Sensitivity Analysis of the EPBD Energy Performance Grading of Buildings

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ABSTRACT

The Energy Performance of Buildings Directive (EPBD) obligates EU member states to develop a reliable methodology capable of calculating and certifying the energy performance (EP) of their building stock. In this paper, studies on a series of school buildings, based on Standard prEN15217:2005, consider the impact that a lack of transparency in the data gathering procedure might have on the repeatability of the EP grades. The results showed that variations in EP grades ranging from 0.06 to 1.06 EP grades were possible. The sensitivity of prEN15217: 2005 to variations of input parameters was also investigated and was found to be most sensitive to air change rates and boiler efficiency with grade changes of up to 1.5 grades possible. It was also found that prEN15217:2005 was not heavily influenced by improvements in roof and window specifications.

1. INTRODUCTION

As global energy demands continue to increase, security of energy supply and climate change issues have come to the fore, resulting in a renewed impetus to curb energy consumption across key energy sectors. Buildings, which are responsible for approximately 40% of EU primary energy consumption, have an important role to play in realising this objective (European Commission 2000). One of the means by which the European Commission is addressing this agenda in the building sector is by way of the Energy Performance of Buildings Directive (EPBD) (European Commission 2002). This Directive has the potential to be an important instrument in motivating all EU member states to achieve higher building energy performance. This paper investigates two key issues central to the successful implementation of the Directive. First, it considers the impact that a lack of transparency in the data gathering procedure may have on the repeatability of the EP grade calculated. Second, it examines the influence of potentially cost effective retrofit measures on a buildings EP grade.

2. THE EPBD AND ENERGY RATING

There are two types of building EP ratings of concern in the context of the EPBD, (i) an operational rating, and (ii) an asset rating (European Commission 2002). An operational rating is based on metered energy and hence rates the performance of the occupier as well as the building. An asset rating, on the other hand, is a calculated approach and represents the intrinsic energy potential of the building under standardised conditions (prEN 2005). The sophistication of the calculation tool to be used in any calculated approach to building energy performance assessment is of core importance. Sahlin highlighted that although hand calculations may be sufficient for the prediction of the annual energy consumption of simple buildings, more complex buildings may require more sophisticated calculation methods (Sahlin 2004). Burke et al., in a study based on the analysis of a sample of school buildings in Ireland, found that estimates of annual space heating energy consumption varied by up to ±25% between predictions made using a simplified calculation method and those from dynamic simulation using EnergyPlus (Burke 2006). This gives rise to a potential concern which relates to the influence that the use of a low technology approach determining building specifications will have on the result of the energy performance calculation and hence its grading. This appears to be of vital importance as no matter how accurate a calculation method is, if the input data to the calculation method is inaccurate, then the result will be inaccurate. This issue appears to be of particular concern given that Member States have indicated that a relatively low cost approach to building EP certification will be adopted where uncertainties in design evaluations can be quite substantial (deWit 2001). Given these concerns, it is important that all building assessors are aware of the parameters which have a significant influence on the energy performance grade of a building.

3. METHODOLOGY

Assessments were carried out on primary schools throughout Ireland. Four schools were selected from a sample of thirty six. The methodology considered each of the following issues: data gathering, the calculation method, and sensitivity analysis.

3.1 Data Gathering

The data gathering approach employed sought data at two levels; (i) stock data on the selected building typology, and (ii) detailed data on a selected number of existing buildings. The stock data gathering phase aimed to direct the study towards schools with available quality data on their construction and renovation history. This was carried out by disseminating 500 questionnaires to a representative sample of 3300 schools. The second data gathering phase involved a site visit to ten primary schools which possessed building drawings and a high level of knowledge of their renovation history. The site visits focussed on obtaining building geometry, construction material, HVAC system, activity and schedule data. This constraint was applied so as to stay consistent with a €300 maximum grading cost as recommended by Sustainable Energy Ireland [4]. From this group of ten schools, four schools of varying location, size and age were selected.

3.2 Calculation and Certification Methods

As no EPBD compliant calculation method was developed for the Irish EPBD methodology at the time of the study, the calculation method employed in the research was based on EnergyPlus (EnergyPlus2006) with a DesignBuilder interface (DesignBuilder 2006). The draft European standard prEN15217:2005 was used for certification.

3.3 Sensitivity Analysis

The use of inference methods and reference data was employed for the estimation of a number of key building parameters. This approach was largely based on assessor interpretation of on-site conditions and supplemented by available records. Four parameters were considered; building air change rate, boiler efficiency, roof insulation and window specification. The building air change rate and boiler efficiency parameters were selected due to the lack of transparency involved in their definition. As experimental testing of building air tightness as applied in this case study would not be practical in an implemented EPBD EP assessment, default values of between one and two ACH were defined (CIBSE 2002). Similarly, it became clear from the site visits, that determining the efficiency of a boiler was also beyond what might be expected of an assessor. Due to the lack of transparency which this may cause, the investigation of the EP certification schemes sensitivity to boiler efficiency was considered important. From the questionnaires returned, it was found that 73% of pre-1979 school building windows were retrofitted. Given the frequency of this and other retrofit measures, it is important that their influence on building EP grade is understood and for this reason window specification and roof insulation were investigated in the parametric study analysis. For each of the four identified parameters, a sensitivity analysis specification was defined with respect to the information gathered during the data gathering phase. The specifications defined for each parameter were chosen to represent each of the following scenarios; (i) worst case, (ii) 1991 regulations, (iii) 1997 regulations, (iv) 2006 regulations and (v) best case (see Table 1).

Table 1: Parameter Sensitivity Analysis Specification data

Specification	Seasonal Boiler Efficiency	ACH (hr^{-1})	Window Specification (W/m^2K)	Roof Insulation (W/m^2K)
Worst Case	50%	2.0	5.8	1.20
1991 regulation	60%	1.5	5.6	0.40
1997 regulation	70%	1.0	3.3	0.25
2006 regulation	80%	0.5	2.2	0.16
Best case	90%	0.1	1.3	0.10

4. RESULTS

4.1 School A

This building was constructed in 1970 and consisted of a single storey school of floor area 570m^2. The base case EP grade was calculated as an E grade. As the classification indicator was 2.01 and is only just outside a D grade, the transparency and repeatability of the input data are especially important in ensuring the accuracy of its EP grade. As both the ACH and boiler efficiency figures assigned were defaults, the interpretation of the assessor of the on-site conditions may have influenced the EP grade that the building was attributed. The school was located in an exposed rural location and therefore a larger ACH than the default 1.0 ACH specified could be considered to be more appropriate. Analysis indicated that the use of a 2.0 ACH increased the predicted energy consumption of School A by over 9,500 kWh/year, it did not alter its grade.

Table 2: School A - ACH and boiler efficiency results

ACH	Space Heating Delivered (kWh/yr)	Energy Performance Indicator (kWh/m^2/yr)	Classification Indicator	EP Grade
Worst (2.0)	42,704.7	74.92	2.31	E
1991 regs (1.5)	38,043.8	66.74	2.17	E
1997 regs (1.0)[a]	33,009.6	57.91	2.01	E
2006 regs (0.5)	27,588.7	48.40	1.77	D
Best (0.1)	22,920.6	40.21	1.55	D
Boiler Efficiencies				
Worst (50%)	39,611.5	69.49	2.21	E
1991 regs (60%)[a]	33,009.6	57.91	2.01	E

1997 regs (70%)	28,294.0	49.64	1.80	D
2006 regs (80%)	24,757.2	43.43	1.63	D
Best (90%)	22,006.4	38.61	1.51	D

[a] Base case definitions and results

Therefore, in this case, the use of a default air change rate figure does not affect the EP grade of the building. It was not possible to confirm the boiler efficiency without physical testing, therefore a default seasonal efficiency of 60% was assigned based on a typical existing oversized boiler efficiency (CIBSE 2002) However, the range of default values for such a boiler ranges from 40% to 70%. As can be seen in Table 2, when a boiler efficiency of 50% is applied, the classification indicator goes from a base case 2.01 to 2.21, but the grade remains the same. However, if an efficiency of 70% is applied, the EP grade of the building changes from an E to a D grade. This indicates a high possibility of non-repeatability should another assessor carry out the assessment. Considering the influence of window specifications, the parametric study shows that School A, which had almost two thirds of its windows retrofitted to 1997 regulations, would have the same EP grade if it had not retrofitted its windows. Neither would the EP grade have changed if all the windows were retrofitted to 1997 regulations. However, if all the original windows were replaced with windows of thermal transmittance 2.2 W/m^{2}K (2006 regulations), an EP grade of D was predicted.

Table 3: School A roof insulation window results

U-value (W/m^{2}K)	Space Heating Delivered (kWh/yr)	Energy Performance Indicator (kWh/m^2/yr)	Classification Indicator	EP Grade
Window				
Worst (6.0)	34,493.3	60.51	2.058	E
1991 (5.8)	34,458.0	60.45	2.057	E
Base Case	33,009.6	57.91	2.01	E
1997 (3.3)	32,511.3	57.04	1.996	E
2006 (2.2)	31,468.4	55.21	1.947	D
Best (1.4)	31,519.2	55.30	1.949	D
Roof				
Worst (Uninsulated)	37,689.3	66.12	2.156	E
Base Case	33,009.6	57.91	2.01	E
1991 (0.40)	28,857.3	50.63	1.826	D
1997 (0.25)	28,186.2	49.45	1.794	D
2006 (0.20)	27,772.9	48.72	1.775	D
Best (0.10)	27,326.1	47.94	1.754	D

Similarly, the base case specification for School A shows that over half of the building's roof area was retrofitted with 200mm of glasswool insulation almost meeting 2006 regulation standards. Despite this, the building EP grade is the same as if uninsulated (see Table 3). If the whole roof was brought up to 1991 regulation standard the EP grade would improve to a mid-bandwidth D grade. Figure 1 illustrates the sensitivity of School A to the different regulation standards. In all the EP grades, it can be seen that School A would improve from a worst case F grade to a best case B grade if the various building regulations were implemented in their totality. This demonstrates the ability of prEN15217:2005 to reflect large scale improvements in building energy performance if comprehensive retrofit solutions are prescribed.

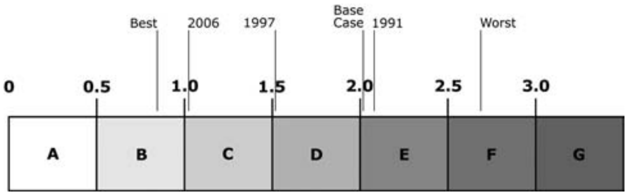

Figure 1: Impact on the EP of School A of applying all of the selected parameters

4.2 School B

School B consists of two double storey blocks. The total internal area of the school is 1650m^2. For School B, as with School A, the air change rate and the boiler efficiency parameters have a significant impact on the calculated EP and EP grade. School B is located in an exposed coastal setting. A default air change rate of 1 ACH was assigned. It is possible, depending on the air tightness of School B, that an air change rate of 2 ACH may be more appropriate. If, in fact, this is the case, it can be seen from Table 2 that by applying this air change rate instead of the default value, it not only increases the calculated space heating energy consumption by over 23,000kWh (an increase of almost 40%), but also changes the buildings grade from a high C to a mid range D grade. School B's boiler was less than 10 years old, well insulated and serviced annually. On this basis, it was attributed a default 80% boiler efficiency (between the CIBSE (CIBSE 2002) recommendations for a "good modern boiler design" and a "modern high efficiency non-condensing boilers"). As can be seen in Table 4 by replacing the boiler the performance of the building may be improved by up to two grades, from an E (if the boiler efficiency was 50%) to a C grade. Furthermore, it should be noted that if the efficiency of the boiler was closer to 70% than 80%, the building would have been attributed a D grade rather than a C grade. In 1999 all of School B's glazing was retrofitted to 1997 regulations standards and its entire roof was brought close to 2006 roof regulations standard (U = 0.23 W/m^{2}K). Given this investment, it would be expected that the EP grade of the building would improve. The parametric study results in Figure 2 show that if School B's roof was still uninsulated, it would consume approximately 20,000 kWh/year more and would be D rated. If the roof insulation had only been brought up to 1991 regulations standard however, it would consume approximately 1000 kWh/year more than it currently does and would still be C rated. Figure 2 also shows that if School B's windows had not been retrofitted to at least 1997 regulations specifications it would be a D rated building.

Table 4: School B air change rate and boiler efficiency PSA results

	Space Heating Delivered Energy (kWh/yr)	Energy Performance Indicator (kWh/m²/yr)	Classification Indicator	EP Grade
ACH				
Worst (2.0)	85997.4	52.07	1.81	D
1991 (1.5)	74347.3	45.02	1.63	D
1997 (1.0)*	62357.8	37.76	1.45	C
2006 (0.5)	47637.1	28.84	1.23	C
Best (0.1)	34827.3	21.09	1.04	C
Boiler Efficiency				
Worst (50%)	98686.8	59.75	2.00	E
1991 (60%)	82239	49.79	1.75	D
1997 (70%)	70490.6	42.68	1.58	D
2006 (80%)*	62357.8	37.76	1.45	C
Best (90%)	54826	33.20	1.34	C

* Base case definitions and results

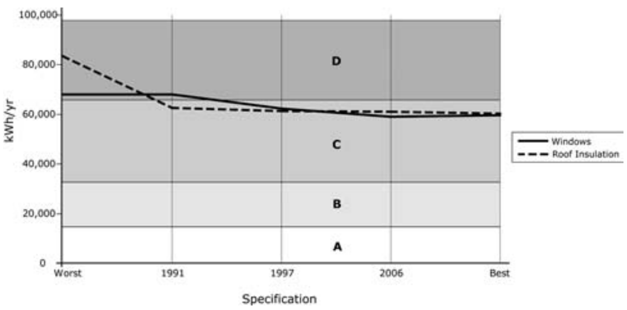

Figure 2: School B window and roof insulation: parametric study results

4.3 School C

School C was built in 1953 and consists of three two-storey blocks, varying in height, and a single storey hall. The total internal area of the school was 2050m². Specifications on the external wall construction of the school were not available. The wall was assumed to consist of 300mm thick blockwork. A new gas fired non-condensing boiler was installed in 1997 and a SEDBUK C rating and an 80% seasonal efficiency was assumed (CIBSE 2002). Examining Figure 3, it can be seen that for School C, the ACH and the boiler efficiency specifications were observed to give rise to the biggest variation in the building's EP grade. Both parameters exhibit potential grade changes of approximately 1.4 grades. Thus their accurate specification is of critical importance to the repeatability of the EP grade attributed. However, the impact of window and the roof insulation is observed to have a weaker influence on EP grade for the building. During the mid-1990s, all of the single glazed windows (380m² approx) were retrofitted with double glazed windows. Despite this, the study shows that its grade does not change, and neither would it, even if it had been retrofitted with triple glazed PVC framed windows (Figure 3). It can be observed that the difference between specifying 3mm single glazed aluminium frame windows and triple glazed windows is only 0.08 of an EP grade and a decrease in consumption of 5,500kWh per year. Newer and better quality windows will have the effect of reducing infiltration. Similarly, the impact of roof insulation on the performance of School C is much less than that for the other three schools. Across the range of roof specifications School C's EP grade changes by only 0.4 grades compared to 0.8, 0.69 and 0.79 in Schools A, B and D respectively. The reason for this is believed to be due to solar radiation. As shown in Figure 3, the largest decrease in energy consumption occurs when an uninsulated roof is brought up to 1991 regulations standard.

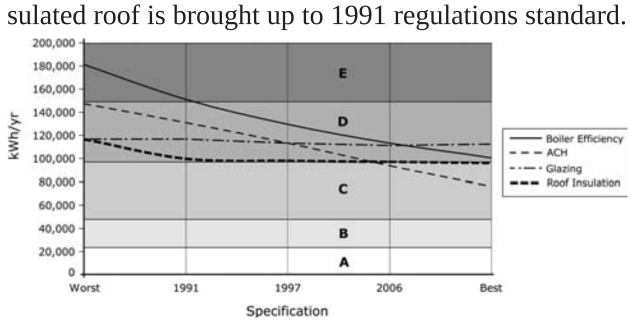

Figure 3: School C parametric study results

4.4 School D

School D was built in 1976 and was a single storey rectangular building with an internal clear space 2.6m in height. The total internal area of the school was 214m². The external walls are 280mm thick and were assumed to be medium weight blockwork with an uninsulated cavity. Inspection of the roof revealed that it was uninsulated. Examining Figure 4 it can be seen that boiler efficiency and air change rate have a substantially greater effect on the EP grade than does the roof insulation and the glazing. Interestingly, the air change rate results have the smallest affect (1.25 grades from the worst ACH to the best ACH) on School D, the building with the smallest volume. It was found earlier however, that the EP grade of School B, which had a smaller volume than School C, was affected more by the air change rate sensitivity analysis.

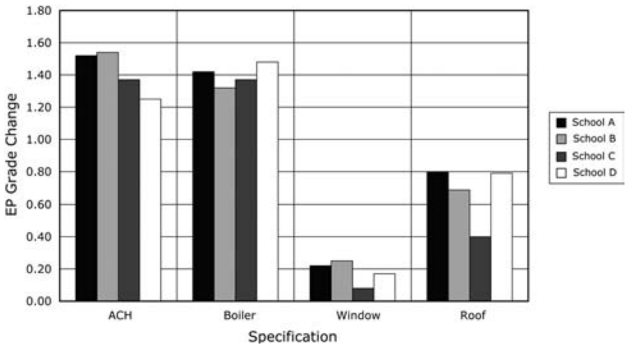

Figure 4: EP grade change that each parameter made on each school building

Given that School D has a relatively inefficient boiler, approximately one third of its windows are single glazed and its roof is uninsulated, the subsequent findings from this parametric study are relevant in illustrating the potential of prEN15217:2005 to reflect more generally the energy saving retrofitting measures on the EP grade of a given building. They are summarised as follows: if the roof is insulated, its EP grade improves by at most, one grade regardless of whether it is insulated to 1991 levels or best case (passive house standard); if the building is completely retrofitted with triple glazed windows it does not alter the EP grade of the building; if the existing boiler is replaced with a new condensing boiler, the grade of the building improves by almost a grade and a half to a low D grade; if the buildings roof, window, ACH and boiler efficiency are brought up to 2006 regulation standard (0.16W/m^{2}K, 2.2W/m^{2}K, 0.5 and 80% respectively), its EP grade improves by two grades to a C rating (Figure 5).

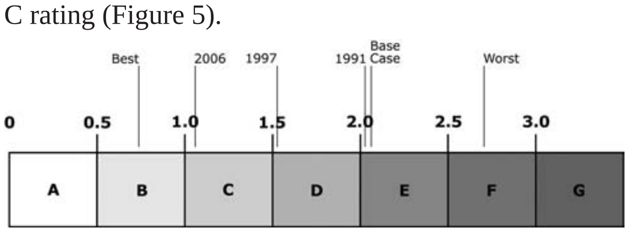

Figure5: The combined influence of the regulation parameter set on School D

5. CONCLUSIONS

The European standard EP grading scheme, pr EN15217:2005, was found to be most sensitive to variations in the air change rate and boiler efficiency parameters. Across the four school buildings investigated, the application of the parameter sensitivity analysis for air change rate parameters showed a minimum of 1.25 and a maximum of 1.54 EP grade changes for the worst and best case respectively. The equivalent results for the boiler efficiency parameter showed minimum and maximum EP grade changes of 1.32 and 1.48 grades respectively. It was found that prEN15217:2005 was not heavily influenced by improvements in roof and window specifications. Although these retrofits were the most common carried out on Irish school buildings, the potential for improvement in EP grade from worst to best case specifications was found to be as low as 0.08 for windows and 0.4 for roofs. Knowledge on the relative influence of parameters on the EP and EP grade of a building is of utmost importance in ensuring that an EP grading scheme such as prEN15217:2005 is successfully implemented. It enables assessors to take special care when setting parameters which are uncertain. It aids in optimising the EP and EP grade improvement through energy saving retrofit measures and it is also educates building owners so that they are not disillusioned by the credibility of the EP certification scheme. Finally, the findings of this research suggest that the EP and EP grades derived for buildings are clearly approximations based on best assumptions. There use in subsequent comparative studies, in the development of national policy and regulations and in encouraging owners to improve the performance of their building stock must be see as relative comparators of building performance and cannot not be considered as absolute performance indicators.

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