculation period becoming cheaper in terms of net present value. Indeed, for some non-residential buildings, increasing the discount rate from 3% to 6% as much as doubled the cost-optimal level of primary energy.
- It often changed the preferred heating technology. In residential buildings, gas tended to be the cost-optimal solution for lower energy prices, while biomass was preferred at higher energy prices. It is noted that the gas and biomass energy prices do come from different sources and this analysis assumes their comparability.

The sensitivity analysis of PEFs and the price of carbon showed little impact when averaged over the calculation period. In both instances, the sensitivity case simply increased the cost-optimal primary energy, without changing the optimal technology for the lowest cost solution. Only in one non-residential building (Air-conditioned Office) did the cost-optimal solution change. In this case, a less efficient services package was selected.

No learning rates were included in this analysis and it would be expected, for example, that PV would become more cost-effective over time, which would affect the cost-optimal primary energy and the associated technology solution.

4. Discussion

The results presented in the previous section show that the national standard for residential buildings is near, or in some cases, beyond cost-optimal. The standard in non-residential buildings is far above the cost-optimal point in all cases. This section discusses these two results in further detail.

4.1 Residential buildings

As the requirements for new dwellings are already in the cost-optimal range and are better than the cost-optimal level in many cases, there is no plan to review the current requirements for new dwellings to achieve cost-optimal levels. These cost-optimal calculations will be used to inform the roadmap to Nearly Zero Energy Buildings and associated NZEB targets as required by the EPBD Recast.

Nonetheless, this analysis does highlight an important issue regarding the role of biomass heating in Nearly Zero Energy Buildings. The analysis shows that biomass heating has, at best, only a marginal benefit in primary energy terms. The primary energy factor for biomass is similar to natural gas, but the efficiency of biomass boilers is poorer than that of equivalent natural gas boilers. No doubt biomass heating will be an important alternative in Ireland in future, especially since the gas network is relatively limited. However, to achieve Nearly Zero Energy Buildings, alternative heating sources or additional on-site generation technologies will be required.

4.2 Non-residential

Part L for non-domestic buildings was last revised in 2008 to include a maximum permitted whole building energy performance coefficient and a carbon dioxide performance coefficient, calculated in comparison with a reference building. The regulation and guidance is currently undergoing a review process due for completion in 2014. The Department of Environment Community and Local Government is committed to the new regulation and guidance achieving cost-optimal levels. This will be the first milestone on the roadmap for non-residential buildings to Nearly Zero Energy Buildings, which is due for public buildings in 2018 and for all buildings by 2020. While there are clearly considerable opportunities for improvement across all non-residential buildings, the revised standard will need to consider additional factors beyond cost-optimality, such as buildability, technology supply chain or the robustness of newer technologies.

Indeed, setting a cost-optimal standard in non-residential buildings is not straightforward due to the varied energy demand profiles. For example, the Naturally-Ventilated Office and the School are similar in terms of servicing strategy and have a similar total primary energy demand at the cost-optimal point (52 kWh/m² for the Naturally-Ventilated Office and 55 kWh/m² for the School). However, in the Naturally-Ventilated Office lighting is the predominate energy demand, far exceeding the heating demand (28 kWh/m² against 13 kWh/m²). The School is the opposite, with the heating energy demand three times the lighting energy demand (28 kWh/m² against 9 kWh/m²).

At the cost-optimal point, the different energy profiles have a clear impact on the selected packages. In the Naturally-Ventilated Office the cost-optimal point is achieved with the maximum-sized PV array and GSHP heating, while the selected fabric package is the minimum, package F1. In the School, the cost-optimal point does not require any PV, selecting gas heating and improving the fabric to package F3. This serves to illustrate the great diversity between non-residential buildings, since apparently similar building types may have quite different cost-optimal solutions.

It should also be noted that adding PV often achieves large primary energy reductions, while incurring very little additional lifecycle cost. Adding PV was most cost-effective in the School. Beyond the cost-optimal point, increasing the PV array from 0% to 40% reduced primary energy from 52 kWh/m² to 4 kWh/m², with a macroeconomic cost increase of only 8 EUR/m². Adding PV to the Air-Conditioned Office had a similarly high cost-effectiveness, although the size of the primary energy reduction was limited by the available roof area. The precise cost and benefits depend on the both the estimation of long-term primary energy factors and electricity costs, nonetheless, PV is a favourable addition when viewed over the lifecycle calculation period.

5. Conclusion

This paper has described the first cost-optimal assessment of buildings in Ireland undertaken in accordance with Article 5 of the EPBD Recast. The results show that for residential buildings the current national standard is within, or beyond, the cost-optimal range. However, for non-residential buildings the current standards lie outside the cost-optimal range.

Consequently, there are various implications for future updates to the national standard. This analysis showed that some solutions on the cost-optimal curves in residential buildings may contain biomass heating. However, the impact of biomass heating in Nearly Zero Energy Buildings will be limited by the primary energy factor of the fuel and the efficiency of the boilers.

The analysis of non-residential buildings showed more variability in the cost-optimal solution. In most cases, adding PV and selecting GSHPs was preferred, although the cost-optimal solution for the School maximised fabric improvements. Meanwhile, in several cases, and for very little additional lifecycle cost, significant primary energy reductions were achieved through the inclusion of the largest-sized PV arrays.

Acknowledgements

This paper contains material taken from the full cost-optimal calculations report [DECLG, 2014] and is reproduced with the consent of the Department of Environment, Community and Local Government.

References

Commission Regulation (EU) No. 244/2012 of 16 January 2012 on the Energy Performance of Buildings by Establishing a Comparative Methodology Framework for Calculating Cost-Optimal Levels of Minimum Energy Performance Requirements for Buildings and Building Elements.

Council Directive 2010/31/EU of 19 May 2010 on the Energy Performance of Buildings (Recast).

Department of Education and Skills. 2013. *Exemplars and Template Designs*. [Online]. [Accessed: November 2013]. Available at: http://www.education.ie/en/School-Design/Exemplars-Template-Designs/Exemplars-and-Template-Designs.html.

Department of Energy and Climate Change. 2013. The *Interdepartmental Analysts' Group (IAG) Toolkit Supporting Tables.* [Online]. [Accessed: November 2013]. Available at: http://tools.decc.gov.uk/en/content/cms/about/ec_social_res/iag_guidance/iag_guidance.aspx.

Department of the Environment, Community and Local Government, 2014. *Report on the Development of cost-optimal Calculations and Gap Analysis for Buildings in Ireland under Directive 2010/31/EU on the Energy Performance of Buildings (Recast).* Dublin: DECLG.

Department of the Environment, Community and Local Government, 2012. *Towards a New Climate Change Policy: Interim Report of the NESC Secretariat.* Dublin: DECLG.

European Commission, 2010. *EU Energy Trends to 2030 – Update 2009.* Luxembourg: Publications Office of the European Union.

Guidelines accompanying Commission Regulation (EU) No. 244/2012 of 16 January 2012 on the Energy Performance of Buildings by Establishing a Comparative Methodology Framework for Calculating Cost-Optimal Levels of Minimum Energy Performance Requirements for Buildings and Building Elements.

National Standards Authority of Ireland. 2007. IS EN 15459:2007. *Energy performance of buildings – Economic evaluation procedure for energy systems in buildings.* Dublin: NSAI.

Sustainable Energy Authority of Ireland, 2012. BioEnergy Supply Curves for Ireland 2010-2030. Dublin: SEAI.

UCD Energy Research Group, 2007. Energy Efficiency Regulations for New Dwellings and Options for Improvement. Dublin: Department of Environment, Heritage and Local Government.