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Development of energy performance benchmarks and building energy ratings for non-domestic buildings: An example for Irish primary schools

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Abstract

The EU Member States are in the process of implementing energy rating procedures for buildings. For non-domestic buildings in particular, devising a robust and cost effective energy rating method is not a simple task. The situation becomes more complicated where countries do not have a tradition of performing energy calculations or undertaking energy measurements in buildings.

This paper outlines a methodology to develop energy benchmarks and rating systems starting from the very first step of data collection from the building stock. Methods for rating a sample Irish school according to both calculated and measured ratings are applied, and finally the paper discusses the advantages and disadvantages of the two approaches.

Keywords: Buildings energy rating; Regulation; Certification; Benchmarking; Energy performance; Schools

1. Introduction

The EU Energy Performance of Buildings Directive (EPBD) [1], adopted in December 2002 and which should have been transposed into EU Member States national legislation since January 2006, has as its main objective "to promote the improvement of the energy performance of buildings". Energy performance rating and certification are required as part of the EPBD implementation, as stated in Article 7. A robust, credible and cost efficient certification scheme will play a key role in the achievement of that objective, and a prior requirement is to establish benchmarks to enable comparison of a particular building's energy performance. Some benchmark figures already exist in many EU states, for example, typical yearly heating use in school buildings have been reported as 57 kWh/m^2/year in Greece, [2], 197 kWh/m^2/year in Flanders [3], or 119 kWh/m^2/year in Northern Ireland [4]. Countries such as the UK have been producing energy benchmarks and performance guides for almost 30 years, as Good Practice Guide 343 [5], which includes typical and best practice values for primary schools, respectively, 157 kWh/m^2/year and 110 kWh/m^2/year.

In contrast, there are other states that might not have historical data for building energy performance or a procedure for calculating building energy performance, especially in the case of the non-domestic building sectors. This paper discusses practical issues for the development of energy performance benchmarks and energy rating systems in such situations where no data is available. A simplified method is presented and tested with the specific application of thermal energy use in Irish primary schools.

Although the authors are aware of the importance of indoor environment issues in the building sector, and particularly in schools, they are not considered in this paper, as indoor environment requirements, not being compulsory within the EPBD, are at the moment and to the knowledge of the authors not being considered for inclusion in the rating procedures of EU Member States.

2. Starting point—data collection and benchmark preparation

This research targeted primary schools, since they were considered to comprise a sector with reasonably homogeneous buildings, occupancy and activities. Given that the data collection was planned to be achieved by means of questionnaires, it was also pragmatically relevant that schools

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were expected to provide a better response rate compared to other building types.

2.1. Construction and activities benchmarks

A first goal of the data collection was to set benchmarks for reference buildings, both for the existing building stock, and for new buildings conforming to the present Building Regulations [6].

A first set of detailed questionnaires was distributed to 500 schools in Ireland, with the aim of collecting details on construction, activities and energy uses in each building.

The questionnaires included the following sections:

- General information about the school (name, address, pupil numbers, etc.);
- Construction details (drawings and specifications of the walls, roofs, windows and doors);
- Heating (space and water), ventilation and lighting: Data on fuels used, school heating hours, boiler specification and control, lighting installations, ventilation characteristics of the school, and domestic hot water heating.

2.1.1. Stock reference building

Sixty-seven completed questionnaires were returned (13%), and this data, which included occupancy densities, activity and heating schedules, was used to develop a standard activity schedule for primary school buildings. The characteristic construction values for stock reference buildings were also inferred from the construction data included on the questionnaire responses. A summary of the main characteristics used for the stock reference building is displayed in Table 1.

For the stock reference building, 1.5 air changes per hour were selected to represent infiltration and natural ventilation, and seasonal boiler efficiency was estimated to be 70%. Those values were approximated from a number of site visits, visual inspections and personal experiences.

2.1.2. Regulation reference building

The Irish Building Regulations 2005 Technical Guidance Document Part L [6] was considered as the reference for new buildings constructed according to the Regulations. A summary of characteristics is presented in Table 2.

As no more accurate information was available, a default air change rate per hour of 0.5 was selected, so as to reflect presumed improvements in modern construction and natural ventilation system. Similarly, a default value for a 2006 boiler seasonal efficiency of 90% was chosen to represent the realistic seasonal performance that could be achieved by a new condensing boiler [7].

2.2. Statistical energy performance benchmarks

A second goal of the data collection was to obtain details of the energy performance of the building stock. The disseminated questionnaire included questions about the actual measured consumption; however, of the detailed questionnaires collected, only 69% provided the requested measured energy data. As this represented just 46 valid responses, another simpler one-page questionnaire was developed to get a better sample for operational energy consumption data. Data sought in this second questionnaire was limited to energy consumption by type of fuel for a sample year and internal floor area of the building (or number of pupils, if area was unknown). Another 500 questionnaires of this kind were distributed, and 62 new responses returned. Combining the two surveys, a total of 108 entries containing energy consumption (or costs) by fuel type, and a size measure of the school (either area or number of pupils) were gathered.

Where respondents were unable to provide energy consumption data, and instead provided energy expenditure data, assumptions were made so as to translate the costs of energy based on the type of fuel and the energy provider.

The normalisation of the data per area where only pupil figures were provided (which occurred in around 50% of the responses), was inferred based on the average floor area per pupil in schools that provided a complete dataset.

The primary objective of the analysis was to consider the distribution of specific energy consumption across the sample of school buildings. The result describes the performance of the sample of the building stock and clearly shows best and worst performers for the sector. The distribution obtained followed the patterns of previous analyses elsewhere [8–10], which have shown that distribution of specific energy consumption is likely to be positively skewed rather than normally distributed. This means that the most appropriate measure of typical building stock performance is the median rather than the mean.

The mean and standard deviation of the distribution was used to determine outliers. As our distributions were skewed, it was decided to eliminate those points lying more than four standard deviations from the mean, to remove statistical ‘‘blips’’ and increase confidence in the final result. Three very high-energy consumers were excluded from the analysis this

Table 1
Stock reference building characteristics

Element	$W/m^2 K$
External walls (as per original construction)	1.2
Ground floor (as per original construction)	2.0
Flat roof	1.4
Pitched roof (insulated at ceiling level)	0.47
Pitched roof (insulated on pitch)	0.47
Windows and doors	4.9 and 2.2

Table 2
Regulation reference building characteristics

Element	$W/m^2 K$
External walls	0.27
Ground floor	0.25
Flat roof	0.22
Pitched roof (insulated at ceiling level)	0.16
Pitched roof (insulated on pitch)	0.2
Windows and doors	2.2

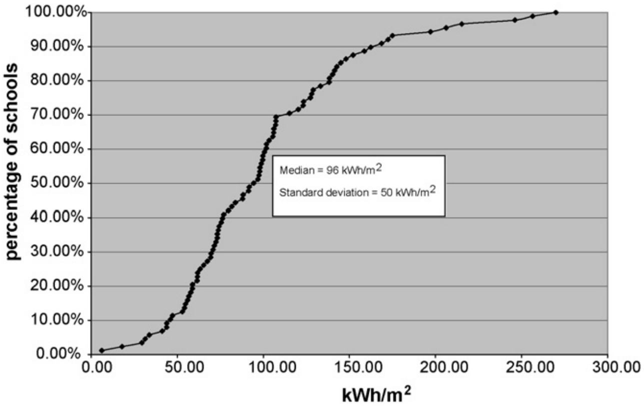

Fig. 1. Cumulative distribution of energy use for heating in 88 primary schools.

way. Seventeen other data entries from schools that used some electricity for space heating were also excluded from the analysis, as the electricity used for heating was not separately metered.

From the original 108 responses providing the necessary data, 88 were finally used for the detailed analysis. Fig. 1 shows in a cumulative distribution the 88 used responses.

The main results for annual heating energy use are:

- Median use of 96 kWh/m^2. This median will be used as a building stock energy performance benchmark.
- Upper quartile of our distribution 65 kWh/m^2. This upper quartile will be adopted as ''current practice'', representative of performance of a building constructed according to current Building Regulations.

3. Utilisation of benchmarks in energy ratings: case studies

Two main types of rating have been described and proposed in the draft European standard prEN15203: 2005: Energy performance of buildings—Assessment of energy use and definition of energy ratings [11]:

A calculated energy rating—obtained by calculation based on drawings and design values of buildings. It can be termed ''asset energy rating'' when calculated for an existing building on the basis of the actual building, and ''design energy rating'' when calculated at the design phase, using design building data.

A measured energy rating—The measured energy rating is the weighted sum of the measured annual amounts of all the energywares used by the building. It is also called operational rating.

The benchmarks generated through the survey presented in this paper can be applied within either rating, and this is illustrated for a sample school building.

The sample school is a two-storey primary school building constructed in 1966. The original building, seen on the South side of Fig. 2, was extended in 1975 with two large extensions, one a single storey block on the West and the second a two storey block to the North. In total the school is approximately 1760 m^2 in external area and is a naturally ventilated building.

The construction comprises:

- Uninsulated solid floors, with a screeded concrete slab.
- Uninsulated cavity wall with 13 mm external rendering, 100 mm medium weight concrete block, 50 mm cavity and 100 mm medium weight concrete block, 13 mm dense plaster.
- PVC frame 6 mm double glazed windows with a 13 mm air gap, retrofitted between 1999 and 2000.
- The original building's flat roof was retrofitted in 2002 and now consists of 19 mm asphalt on 100 mm polyurethane board on 200 mm cast concrete slab.
- Heating comprises one floor standing 355 kW non-condensing oil-fired boiler. This was installed in 1995 and generates hot water solely for the central heating system.

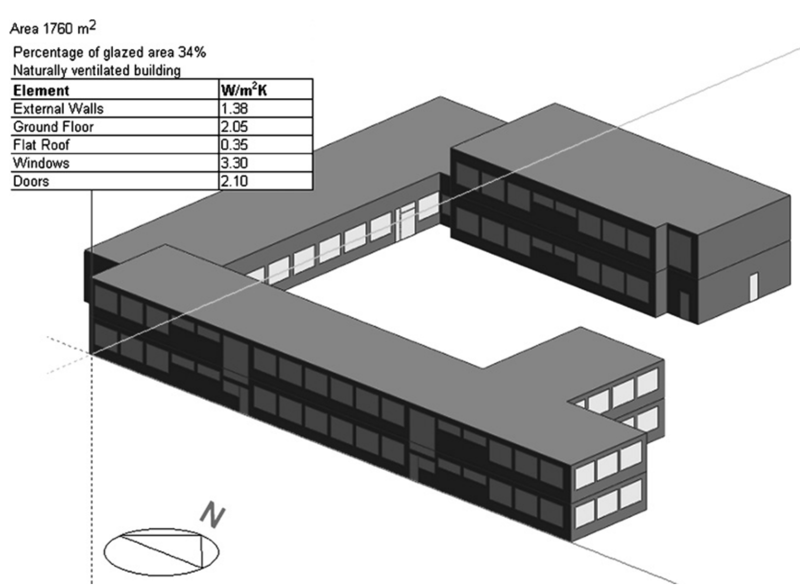

Fig. 2. Sample school model.

3.1. Calculated rating (asset rating)

There are a number of tools and procedures to calculate the energy performance of a building, from monthly calculation methods to detailed dynamic simulation models. The process generally involves a detailed numerical description or the preparation of a computer model for the building we want to rate, with standard occupancy and activity templates.

Having benchmarks for reference stock buildings and reference regulation buildings can facilitate the rating of a building, as they provide ''notional'' building models to which our actual building can be compared. The concept of a ''notional building'' which complies with the regulation is being used in various countries in Europe for compliance with building regulations. Spain uses software called LIDER as part of the new building regulations, which is used to determine if a building performs better than a 'notional building' using a calculation method based on the DOE dynamic simulation tool [12]. UK uses a similar procedure in their National Calculation Method [13], which can be applied with a calculation tool based on the Dutch methodology NEN 2916:1998 (Energy Performance of Non-Residential Buildings) and modified to comply with the emerging CEN Standards, or also with commercial but approved software packages that perform dynamic simulations.

For this demonstration of calculated rating, the sample existing school building has been modelled and calculations have been made for the actual buildings and for the stock and regulation reference buildings.

3.1.1. Sample school energy performance calculation

The EnergyPlus calculation software [14] was used to calculate the school's energy performance. Results for the performance of the building and even the rating obtained are strongly dependent on the tool used and particularly on the input parameters applied [15], which underlines the importance of developing robust methods. All the assumptions made and standard data used in developing the model for this paper were based on the data gathered from the questionnaires.

Applying the standard activity data and the stock construction template to the building model and calculating the performance, and then re-calculating the building performance after assigning the regulation reference building characteristics, the stock reference and regulation reference building performance were determined. The results, presented in terms of kWh used for heating per square meter, can be seen in Fig. 3.

3.1.2. Grade calculation

There are different calculation grades that might be used for rating. Equal steps grading, equal frequency grading, and even fuzzy clustering grading techniques [2] have been proposed as possibilities. The grading method used for this case study uses a simple methodology set out in prEN15217:2005 [16], and is described in Table 3, where EP corresponds to the energy performance of our sample school, R_r to the regulation reference, and R_s to the building stock reference.

The annual results for the sample school thermal energy demand, adding the values for each month, result in

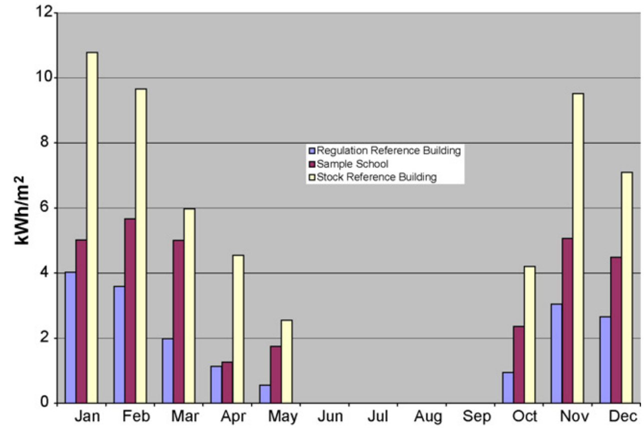

Fig. 3. Calculated thermal energy (kWh/m^2).

EP = 31 kWh/m^2/year, R_r = 18 kWh/m^2/year, R_s = 54 kWh/m^2/year.

EP for the sample school is in this case higher that R_r, but lower than $0.5(R_r + R_s)$, so the energy performance grade of our school sample according to this calculated rating (Table 3) is then C grade.

3.2. Operational rating—measured energy rating

To rate a building according to the operational rating method, the procedure is simpler and generally requires less input and less effort, once the base information is collected.

The EPLABEL EU part-funded project [www.eplabel.org] has developed an operational rating system, which starts with the following basic steps.

Step 1: Collect quality data and calculate the building's Energy Performance Indicator (EPI).
Step 2: Identify appropriate benchmarks with which the EPI can be compared.
Step 3: Grade the energy efficiency of the building by comparing the EPI with the benchmarks.

In our sample case, the school energy consumption for thermal use (8760 l of oil) has been normalised to kWh using a conversion factors of 10.6 kWh/l of oil, which for the size of the school (1760 m^2) give us an energy performance (EP) of 53 kWh/m^2/year. The appropriate benchmarks for comparisons of measured values are the statistical benchmarks developed from the questionnaire survey presented in this paper. We consider the median as our reference stock building reference

Table 3
Building energy performance classification prEN 15217:2005

Class A	$EP < 0.5R_r$
Class B	$0.5R_r \le EP < R_r$
Class C	$R_r \le EP < 0.5(R_r + R_s)$
Class D	$0.5(R_r + R_s) \le EP < R_s$
Class E	$R_s \le EP < 1.25R_s$
Class F	$1.25R_s \le EP < 1.5R_s$
Class G	$1.5R_s \le EP$

(R_s = 96 kWh/m^2/year) and the upper quartile as our regulation reference (R_r = 65 kWh/m^2/year) for this rating exercise.

Applying the grading methodology from prEN15217: 2005 [16] as described in Table 3, our sample school EP = 53 kWh/m^2/year has a grade B according to the calculated rating, as it is lower than the R_r, but not lower that half the value of R_r.

4. Discussion and conclusions

The operational rating and the benchmark comparisons presented in this paper are very limited in accuracy and application due to the reduced data gathering exercise and the simplicity of methods and assumptions used. Leaving aside those limitations, a possible first interpretation of the grade C for calculated rating is that the construction quality and thermal energy performance characteristics of the sample school is somewhere in between the building stock and building regulation reference buildings. A measured rating of grade B indicates that the school's actual energy use for heating is quite low when compared to the existing building stock, even lower than the regulation reference value.

Some other interesting aspects of the methodology and results can be discussed:

(a) *Benchmark development*

Being able to compare a building with the representative building stock performance and with regulations is a vital step for certification.

In the case of calculated ratings, the comparison benchmarks can be set as those building characteristics corresponding to the regulations and/or to the building stock. The development of those reference building benchmarks requires some assumptions and data collection, which can prove a difficult task. While some factors such as activity, occupancy data, building area, number of pupils, age of building, etc. can be easy to obtain by means of questionnaires, other vital information for evaluation for energy performance of the building, such as construction details and type and efficiency of heating systems are often not known by respondents. Combining questionnaires with a number of building surveys to collect detailed data for a smaller sample of buildings, as was done in this research, could be the most practical solution for the development of reference building benchmarks.

The development of statistical benchmarks of measured energy can also be an arduous task in countries without a tradition of measuring and monitoring energy uses. To optimise energy data collection, this research suggests facilitating the respondent by including different factors that should be available from energy bills, such as litres of oil or cost. Also different options for measuring scale (area, classrooms, number of pupils) are useful to offer to maximise the response rate. Post processing of the data allows incomplete responses and outliers to be discarded.

(b) *Rating procedure*

Once the benchmarks are in place for both methods of rating, the asset rating procedure generally requires much greater resources for an individual rating than the simplified operational rating. Although interfaces which could simplify the building modelling task are well developed (including templates for building and activities characterisation), calculations still require a certain experience of modelling and energy simulation. Often at least one day's work is required for a medium sized building such as the one presented in this paper.

Operational rating in this simplified procedure requires few data entries and comparison with the benchmarks to produce a label.

(c) *Advantages of each rating method*

The calculated energy performance indicator for the selected sample school building is 53 kWh/m^2, while the real measured value is 31 kWh/m^2. An explanation for that discrepancy could be that factors such as standard activities and occupancy patterns that have been used in the model, derived from the benchmarking exercise, do not correspond to the reality of that particular building. However, a rating based on calculated results, has the benefit of neglecting those operational issues. In turn, conclusions can be extracted about the potential energy performance of the building, which may be useful for sale or rental purposes.

The measured rating, on the contrary, has the benefit of representing the actual use of the building, and producing a rating according to this use. This is particularly appropriate to public buildings, as it assesses the actual performance, and generally this is a more important factor for public buildings than the "energy potential", as sale or rental is not always relevant. A current drawback of the proposed measured rating is the difficulty of defining appropriate benchmarks for comparison, both for the building stock for which performance data is not available in various countries, and for the current practice buildings, which correspond to new buildings from which we would need some time to collect data. This study has presented a practical simplified approach to collecting those energy consumption benchmarks by means of questionnaires, assigning the median value of the responses for building stock reference (R_s) and the upper quartile value for the current practice regulation reference (R_r). However, if a measured energy rating is adopted in a country or region, the statistical benchmarks could be progressively refined with the addition of data for all the measured and rated buildings.

As a final remark, we can note that consideration of both a calculated rating and a measured rating together may be of significant advantage in seeking improvement of energy performance.

Developing ratings using both approaches would require considerable efforts in data collection and data analysis in those countries without previous experience in this area.

An extra effort would be required to allow the comparison of both ratings, in the form of validating the calculation and simulation methods. These efforts would offer considerable added value in assessing the performance of the building accurately, and discerning whether its performance is due to intrinsic characteristics of the building, or to occupancy, activity and management issues.

This research has not included indoor temperatures, ventilation and indoor air quality analysis. Indoor temperatures and air change rates have been assigned standard and estimated values in the calculated rating, and are unknown and not considered in the calculated rating. However, rating methodologies should somehow take account of indoor environment issues to ensure that energy efficiency never compromises the quality of the indoor spaces. The EPLABEL approach proposes to include an indication of approval by an assessor of the adequacy of the indoor environment, to be reported in the measured rating.

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