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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.

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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 CO₂ emissions estimated that a total of 12.6 million tonnes of CO₂ 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 CO₂ 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.
A cost-optimal assessment of buildings in Ireland using Directive 2010/31/EU

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 Moslet to confirm typical area, form, glazing ratios, and construction methods [DECLG, 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.

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

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.
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

<table>
<thead>
<tr>
<th>Fabric</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall U-value (W/m²K)</td>
<td>0.27</td>
<td>0.20</td>
<td>0.13</td>
<td>0.13</td>
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<tr>
<td>Roof U-value (W/m²K)</td>
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<td>Floor U-value (W/m²K)</td>
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<td>0.13</td>
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<tr>
<td>Window U-value (W/m²K)</td>
<td>1.6</td>
<td>1.4</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Thermal Bridging (y-value)</td>
<td>0.15</td>
<td>0.08</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Air Tightness (m³/m².hr @ 50 Pa)</td>
<td>10</td>
<td>7</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Heating Strategy</td>
<td>Natural Ventilation</td>
<td>MVHR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4 – Measures included in non-residential analysis

<table>
<thead>
<tr>
<th>Fabric</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
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<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>Roof U-value (W/m²K)</td>
<td>0.25</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Floor U-value (W/m²K)</td>
<td>0.25</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Window U-value (W/m²K)</td>
<td>1.8</td>
<td>1.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Improved Thermal Bridging</td>
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<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Air Tightness (m³/m².hr @ 50 Pa)</td>
<td>7</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Services</td>
<td>S1</td>
<td>S2</td>
<td>S3</td>
</tr>
<tr>
<td>Lighting (Lumen)</td>
<td>55</td>
<td>60</td>
<td>65</td>
</tr>
<tr>
<td>Daylight Lighting Control</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Occupancy Lighting Control</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Heat Recovery</td>
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<td>NO</td>
<td>65%</td>
</tr>
<tr>
<td>Chiller Efficiency (COP)</td>
<td>3.5</td>
<td>4.5</td>
<td>5.5</td>
</tr>
<tr>
<td>AHU SFP</td>
<td>2.2</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>FCU SFP</td>
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<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Demand Control Ventilation</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Additional Services</td>
<td>FC1</td>
<td>FC2</td>
<td></td>
</tr>
<tr>
<td>Free Cooling (FC)</td>
<td>NO</td>
<td>YES</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4 – Measures included in non-residential analysis

<table>
<thead>
<tr>
<th>Fabric</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
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<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>Roof U-value (W/m²K)</td>
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<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Floor U-value (W/m²K)</td>
<td>0.25</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Window U-value (W/m²K)</td>
<td>1.8</td>
<td>1.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Improved Thermal Bridging</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Air Tightness (m³/m².hr @ 50 Pa)</td>
<td>7</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Services</td>
<td>S1</td>
<td>S2</td>
<td>S3</td>
</tr>
<tr>
<td>Lighting (Lumen)</td>
<td>55</td>
<td>60</td>
<td>65</td>
</tr>
<tr>
<td>Daylight Lighting Control</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Occupancy Lighting Control</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Heat Recovery</td>
<td>NO</td>
<td>NO</td>
<td>65%</td>
</tr>
<tr>
<td>Chiller Efficiency (COP)</td>
<td>3.5</td>
<td>4.5</td>
<td>5.5</td>
</tr>
<tr>
<td>AHU SFP</td>
<td>2.2</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>FCU SFP</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Demand Control Ventilation</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Additional Services</td>
<td>FC1</td>
<td>FC2</td>
<td></td>
</tr>
<tr>
<td>Free Cooling (FC)</td>
<td>NO</td>
<td>YES</td>
<td></td>
</tr>
</tbody>
</table>
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 ($CL$) is defined in the equation below:

$$CL = C_0 + \sum_{t=1}^{n} \left( C_{\text{m}}(t) + C_{\text{r}}(t) \right) \cdot \left( \frac{1}{(1+r)^t} \right)$$

where:
- $C_0$: initial investment cost
- $C_{\text{m}}(t)$: annual cost for package of measures during year $t$
- $C_{\text{r}}(t)$: cost of replacement of package of measures at the end of the calculation period (discounted to starting year $t_{\text{ref}}$)
- $t$: 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 DECC. 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.
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.

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.
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 I 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 predominant 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 costs.
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.