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THE TRANSPARENCY AND REPEATABILITY OF BUILDING ENERGY PERFORMANCE CERTIFICATION

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ABSTRACT

The European Union's (EU) Energy Performance of Buildings Directive (EPBD) aims to increase the energy performance (EP) of buildings by requiring EU Member States to develop an EP calculation methodology and to certify the EP of their buildings. Dynamic simulation offers an important means of developing accurate EP ratings. However, its value may be undermined due to the difficulty in obtaining transparent and repeatable input data on existing buildings. Using the EnergyPlus simulation engine and a DesignBuilder interface this research investigated the impact of this difficulty on the EP grade of four primary school buildings. Survey and on-site refinement phases enabled base case buildings to be modelled, a standard activity schedule to be developed and the lack of transparency and repeatability in the specification of the infiltration air change rate (ACH), the boiler efficiency and glazing parameters to be seen. Using parametric sensitivity analysis in combination with the draft European standard for the energy certification of buildings, prEN15217:2005, it was found that variations in the specification of these parameters could lead to up to two grade changes for boiler efficiency and ACH, one grade change due to the sensitivity of the glazing parameter and three grade changes should their affect be combined. Although repeatability and transparency can be improved through careful training of building EP assessors and the awareness of a particular parameters affect on an EP grade, it will be difficult to ensure repeatability and transparency using a dynamic simulation EP grading methodology if experimental testing is not utilised.

Keywords: energy performance, energy auditing, performance modelling, EPBD

1. INTRODUCTION

Two key factors have influenced the drive for energy efficiency in the EU and in the global community as a whole; the depletion of global fossil fuel reserves, and climate change.

The Kyoto Protocol compels the EU to reduce, by 8%, its 1990 greenhouse gas (GHG) emission levels by 2008-2012. As of 2003, the EU had reduced emissions by only 1.7%, less than a quarter of the 8% target [1]. With buildings being the single largest energy consuming sector and accounting for 40% of the EU's final energy demand [2] it is a necessity that building energy performance becomes a priority for all EU Member States.

The Energy Performance of Buildings Directive [3] (EPBD) was proposed by the European Commission in May 2001 and transposed into European law on the 4th January 2003. The Directive will be an important instrument to motivate all EU Member States to target and achieve higher building energy performance. The EPBD compels Member States to confront the inefficiencies of their buildings by requiring them to:

- Develop a methodology for calculating the energy performance of buildings.
- Establish and apply minimum energy performance requirements to new and existing buildings.
- Certify the energy performance of buildings over 1000m^2 and buildings which are constructed, sold or rented, and
- Inspect/provide advice on boilers and air-conditioning systems.

The Directive must be transposed into Member States laws by 4th January 2006, the only exception to this being if Member States do not have sufficient numbers of suitably qualified personnel to carry out the energy performance (EP) certification and the inspection of/provision of advice on boilers and air-conditioning systems. In this case, the transposition into Member States laws may be deferred until 4th January 2009.

The European funded BESTCert project was undertaken in response to the EPBD. The project was lead by the Building Research Establishment (UK) in partnership with University College Dublin's Energy Research Group (Ireland), Centre d'Energetique and Centre Scientifique et Technique du Bâtiment (France), Instituto per le Tecnologie della Costruzione (Italy) and the Danish partner Cenergia Energy Consultants. A key objective of BESTCert was to develop a common methodology for certifying the energy performance of buildings based on the "as built" or asset energy consumption of the building. An asset rating is "a measure of the intrinsic performance capability of the building, and rates the standard of the building fabric, building services equipment and the controls for a standardised pattern of use and climate" [4]. Underpinning such a system is the data gathering and energy performance calculation methodology. Following a study of suitable energy performance certification methodologies, two primary requirements of an EPBD compliant calculation methodology were highlighted; transparency and repeatability [4, 5]. Its market credibility and successful and widespread implementation is dependent upon this.

J.A. Clarke, in the preface to "Energy Simulation in Building Design" [6], states that a major problem encountered in the design of any energy system, in this case a building, is that the number of required parameters is large. He points out that simulation represents a possible solution to this problem. It follows that when assessing the energy performance of a building, simulation is to be considered as an important means of developing accurate energy performance ratings. Despite this the value of a simulation tool's attempt to accurately represent a building's energy balance may be undermined by the difficultly in obtaining quality and repeatable input parameters for assessment. This is particularly the case when assessing multiple existing buildings for comparative assessment as is typical in certification and energy labelling schemes.

The aim of this research was to:

1. Highlight the parameters required for the dynamic simulation determination of a building energy performance rating which are least likely to be repeatable and transparent, and
2. Investigate the consequence of variations in these input parameters on the energy performance grade (based on the proposed EPBD grading scale) of buildings as derived from dynamic simulation.

2. DATA GATHERING

Parametric data gathering was carried out on primary schools for pupils ranging in age from 4 to 12 years old. The major energy consumers in the primary schools investigated were space heating and electrical energy consumed by lighting and appliances. It was on these energy flows that the study focused.

The information available to building energy performance assessors when auditing existing buildings is rarely, if ever, as comprehensive as desired. Difficulties are encountered when attempting to assemble the data necessary to completely satisfy the EP certification methodology. The data gathering method employed in the present research to ensure the greatest quantity of quality information was broken down into an initial data gathering phase through the use of surveys and an on site data refinement phase.

The initial data gathering phase had two objectives. Firstly, it aimed to direct the research towards schools with quality data on their construction and renovation history. Secondly, it aimed to collate a working dataset of the Irish primary school building stock so as to develop a standard activity schedule to produce an asset rating. This initial data gathering phase was carried out by disseminating five hundred questionnaires to a representative sample of primary schools. Currently, there are approximately 3300 primary schools in Ireland. It was anticipated that the survey would result in a typical response rate of 10% [7] and in a sample group of fifty schools which CIBSE [8] recommends as the minimum for benchmarking purposes.

The questionnaire was designed so as to strike a balance between an acceptable response rate and obtaining as much information as possible on schools' construction, systems and schedules. This task was made more difficult due to the fact that many Irish primary schools are made up of more than one building and have had extensions or prefabricated buildings added over the years. In order to deal with this possibility, the questionnaire provided tick boxes for possible answers and space provision for alternative constructions or for schools that wished to expand.

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 schools renovation history. As at the time of this research no EPBD compliant methodology was in place, the sophistication of the parameter determination methods used was influenced by three interrelated factors:

1. The input parameters required by the dynamic simulation tool,
2. The expected energy performance rating assessment input time, and
3. The practicality of experimental determination.

3. THE SIMULATION TOOLS

The simulation tool employed in the research was the EnergyPlus simulation engine with a purpose built interface called DesignBuilder. EnergyPlus was developed by the U.S. Department of Energy, Lawerence Berkeley Laboratories, U.S. Army Construction Engineering Research Laboratories and the University of Illinois. EnergyPlus is a modular structured software tool based on the best attributes of the BLAST and DOE-2.1 software [9]. Formal independent testing has been an integral part of its development [10]. DesignBuilder version 0.8.0 was developed in parallel with the BESTCert project as an interface for EnergyPlus and as a possible energy performance certification tool. DesignBuilder version 0.8.0 facilitates the attribution of a building's construction, internal environment conditions, standard activity schedules and system characteristics to the simulation model in a quick and user-friendly manner. The initial development phase of DesignBuilder focussed on school buildings and hence the energyflows and construction methods commonly used in this construction type have been well defined. The greater the availability of information on a building's construction and system parameters the more accurate DesignBuilder 0.8.0 and EnergyPlus can be in representing and simulating its energy performance.

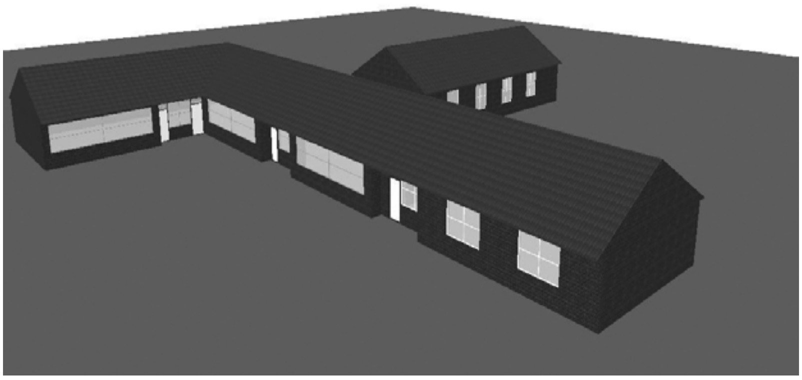

Figure 1. Visualisation of completed School A.

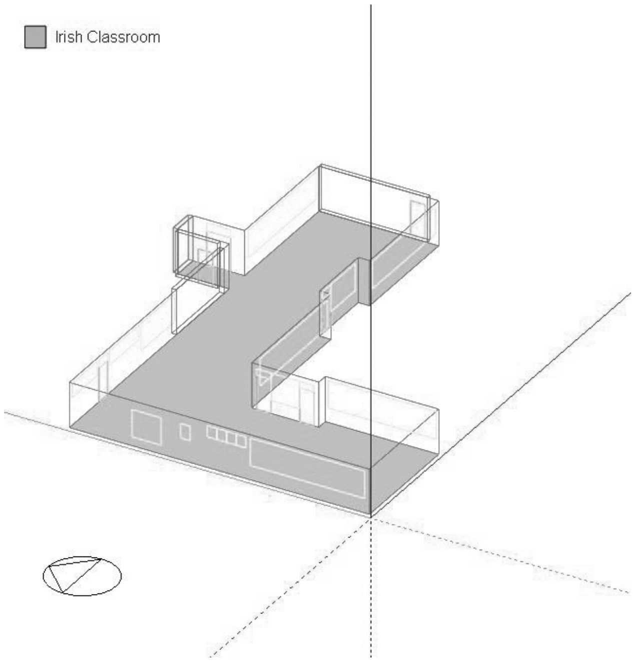

Figure 2. Block construction and definition of openings in School A.

3.1 Base Case Model Development

Of primary concern during the site visit data gathering phase was the confirmation and/or the inferring of the construction and the respective thermal transmittance of the schools' walls, roofs, windows, doors, and floors. Other key parameters included the air change rate of the building and the seasonal efficiency of the schools' boilers.

In Ireland, early indications suggest that the EP certification procedure, for residential buildings at least, will be a relatively short and cost effective procedure [11]. The site visit phase aimed to carry out an appropriately 'efficient' assessment. Hence, visual assessment, in addition to physical measurement, was used to fill in omissions in input parameters where in building records or drawings were available. Base case models for four primary schools were constructed in DesignBuilder 0.8.0. EnergyPlus was then used to simulate thermal and electrical energy performance results. The four schools varied in size from approximately 230m^2 to 2160m^2 and were built between 1953 and 1974. Two of the schools were located in a rural setting with the other two schools being situated in an urban and a suburban location. A standard activity schedule was developed for Irish primary schools from the occupancy and heating period data provided by the sixty-five questionnaires (13%) returned.

3.2 EP Rating Procedure

The draft European Standard prEN 15217 "Energy performance of buildings – Methods for expressing energy performance and for energy certification of buildings" [12] developed within the CEN EPBD work group was used to determine the EP rating of the base case models.

The energy performance grading procedure used was as follows:

1. Firstly the global performance, EP, for the base case buildings was calculated in kilograms of carbon dioxide per metre squared per year (kgCO_2/m^2/year). This was achieved by modelling and simulating the base case building using the dynamic simulation tools, the building drawings and the building's construction information.

2. The "Energy Performance Regulation" reference, R_r, and the "Building Stock" reference, R_s specifications were then defined. Based on the prEN15217 methodology the "Energy Performance Regulation" reference corresponds to the building regulations likely to be in place in 2006 and the "Building Stock" reference represents the energy performance specifications met by 50% of the building stock. This research utilised Ireland's 2003 draft non-domestic building regulations which are due to be implemented as part of the EPBD methodology [11] as the "Energy Performance Regulation" reference. The stock reference values were inferred from the information gathered in the

initial data gathering phase. Default values were used for the boiler efficiency and the ACH parameters. Both of these sets of specifications are outlined in table 1.

Table 1. Regulation and Stock Reference Specifications.

Element	**Stock Reference, Rs**	**2006 Regulations, Rr**
	W/m^2K (unless stated)	**W/m^2K (unless stated)**
External Walls	1.2	0.27
Ground Floor	2.05	0.25
Flat Roof	1.4	0.22
Pitched Roof (insulated at ceiling level)	0.47	0.16
Pitched Roof (insulated on pitch)	0.47	0.20
Windows and doors	4.9 and 2.2	2.20
Seasonal Boiler Efficiency	70%	90%
Infiltration Air Change Rate	1.5 (1/hr)	0.5 (1/hr)

3. The "Energy Performance Regulation" reference indicator, R_r, and the "Building Stock" reference indicator, R_s for the selected buildings were ascertained by applying the specification defined in Table 1 to the base case models and running the simulation tool.

4. The calculation of EP/ R_r and EP/ R_s was then carried out so as to aid in determining the EP grade of the base case building.

5. The building EP classification indicator C was then defined using the following criteria:
   a. If $EP/ R_r \leq 1$ then $C = EP/ R_r$.
      In this case the EP of the building is better than the 2006 Energy Performance Regulations
   b. If $EP/ R_s \geq 1$ then $C = 1 + EP/ R_s$.
      In this case the EP of the building is poorer than the Building Stock Reference.
   c. In all other cases take:
      $C = 1 + (EP – R_r)/(R_s – R_r)$.
      This case incorporates all EP indicators between the stock reference and the 2006 building regulations.

6. The EP grade of a building was then determined using the grading scheme outlined below, Table 2.

Table 2. Draft EP Grading Criteria as per prEN 15217.

Energy Performance Grade	**Criteria**
Grade A	If $C < 0.5$
Grade B	If $0.5 \leq C < 1$
Grade C	If $1.0 \leq C < 1.5$
Grade D	If $1.5 \leq C < 2.0$
Grade E	If $2.0 \leq C < 2.5$
Grade F	If $2.5 \leq C < 3.0$
Grade G	If $3 \leq C$

3.3 Parametric Sensitivity Analysis

The use of textbook figures and inferal methods to estimate input parameters was necessary for a number of key parameters. This methodology was heavily based on the assessors interpretation of the on site conditions. This highlighted the lack of transparency in three parameters in particular. Glazing types, boiler efficiencies and air change rates were especially difficult to determine due to the lack of documentation and records.

The effect of these uncertainties on the EP rating of the four base case schools was assessed using parametric sensitivity analysis. Parameters representing possible alternative constructions/values were specified and the parametric sensitivity analysis was carried out by applying these parameters to the base case models.

The ACH and particularly the ACH due to infiltration of the base case models was considered to be one of the uncertainties that could have the greatest affect on final grades. This was due to the fact that no experimental testing was carried out to determine the air change rate of the buildings and default figures chosen based on on-site observations were considered to be too dependent on expert discretion. Two commonly used methods for experimentally estimating the air leakage from a building are the fan pressurisation test and the tracer gas test. The application of these tests to the base case models was considered impracticable for a number of reasons.

1. The sealing of doors and vents for large schools in particular would significantly add to the overall energy audit time and hence cost.
2. The results of the test may be skewed by the external climate conditions at the time of testing, in particular the wind speed and direction.
3. In the case of the fan pressurisation test the use of a fan suitably sized to develop the required range of pressure differences across the building would be necessary. For large buildings such as non-residential building types, a large pressurisation fan would be needed to achieve the required pressure difference. For the purposes of an EP rating the time and cost of such a procedure may be considered “over-kill”.

DesignBuilder provides for the specification of both the intentional and the unintentional ventilation of a building. Natural ventilation was activated in the simulation process when the internal temperature rose above a benchmark temperature (26°C). As this did not occur very often due to Ireland’s moderate climate and as all of the buildings investigated did not use mechanical ventilation, ventilation due to infiltration was the primary contributor to the ACH of the investigated school buildings. Department of the Environment and Royal Institution of Chartered Surveyors [14] states that a school or college building “under normal conditions of exposure in Winter” has an ACH of 1 to 2 air change rates per hour. This value may vary depending on external weather conditions, ventilation technique employed and the state of repair of the school’s construction. To represent the variation in the ACH, which may be incurred when relying upon assessor’s discretion, the values in Table 3 were applied in the parametric analysis.

Table 3: Infiltration Air Change Rate Parameters.

Description	**1/hr**
Default base case models	1.0
ACH Parameter 1	2.0
ACH Parameter 2	1.5
ACH Parameter 3	0.5

The uncertainty in determining the thermal transmittance of glazing elements in existing buildings has been greatly increased by the emergence of scores of different glazing types. The EnergyPlus dataset contains 134 different types of double glazing pane alone, varying in properties such as glazing coating, pane and void thickness and the separating gas used. The lack of transparency in setting the glazing parameter is accentuated when one considers that the thermal transmittance of the EnergyPlus dataset double glazing panes ranges from 1.322 W/m^2K to 3.187 W/m^2K. The uncertainty arises when no records of the type of glazing installed have been kept. To an extent the repeatability of the EP grade calculation can be increased by visual inspection, knowing when the windows were installed and knowing what building regulations were in place at that time. However, the pane and gap thickness are very difficult to visually determine. To reflect this uncertainty parametric sensitivity analysis of the glazing specifications in table 4 was conducted.

Due to incomplete or inaccurate records of fuel consumption, the lack of information on boiler sizes, the imprecise monitoring and control of heating hours and inaccessible boiler flues (for experimental testing using a boiler efficiency test kit), it was difficult to determine the efficiency of the base case schools’ boilers. The efficiency of these boilers was set based on standard figures outlined by CIBSE [15]. Two of the four schools’ boilers were installed within the last ten years and were well maintained and insulated. Hence, they were attributed a default efficiency of 80%. The other schools’ boilers, although maintained well, were over 20 years old. A default efficiency value of 60% was therefore assigned to those schools. Although these efficiencies were within the range prescribed by CIBSE [15] the default figures assigned may differ depending on the assessors opinion. The potential difference this disparity could have on the

EP grade of a building was investigated by applying the parameters set out in Table 5 to the appropriate base case models.

Table 4. Glazing Parametric Sensitivity Analysis Specifications.

Part A: Single Glazing	
Base case model	6mm clear glazing
SG Parameter 1	3mm clear glazing
SG Parameter 2	Clear Low iron 5mm
SG Parameter 3	Clear LowE (e2 = 0.2) 6mm
Part B: Double Glazing	
Base case model	6mm panes with 13mm air gap
DG Parameter 1	3mm panes with 6mm air gap
DG Parameter 2	Clear 6mm panes with 13mm argon gap
DG Parameter 3	Clear Low-E (e2 = 0.2) 6mm panes with 13mm argon gap

Table 5. Boiler Efficiency Parameters.

Base Case Model Boiler Efficiency Parameters		
Description	**Part A: Where the base case was 60%**	**Part B: Where the base case was 80%**
Efficiency Parameter 1	40%	60%
Efficiency Parameter 2	50%	70%
Efficiency Parameter 3	70%	90%

4. RESULTS

Results: School A

The first school investigated, School A (seen in figure 1), was a single storey building constructed in 1970. Two extensions were added to the original building, one in the 1980's and the second in the late 1990's. School A was located in an exposed rural setting and therefore would be subject to substantial variations in wind speed, significant in maritime climates. The ACH of the building may in fact be much greater than the base case ACH specified (1 ACH/hr). It can be seen in Table 1 that the result of changing the specified ACH from 1.0 to 1.5 alone (Base Case to Parameter 2) results in the difference of one EP grade.

The school's 1998 extension and the original building both contained double glazed windows, the latter being retrofitted, while the 1980's extension was single glazed. As neither of the window types exact specification was known and in total glazing accounted for approximately 44% of School A's façade, it was considered important to investigate the effect of the glazing parametric sensitivity analysis on the school's EP grade. Table 6 shows that although the variation in glazing specification does have a noticeable affect on the unit EP of the school (i.e. $kgC0_2$/year) the glazing parameters explored did not alter the EP grade of the school. Indeed it can be seen in figure 3 that the glazing parameter has by far the least effect on the EP of School A.

Table 6. School A parametric sensitivity analysis results.

Area	**568**	**m^2**				
	$kgCO_2/yr$	**$kgCO_2/m^2/yr$**				
2006 regulations reference, R_r	4770.68	**8.40**				
Stock Reference, R_s	9918.66	**17.46**				
ACH	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2/yr$**				
Parameter 1	12321.75	21.69	2.58	1.24	2.24	E
Parameter 2	10934.07	19.25	2.29	1.10	2.10	E
Base Case	9740.75	17.15	2.04	0.98	1.97	D
Parameter 3	8433.54	14.85	1.77	0.85	1.71	D
Boiler Efficiency	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2/yr$**				
Parameter 1	13445.06	23.67	2.82	1.36	2.36	E
Parameter 2	11222.47	19.76	2.35	1.13	2.13	E
Base Case	9740.75	17.15	2.04	0.98	1.97	D
Parameter 3	8682.38	15.29	1.82	0.88	1.76	D
Glazing	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2/yr$**				
Parameter 1	9892.88	17.42	2.07	1.00	1.99	D
Parameter 2	9703.71	17.08	2.03	0.98	1.96	D
Base Case	9740.75	17.15	2.04	0.98	1.97	D
Parameter 3	9413.47	16.57	1.97	0.95	1.90	D
Combined	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2/yr$**				
All Parameters 1	17080.98	30.07	3.58	1.72	2.72	F
All Parameters 2	12613.33	22.21	2.64	1.27	2.27	E
Base Case	9740.75	17.15	2.04	0.98	1.97	D
All Parameters 3	7253.24	12.77	1.52	0.73	1.48	C

Figure 3 also shows that the boiler efficiency parameters examined had the greatest effect (excluding the combined effect). The school's non-condensing oil boiler was installed in 1987 and was serviced annually. On this basis a base case efficiency of 60% was set. Although this was in line with the suggestion of between 40% and 65% of CIBSE [15] there was no way of confirming where School A's boiler fell within this efficiency band, or if indeed, it did fall within it without physical testing. When applying the efficiency parameters outlined in table 5 Part A to School A it can be seen that the unit EP value of the school varies by almost 55% and the EP grade alters by a full grade from D to E.

The combined effect of a lack of transparency when specifying the boiler efficiency, ACH and the glazing values was scrutinized by combining all the parameters specified under the same name (i.e. parameter one, parameter two, parameter three) to the School A model. This analysis shows that the EP grade of School A could vary by as much as three grades if two assessors interpreted the investigated parameters as per all parameter 1 or as per all parameter 3.

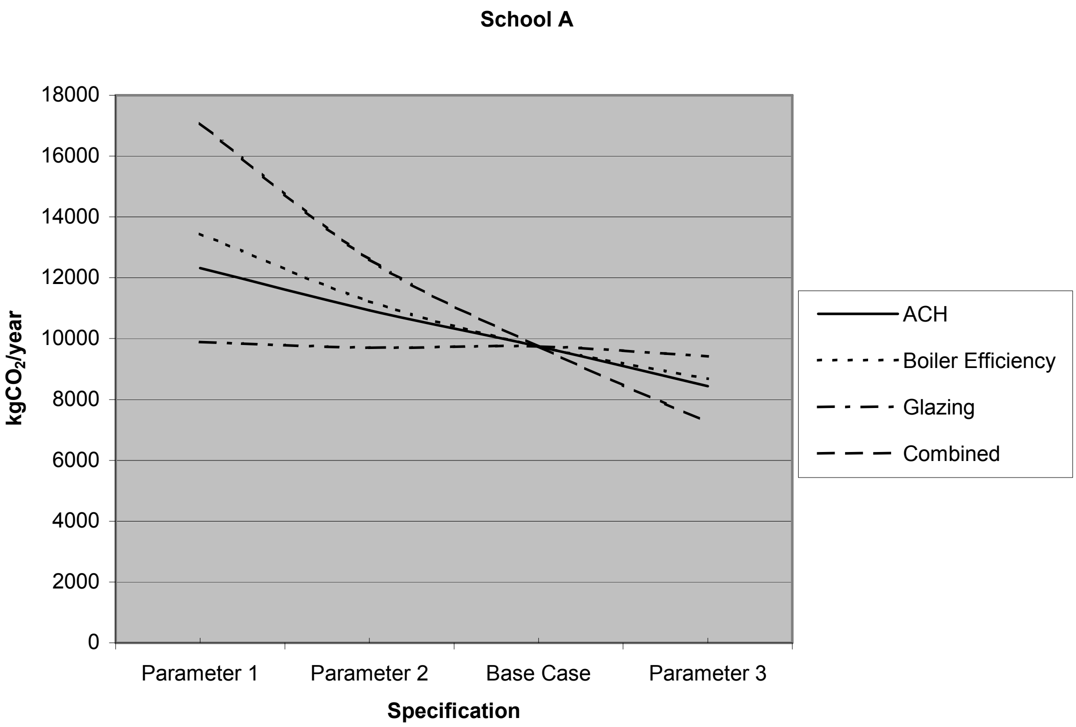

Figure 3. School A parametric sensitivity analysis results.

<u>Results: School B</u>

The second base case school, School B, was constructed in two phases. The South block was built in 1966 with the West and North blocks being added in 1975. The school was located in suburban Dublin by the coast and is subject to the brunt of the coastal winds. All of the school's glazing was replaced between 1999 and 2000 and the school's boiler was less than 10 years old and well insulated and maintained. As indicated in table 7, School B as per its base case construction parameters was found to be a D rated building.

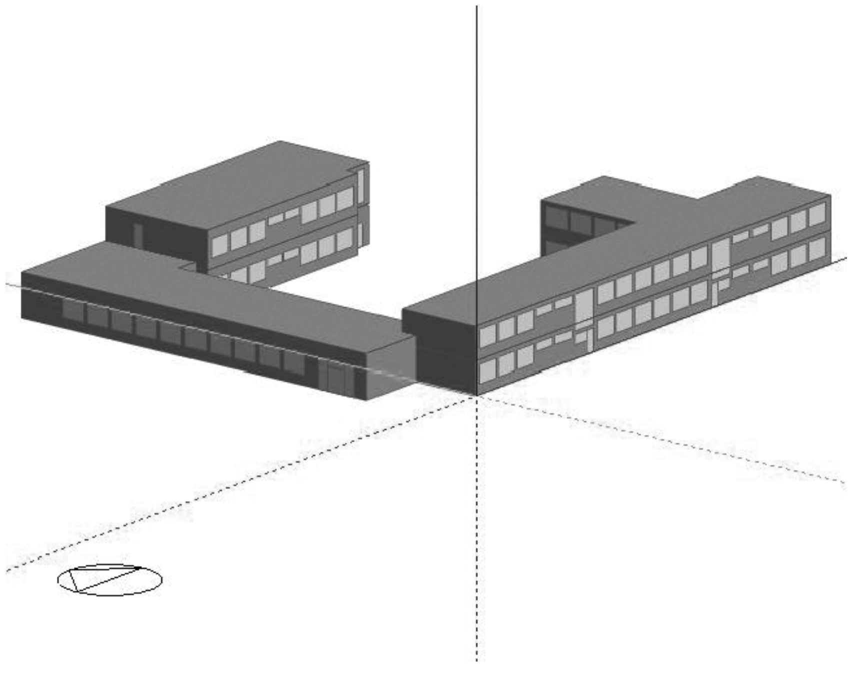

Figure 4. School B DesignBuilder model.

In School A it could be seen that the glazing parametric sensitivity analysis did not affect the EP grade of the building. Although, in the case of School B, the variation in EP induced by the sensitivity analysis had a relatively lesser affect on the EP unit rating (i.e. $kgCO_2$/year) it did in fact change the EP grade of the school from a D grade to a C grade. This highlights the fact that although the specification of glazing does not have a substantial affect on the grade of a building it should be regarded as important when a building's EP is at either end of a grading range.

Table 7. School B parametric sensitivity analysis results.

Area	**1787.7**	**m^2**
	$kgCO_2$/yr	**$kgCO_2/m^2$/yr**
2006 regulations reference, R_r	14335.26	**8.02**
Stock Reference, R_s	30819.62	**17.24**

ACH	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2$/yr**				
Parameter 1	29214.56	16.34	2.04	0.95	1.90	D
Parameter 2	26365.96	14.75	1.84	0.86	1.73	D
Base Case	23314.01	13.04	1.63	0.76	1.54	D
Parameter 3	19965.34	11.17	1.39	0.65	1.34	C
Boiler Efficiency	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2$/yr**				
Parameter 1	28573.84	15.98	1.99	0.93	1.86	D
Parameter 2	25568.22	14.30	1.78	0.83	1.68	D
Base Case	23314.01	13.04	1.63	0.76	1.54	D
Parameter 3	21483.61	12.02	1.50	0.70	1.43	C
Glazing	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2$/yr**				
Parameter 1	23614.44	13.21	1.65	0.77	1.56	D
Parameter 2	23114.65	12.93	1.61	0.75	1.53	D
Base Case	23314.01	13.04	1.63	0.76	1.54	D
Parameter 3	22490.33	12.58	1.57	0.73	1.49	C
Combined	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2$/yr**				
Parameters 1	36624.25	20.49	2.55	1.19	2.19	E
Parameters 2	28769.95	16.09	2.01	0.93	1.88	D
Base Case	23314.01	13.04	1.63	0.76	1.54	D
Parameters 3	17800.99	9.96	1.24	0.58	1.21	C

Figure 5 highlights, in contrast to School A, that the ACH parameters are more sensitivity than the boiler efficiency parameters when applied to School B. This is due to the fact that there is a greater increase in the EP of the base case schools when varying the boiler efficiency between 40% and 70% than there is when varying it between 60% and 90% (35% increase in EP compared to 25% increase in EP for the base case buildings investigated). The result of this is that for School B the EP grades change by 1.12 grades and 0.86 grades from either end of the ACH and boiler efficiency parameter respectively whereas for School A the corresponding EP grades vary by 1.06 and 1.2 grades.

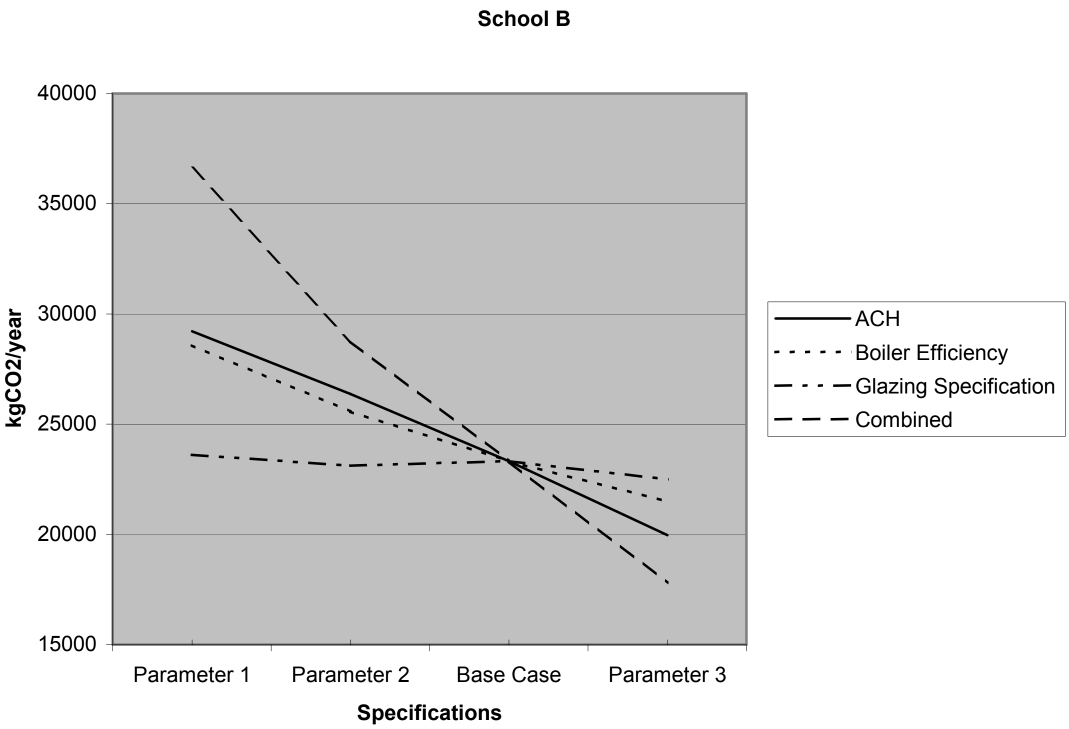

Figure 5. School B parametric sensitivity analysis graph.

<u>Results: School C</u>

School C (figure 6) was an urban, mostly two storey school just under 2150m^2 in external area. Unlike School B this school was situated within a densely populated area of Dublin City. The school was surrounded on all sides by a perimeter wall which separated the school grounds from neighbouring buildings and hence was less exposed to winds. The base case grade of School C was found to be a D grade roughly half way between the C and an E borders.

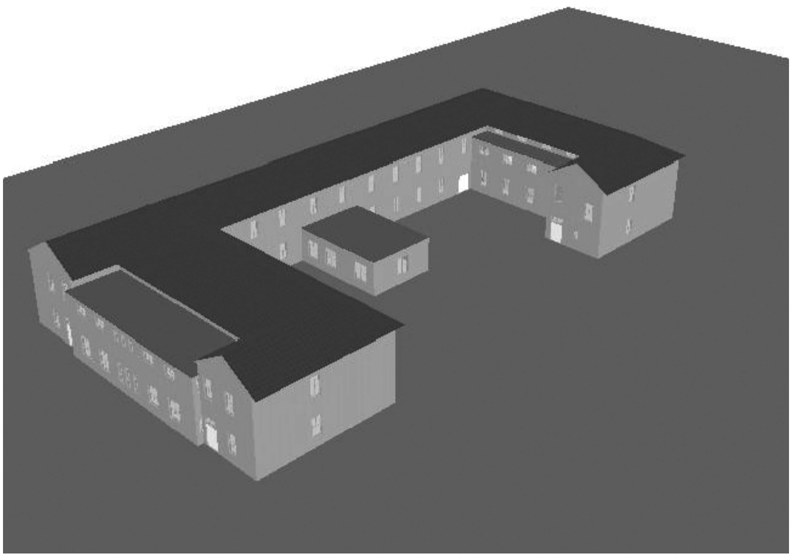

Figure 6. School C DesignBuilder visualisation.

On visual inspection the school's doors and windows appeared to be well fitted and reasonably airtight however due to the age of the building the use of the base case ACH was questionable. For this reason the parametric sensitivity analysis of the ACH was again of significant interest. The affect of the ACH on the

EP grade was substantial. The results shown in Table 8 indicate that the EP grade could change one grade between 0.5 and 1.0 ACH and 1.5 or 2.0 ACH or by two grades across the range of parameters.

The school's storage heating system was replaced with a new gas fuelled non-condensing boiler in 1997. Due to this fact the base case boiler efficiency of School C was specified as per table 5 Part B. It can be seen from table 8 that similar to School B the sensitivity of School C's boiler efficiency sensitivity was again less than that for the ACH parameters. It can also be seen that as School C's base case rating is in the middle of a D grade bandwidth the effect of the parameters specified in Table 4 Part B have minimal impact on the EP of the building and do not alter the building's EP grade.

Table 8. School C parametric sensitivity analysis results.

Area	**2144.9**	**m^2**				
	$kgCO_2$/year	**kg CO_2/m^2/yr**				
Regulation Reference, R_r	15660.16	7.30				
Stock Reference, R_s	31133.60	14.52				
ACH	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2$/yr**				
Parameter 1	31757.45	14.81	2.03	1.02	2.02	E
Parameter 2	29064.23	13.55	1.86	0.93	1.87	D
Base Case	26178.99	12.21	1.67	0.84	1.68	D
Parameter 3	23019.05	10.73	1.47	0.74	1.48	C
Boiler Efficiency	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2$/yr**				
Parameter 1	32357.24	15.09	2.07	1.04	2.04	E
Parameter 2	29067.52	13.55	1.86	0.93	1.87	D
Base Case	26178.99	12.21	1.67	0.84	1.68	D
Parameter 3	24681.23	11.51	1.58	0.79	1.58	D
Glazing	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2$/yr**				
Parameter 1	26339.96	12.28	1.68	0.85	1.69	D
Base Case	26178.99	12.21	1.67	0.84	1.68	D
Parameter 2	26098.23	12.17	1.67	0.84	1.67	D
Parameter 3	25801.69	12.03	1.65	0.83	1.66	D

Combined	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2$/yr**				
Parameters 1	40160.42	18.72	2.56	1.29	2.29	E
Parameters 2	32360.90	15.09	2.07	1.04	2.04	E
Base Case	26178.99	12.21	1.67	0.84	1.68	D
Parameters 3	21393.85	9.97	1.37	0.69	1.37	C

Results: School D

The final school examined, School D, as with School A was situated in a rural setting. The school building, erected in 1974, was a simple cavity block construction with an uninsulated pitched roof. The building was partially single glazed partially double glazed and contained the same non-condensing oil boiler since its construction. The base case EP grade of the building was found to be an E grade.

Table 9. School D parametric sensitivity analysis results.

Area	**232**	**m^2**				
	$kgCO_2/yr$	**$kgCO_2/m^2/yr$**				
Regulation Reference, R_r	1713.67	**7.39**				
Stock Reference, R_s	3215.22	**13.86**				
ACH	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2/yr$**				
Parameter 1	4566.52	19.68	2.66	1.42	2.42	E
Parameter 2	4194.36	18.08	2.45	1.30	2.31	E
Base Case	3810.34	16.42	2.22	1.19	2.19	E
Parameter 3	3414.79	14.72	1.99	1.06	2.06	E
Boiler Efficiency	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2/yr$**				
Parameter 1	5227.93	22.53	3.05	1.63	2.63	F
Parameter 2	4377.37	18.87	2.55	1.36	2.36	E
Base Case	3810.34	16.42	2.22	1.19	2.19	E
Parameter 3	3405.31	14.68	1.99	1.06	2.06	E
Glazing	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2/yr$**				
Parameter 1	3837.04	16.54	2.24	1.19	2.19	E
Parameter 2	3801.41	16.39	2.22	1.18	2.18	E
Base Case	3810.34	16.42	2.22	1.19	2.19	E
Parameter 3	3718.48	16.03	2.17	1.16	2.16	E
Combined	**CO_2 Emissions**	**EP**	**EP/Rr**	**EP/Rs**	**Rating**	**Global Grade**
	kg/year	**$kgCO_2/m^2/yr$**				
Parameters 1	6398.30	27.58	3.73	1.99	2.99	F
Parameters 2	4828.04	20.81	2.82	1.50	2.50	F
Base Case	3810.34	16.42	2.22	1.19	2.19	E
Parameters 3	2981.64	12.85	1.74	0.93	1.84	D

It can be seen from table 9 that the impact of the sensitivity analysis parameters on the EP rating of School D was not as great as for some of the other schools. This is due to the advancement required when trying to improve from an E grade to a D grade. The grading scheme outlined in prEN15217 approximately requires the cumulative EP of a building to improve by 25% when going from the borderline of grades G/F to F/E and from F/E to E/D i.e the cumulative affect of going from G/F to E/D is a 50% improvement in EP. As one continues to increase performance the cumulative increase in EP between grades is by 12.5% from E/D on i.e. 62.5% to 75% to 87.5% from G/F to D/C, G/F to C/B and from G/F to B/A respectively. Table 10 shows that when one examines separately the percentage improvement required to go from one grade to another it can be seen that grade E requires a relatively bigger improvement than grade D does. As School D's rating is firmly in the middle of the E grade the parametric sensitivity analysis does not have as transparent an impact as does schools whose base case rating is a D grade.

Table 10. Percentage improvement in EP required when moving grades.

Grade Borderline	School A	School B	School C	School D		Approximate Cumulative Improvement
G/F to F/E	25.0%	25.0%	25.0%	25.0%		25.0%
F/E to E/D	33.3%	33.3%	33.3%	33.3%		50.0%
E/D to D/C	26.0%	26.7%	24.9%	23.4%		62.5%
D/C to C/B	35.0%	36.5%	33.1%	30.5%		75.0%
C/B to B/A	50.0%	50.0%	50.0%	50.0%		87.5%
B/A to 0	100.0%	100.0%	100.0%	100.0%		100.0%

Despite this, the trends evident in the other base case school buildings appear to be repeating themselves. The base boiler efficiency, was deemed to be the poorer of the base case efficiencies i.e. 60% efficient, and as with School A had a greater affect on the EP grade than the ACH and the glazing. Interestingly, the ACH parametric sensitivity analysis had the smallest affect (0.72 grades from parameter 1 to parameter 3) 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 ACH sensitivity analysis. An explanation for this may be found by considering that the change in the ACH is a function of the base case building's thermal performance and their volume. Using this relationship it was found that the building's volume divided by its thermal performance rating (C) for the base case buildings explored was indicative of the building whose EP grade was most sensitive to the change between ACH parameter 1 and parameter 3.

5. CONCLUSIONS

Through the data gathering phase the boiler efficiency, ACH and glazing parameters were highlighted as difficult to define and repeat. As it is impractical to experimentally determine these parameters due to time and cost restraints in every building default figures and/or assessor discretion may need to be used. Through the investigation of four existing base case buildings a number of interesting conclusions can be drawn from the results obtained.

As expected the boiler efficiency and the ACH due to infiltration parameters had the most substantial impact on the EP grade of the buildings. It was found that over the range of boiler efficiency parameters the EP grade could vary by up to 1.2 grades. Depending on a buildings position within a grade bandwidth this could mean a possible difference of two grades. As highlighted by the contrast in sensitivity of Schools A and D (60% efficient) and Schools B and C (80% efficient), the lower the defined efficiency of a building's boiler the greater the sensitive of the EP grade to variations in the efficiency specification. Hence greater care needs to be taken when specifying the efficiency of an older/more inefficient boiler whose efficiency is unknown.

The problems which may arise in setting a default ACH when modelling a building's EP were highlighted by the variation in the location of the schools chosen for the study (varying from sheltered urban to coastal schools). The application of a default figure which would aid in the repeatability of an EP rating scheme would take away from the ability of a dynamic simulation tool to represent reality, yet experimental testing of every building appears to be impractical this means that the assessors discretion appears to be the best compromise. The ACH parametric sensitivity analysis emphasised the significant influence variations in ACH specifications have on the EP grade of buildings. It was found that the sensitivity of the ACH parameter altered the EP grade by between 0.72 and 1.12 grades. For the four base case models explored the volume of the building divided by the building's thermal performance rating was, for comparison purposes, indicative of the building most likely to be affect by the ACH variation.

The specification of glazing, once it is of the same category, i.e. single glazed, double glazed, has minimal impact on the EP rating of a building. However, glazing as well as boiler efficiency and ACH should be regarded as even more important when a building's EP is found to be at either end of a grading range. A major flaw in leaving the specification of inputs up to assessors discretion can be seen in the contrast of all parameter ones and all parameter threes (which represent the extremes to which two assessors might interpret the on site conditions) for each of the four base case schools. The variation in the EP grading of up to three grades highlights the necessity for a well developed training scheme with clear guidelines and the assessment of on-site conditions.

Repeatability and transparency can be improved through careful training of building EP assessors and the awareness of a parameters affect on an EP grade. The above findings, however, highlight that these attributes within a dynamic simulation EP rating methodology will be difficult to sustain while maintaining the advantage to accurately modelling the energy balance of a building and its environment. Further research into the benefit of possible means of maintaining simulation accuracy while sustaining transparency and repeatability such as the experimental testing of ACHs in a representative sample of buildings, the development of a SEDBUK type boiler efficiency scale for non-residential buildings would be valuable.

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