COMPARATIVE STUDY OF THE LEED AND ISO-CEN BUILDING ENERGY PERFORMANCE RATING METHODS

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ABSTRACT

The use of LEED as a building sustainability rating method is well established in the US. In this paper we concentrate on the calculation of the score in the Energy and Atmosphere category of LEED, i.e. the LEED-EAc1 score. Its calculation is based on an adaptation of the ASHRAE 90.1 calculation method. This paper will argue that the approach is needlessly complicated and laborious because there are simpler, non-simulation based methods that may be equally adequate for the energy rating of a building. One such alternative is the normative EPC rating method, which is widely used in Europe based on the ISO-CEN standard 13970. Each building energy performance rating method has a distinct approach for the calculation of building energy efficiency. Many papers discuss the basis of the calculations and compare them on the merits of their methods. In this paper, we focus on whether the two systems achieve their objective and which system does a better job in rating building designs. This comparison of the two methods is not only based on a direct comparison of outcomes, but is also studied with the consideration of its true intent, the relative ranking of buildings against each other. Consequently we will less focus on the absolute differences between the outcomes of the two methods, which have been found to be 20% or less in the Energy Use Intensities (EUIs), but will focus on statistical tests to verify whether there is a significant difference in the building rankings resulting from the two distinctly different approaches.

INTRODUCTION

There are many different methods to (1) verify whether a building design complies with energy efficiency requirements and (2) rate a building's energy performance, stand-alone or as part of multi-criterion sustainability assessment methods. The difference can be superficial, but can also be quite profound, i.e., when a method is grounded in a quite different philosophy. The starkest contrast can be seen in the U.S. based Leadership in Energy and Environmental Design (LEED) method which defines a score in the Energy & Atmosphere Credit 1; EAc1 (USGBC, 2012) and the Europe based ISO-CEN method (ISO, 2008), which defines an Energy Performance Coefficient (EPC). LEED-EA scoring is based on ASHRAE 90.1 and therefore adopts the philosophy to compare the designed building to a reference building (baseline) that needs to be generated from the same design data but with a set of base assumptions and provisions as described in Appendix G of the ASHRAE 90.1 standard. The advantage of this method is that no other normalization needs to be performed, as the designed building is in the same location, has the same function, spatial design, etc. as the building it is compared to. The EPC approach uses a different philosophy. Each design is calculated and compared to a reference value that is predetermined over a large set of functionally equivalent buildings. The reference value is typically per square meter and normalized for the function and location of the building. Apart from a different philosophy, the two approaches also differ in calculation practice; whereas ASHRAE allows any accredited simulation tool to be used for the energy evaluation, the EPC standard dictates the use of a normatively defined monthly and hourly calculation procedure. This method is normative in the sense that no modelling is required and hence no modeller's bias is introduced. All input values in the model are fully defined and directly related to observable information in the design specs. The background and implications are elaborated below. In this paper, we will only use the monthly calculation version as the basis for the EPC use, as this the most widely used and most popular in the regions that have adopted the EPC approach in their local energy performance standards and regulations. It should be mentioned that some countries like the UK (SBEM, 2008) allow dynamic simulations in special circumstances i.e. when the case can be made that the normative model does not adequately represent the building. One could argue that this "backdoor simulation" option defeats many of the advantages of the EPC approach but as it is not the purpose of this paper we will further ignore this option.

Coming after the first global energy crisis in 1973, NBSIR 74-452, Design and Evaluation Criteria for Energy Conservation in New Buildings, the ASHRAE Standard 90.1, was first developed and published in the U.S. It became a mandatory baseline of building codes and standards for the non-residential sector in almost all of the states. ASHRAE Standard 90.1 states minimum requirements for the energy efficient design of buildings as well as Performance Rating Method (PRM), Appendix G, which is used in rating the building designs that exceed the minimum requirements of the standard, first introduced in ASHRAE Standard 90.1-2004 (Hunn et al., 2010). The Performance Rating Method has been adopted in LEED as managed by the U.S. Green Building Council, and in the federal energy management requirements of the Energy Policy Act of 2005. The general principle of the PRM rating is to compare cost or energy consumption of the proposed design to the baseline that satisfies the minimum standard requirement. The performance is calculated by using detailed dynamic simulation programs such as DOE-2 (and its user-friendly versions like eQuest) and EnergyPlus. The baseline design is used only to determine the specific proposed building's energy performance rating, typically expressed as the percentage of improvement in total energy cost in comparison to the design baseline. In other words, the design od not benchmarked against a (large) set of functionally equivalent buildings but only against the proposed design's own "competitor". Adhering to this philosophy mandates the construction of a baseline following a set of rules and specifications. The constructed baseline is unique for every proposed design since it basically copies the proposed design minus those energy related components for which a more basic version can be substituted. Not surprisingly the rules to construct the baseline can become vague and multi interpretable in all but the simplest cases. What is and what is not allowable is often based on a give and take with the LEED certifier and frequently the subject of discussions among energy modelers.

Instead ofe the baseline design in ASHRAE Standard 90.1, the European building energy performance rating method utilizes an industry wide reference value to normalize the energy performance coefficient (EPC). The reference value (E_{ref}) is set per functionally equivalent building type and location. Sometimes the reference value is expressed as a formula where location is a parameter; in other cases, the local regulatory body has added other parameters to the specification of the reference value. One example is the compactness of the building, which implies that in that case a tall slender building will not be compared against the same reference value as a cube-shaped building. Whether this is done or not is immaterial to the argument we are pursuing in this paper so we will henceforth ignore it and assume a fixed reference value that only depends on function and needs to be defined per location (which for all practical purposes is usually per climate zone).

The reference value defines a representative benchmark that all buildings of a given functional type need to meet. The EPC is found by dividing the calculated energy use of the proposed design (E_{cal}) by E_{ref}. To calculate building energy consumption of the proposed design, the CEN/ISO standard 13790:2008 (ISO, 2008) defines simplified methods based on monthly or hourly calculations with a set of standard conditions and normative assumptions that define for instance usage scenarios, and specify rules that define how HVAC system efficiency is derived from certain properties of the proposed HVAC system design.

As stated above, the two methods are distinctly different in calculation and rating philosophy. This paper examines whether these differences in calculation fidelities (a simple monthly method versus a detailed dynamic simulation) and rating (building specific versus generic benchmarks) will actually lead to different comparative rankings over a given set of buildings. The inspection is based on a set of prototype buildings from which other buildings are generated through parametric variations. The main motivation of our work is to establish whether there is a good reason why LEED should remain based on ASHRAE 90.1 or that a switch to the EPC based rating would work equally well for the EAc1 scoring. In the latter case, one would argue that this switch should be advocated in the light of all the practical advantages of the EPC based rating.

BACKGROUND

As part of building energy rating, the role of the simulation tool and the degree of its precision have been emphasized continuously and the advocacy for its need seems hard to contradict. On the other hand, there has been an argument that raises doubt based on the fact that LEED-certified buildings do not perform as promised by their LEED plaques. It has also been found that 28-35% of LEED certified buildings used more energy than their comparable non-LEED counterparts and furthermore, the measured energy performance of LEED buildings had little correlation with the certification level of the building. (Newsham et al., 2009).

While investigating this, several distinct issues related to building rating systems need to be brought up. First, it should be clear that once the building starts operating, various scenarios do not conform to the predicted ones that were used to obtain the simulation results. The new usage scenarios of the building can only play a role in the as-occupied phase, such as M&V (measurement and verification) or commissioning practices. The significance is that with regard to the building energy performance rating, the degree of precision is no longer important if one of the largest influences, the usage scenario could not be predicted accurately anyway. This makes a strong case for normative assumptions that hold for any building deemed to belong to a functionally equivalence class. In fact, design rating should be understood as what the name says: a rating of the design (specifications). Many realizations of actual energy consumption can result from the same design. This emphasizes even more that a design rating should not be confused with actual energy consumption as the latter leads to an undesirable obsession to guess what will happen in the actual building. Lee et al. (2011) show the necessity of a perspective on what is to be rated, i.e. the building, not the combination of building and occupants, by using the example of car ownership and stressed that there is no need to predict the actual use of the building. Another factor we cannot ignore is the uncertainty embedded in the simulation tool and its users. The role of uncertainties in simulation has been studied with respect to the modelling assumptions and simplifications (de Wit et al, 2002; Corrado et al, 2008). Also due to the high cost of the simulation model in terms of time and expertise, there has been ample speculation on the effect of modeler's bias. Kleinhenz et al. (2012) also addressed the possibility of modeler's manipulations, intentional or unintentional, and the difficulty to safeguard against them since it is very hard for the certifying organization to inspect all the inputs in something as complex as a simulation model.

Considering the issues above, the normative method has great strengths on two counts. First, a set of normative modelling assumptions makes the method transparent such that it eliminates possible modeler's bias, and secondly, by using normative usage scenarios, it only focuses on how the building behaves under assumed conditions (Lee et al, 2011).

Several studies have validated the EPC calculation method in various circumstances. In a comparison study of the ISO 13790 Standard against the ESP-r detailed simulation program, both methods were validated in regards to heating and cooling energy savings for a double ventilated façade (Kokogiannakis et al., 2007). Kokogiannakis et al. (2008) also conducted a parametric analysis with 23 cases comparing the simplified method of the ISO 13790 standard with detailed modelling programs and the results from all methods were found to fall in either the same or an adjacent rating band.

METHODOLOGY

For the comparison of different calculation practices, this paper utilizes an EPC calculator that executes the calculations specified in ISO 13790 (Lee et al., 2011). IES VE-Navigator is used as the dynamic simulation tool to execute ASHRAE 90.1-2007 (IES, 2011).

We will refer to the EPC calculator as the normative model. It is a quasi-steady state model that approximates energy flows in a building at the macro level based on a simplified description of a building and ignoring detailed dynamic effects. IES VE-Navigator for ASHRAE 90.1 facilitates ASHRAE energy modelling and derives LEED scoring through a structured workflow that takes the user through the process and checks that all required steps are complete (IES, 2011). In the LEED system, the points for EAc1 are determined by the relative improvement (**Error! Reference source not found.**) of building energy cost.

Equation 2 shows the standard definition of EPC, i.e. as relative improvement over a reference value. It should be noted that this assumes a reference value for the considered building type, in the given location. In principle, this value can be chosen arbitrarily if we are only looking at one functional building type in one location. The reference value becomes relevant if we want to compare buildings across functional types and locations, as in that case one may want to be able to compare a school in Chicago to an office building in Atlanta. Note that it is not at all readily accepted that such a comparison will always make sense, i.e. whether the fact that if both the school in Chicago and the office building in Atlanta score an EPC = 0.8, has an actual meaning to a stakeholder. It would only have a meaning if indeed the same EPC value for both would represent a value statement regarding their energy performance that would play a role in a particular decision context. This is a deeper discussion that is not material to the subject of this paper. In this paper, we will only look at buildings of the same type and in one location. This only requires us to establish E_{ref} for the chosen building type (office building) and for the chosen climate zone. In our research, we use the 2003 Commercial Buildings Energy Consumption Survey (CBECS) (EIA, 2005) for Atlanta, GA (Climate zone 3A) in terms of the site energy use intensity (EUI) as shown in Table 1. It should be noted that the E_{ref} derived in this way is somewhat arbitrary in its absolute sense but the dependency with location can be expected to be quite reasonable. When this study would be extended to cover buildings in other climates than just one location, more research is necessary to find proper reference values. This could be based partly on available CBECS data but this should be done with care, since CBECS data, indeed, has some uncertainties in itself such as owners or survey respondents' bias and endemic characteristics embedded in its region. Energy Star is one of well-known building energy rating systems for existing buildings in U.S. utilizing CBECS data to rate energy performance of existing buildings. Further study is necessary to analyse CBECS data and test its suitability for the development of E_{ref} across building types and climate zones.

Equation 1

$$\text{Performance Improvement} = 100 \times \left(\frac{\text{Baseline building performance} - \text{Proposed building performance}}{\text{Baseline building performance}}\right)$$

Equation 2

$$EPC = \frac{E_{design}}{E_{ref}}$$

Table 1 2003 CBECS data for office buildings in Climate Zone 3

Sample Size		187 buildings
By End-uses [kWh/m^2]	Heating	120.16
	Cooling	28.00
	Ventilation	16.48
	Water Heating	7.97
	Lighting	81.28
	Refrigeration	8.10
	Office Equipment	10.24
	Computer Use	19.26
	Miscellaneous	32.26
Total [kWh/m^2]		323.74

Table 2 Design parameters for case studies

PARAMETERS	DESCRIPTIONS
1. Building Location	Zone 3A (Warm-Moist): Atlanta, GA
2. Above-grade Wall (Steel-Framed)	Opt 01: U-value; 0.48 W/m^{2}K (Baseline) Opt 02: U-value; 0.36 W/m^{2}K
3. Window	Opt 01: U-value; 3.41W/m^{2}K, SHGC-0.25 (Baseline) Opt 02: U-value; 1.08 W/m^{2}K, SHGC-0.47
4. Window-to-Wall ratio	Opt 01: WWR 40% (Baseline) Opt 02: All orientation 10% Opt 03: All orientation 60% Opt 04: South & North 60%, East & West 10%
5. Lighting Power Density	Opt 01: 10.76 W/m^2 (Baseline) Opt 02: 7.53 W/m^2 Opt 03: 4.20 W/m^2
6. Appliance Power Density	Opt 01: 10.01 W/m^2 (Baseline) Opt 02: 5.38 W/m^2
7. HVAC Type	Opt 01: System 3 (PSZ-AC) (Baseline) Opt 02: System 7 (VAV with Reheat) (Baseline) Opt 03: Air-source Heat Pump (two efficiency options)
Total Cases	119 Case buildings

Table 3 Building geometries for case studies

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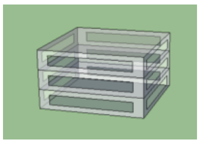
<tr><td rowspan="6">
Case 01
(Basecase)
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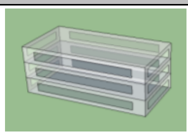
<tr><td>
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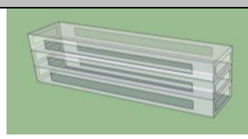
3Flrs, 30mx15m</td><td>
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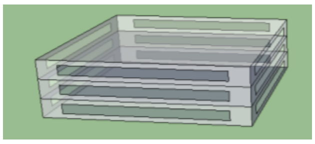
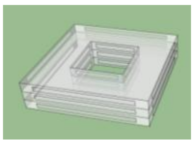
<tr><td>
Case 04
3Flrs, 43mx43m</td><td>
Case 05
10Flrs, 21mx21m</td></tr>
<tr><td colspan="2">SHAPE</td></tr>
<tr><td>
Case 06
3Flrs, 49mx49m, Courtyard</td><td>
Case 07
42mx21mx3Flrs and 21mx21mx7Flrs</td></tr>
</table>

In our parametric analysis, the building design parameters are divided into four categories: building geometries, envelope properties, internal gains and HVAC systems (Table 2 and Table 3) These are typically believed to have a major effect on heating and cooling energy consumption. The different values or options of these parameters are randomly combined to achieve different building designs. The resulting energy performance for each case is calculated with the two competing methods described above.

RESULTS AND DISCUSSION

The comparison of the two methods is presented not only based on a direct comparison of outcomes in a simple regression analysis, but is primarily studied under the condition of its true intent, i.e. the relative ranking of building designs against each other. For the comparison of ranking, the Wilcoxon signed-ranks test is utilized using SPSS Statistics 17.0 (SPSS Inc., 2008). This is the nonparametric test comparing two sets of ranks that come from the same participators which determines statistically whether the sets of ranks are significantly different.

First however, to verify if two different calculation methods result in the comparable outcomes for each case building, the Energy Use Intensity (EUI) results are analysed in a regression model. In Figure 1, EUIs from the normative calculation (the vertical axis) and from the dynamic simulation (the horizontal axis) for each case are plotted. The linear regression has R^2 of 95% indicating that the two sets of outcomes are highly correlated. The actual amounts of EUIs from different calculations fall well within the range of 20% difference for all cases. As seen in Figure 1, the cases can be divided into two groups: Group 1 including HVAC "upgrades" that result in less EUIs than Group 2, and Group 2 including only building envelope, lightings, and/or appliances upgrades. In Group 1, the dynamic simulation outcomes for EUI are lower than what the normative calculation yields whereas Group 2 shows the reverse of this. In other words, this could be interpreted as the dynamic simulation being more favourable to HVAC upgrades and less favourable to the other parameters, whereas the normative calculation seems more favourable to building construction features. Since the EPC calculation utilizes categorized standard values for HVAC systems, it seems to underestimate the true energy efficiency of HVAC systems in its simplified calculation of energy consumption. This would indicate that a study into the improvement of the normative coefficients of HVAC systems in the normative model would be warranted, as indeed has been agued by others (Zweifel, 2007). However, it should not be forgotten that the role of the normative model is not to predict outcomes accurately, but to produce energy rankings that are objectively correct. Indeed, the true motivation for re-adjustments of normative parameters should come from findings that call the resulting rankings into question. Our emphasis therefore shifts to comparing the rankings rather than absolute outcomes.

As shown in Figure 2, Figure 3, and Figure 4, the EPC, Performance Improvement (PI) in ASHRAE 90.1, and the resulting points of LEED EAc1 based on PI are plotted. All three indicators show a fair amount of correlation between the normative calculation result and the dynamic simulation result, 95%, 82%, and 74% R^2 respectively.

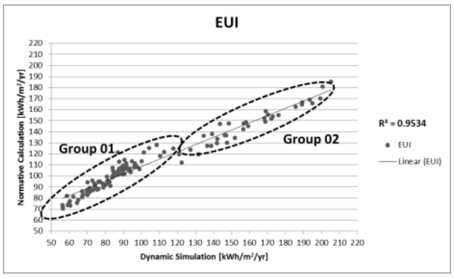


Figure 1 The scatter plot of EUI

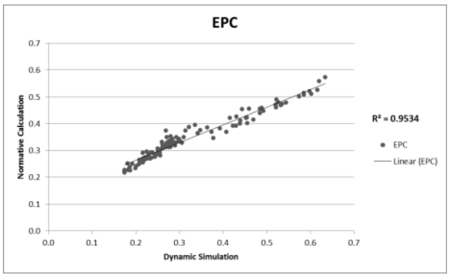


Figure 2 The scatter plot of EPC

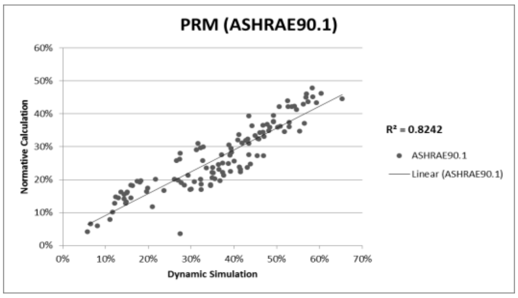


Figure 3 The scatter plot of Performance Rating Method (PRM) in the ASHRAE 90.1 Standard

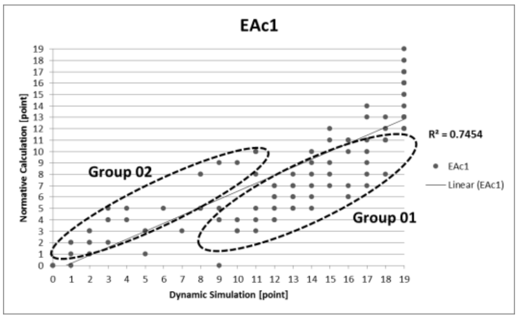


Figure 4 The scatter plot of case buildings

To see if the relative rankings of case buildings in different calculation approaches are significantly different, 119 cases are ranked based on the results from the normative calculation and the dynamic simulation separately. Then each pair of ranks in EUI, EPC, PI and EAc1 is tested using the Wilcoxon signed-ranks test to determine if there is a statistically significant difference between the two rank orderings. When the calculated p-value is smaller than 0.05 from the two-tailed significance level, we can reject the null hypothesis that the median difference between pairs is zero (Norusis, 2008). In other word, if p≤0.05 there is a significant difference between the two rankings. As shown in Table 4, at the significance level of 95%, all pairs have a p-value greater than 0.05, which indicates that there is no strong evidence to conclude that there is a statistically significant difference in each rank ordering.

Table 4 Wilcoxon Signed Ranks Test Statistics

	EUI	EPC	PI	EAc1
p-value (2-tailed)	.467	.467	.780	.060

If the two alternative assessment methods deliver relative rankings that are deemed equal, it is preferred to choose the method that is easiest to use and less ambiguous in terms of possible errors and uncertainties. There is no dispute that dynamic simulation tools have been fulfilling an important role in detailed studies of dynamic building behaviour. This comes at a certain modelling cost and consumes a considerable amount of computation time. Where this can be avoided, one should indeed reconsider.

As shown in Figure 5, EAc1 and EPC have more than 77% correlation with each other, but there is a statistical difference in ranking with the p-value of 0.009 (Table 5). It is mainly because EAc1 points are given in certain ranges of PI whereas EPC is not a point score but a continuous value, which means that some of our case buildings have the same point score but different percentages of energy performance improvement in the LEED system. Therefore, for the apple-to-apple comparison, a comparison of PI and EPC is more appropriate. It was found that this comparison also shows 77% correlation (Figure 6). Furthermore, the Wilcoxon p-value of 0.484 (Table 5) indicates again that there is no significant difference between the rankings using PI or using EPC.

In addition, it was found that to attain 1 point from EAc1, the energy performance of proposed building should be at least 40% better than the corresponding 2003 CBECS data that represents the similar building stock in the same climate region (Figure 6.)

Table 5 Wilcoxon Signed Ranks Test Statistics

	EPC-EAc1	PI-EPC
p-value (2-tailed)	0.009	0.484

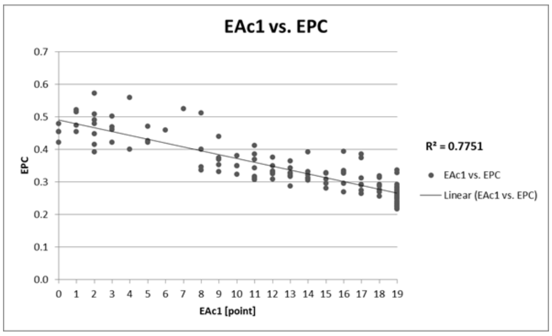


Figure 5 The scatter plot of EAc1 and EPC

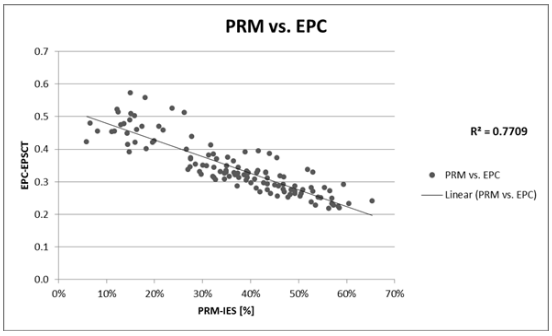


Figure 6 The scatter plot of PRM and EPC

Lastly, we inspect the validity of the argument that the comparison against a baseline of the same building is better than the comparison against a generic (building stock representative) benchmark. This is after all the basis of the ASHRAE 90.1 methodology. Figure 6 and Table 5 show that if PIs are not defined against a baseline but defined as the buildings performance improvement against a fixed benchmark derived from building stock (2003 CBECS) the result is as good as the current method. Note that in this study we look at only one location and one climate zone. To verify that the generation of a benchmark form CBECS would work in all climate zones, further study is necessary. Nevertheless, this study presents the preliminary evidence that the baseline in PRM method could be replaced with one clearly defined reference such as 2003 CBECS maintaining the same results of building ranking as found with the current approach. Adopting this (and rejecting ASHRAE 90.1, Appendix G) would already lead to significant time reduction and transparency enhancement.

As introduced before, one of the main differences between a simulation based and a normative ranking approach, is the fact that dynamic simulation requires extensive expertise and experience and introduces (sometimes significant) modeler's bias. Only few attempts have been done to quantify the effect of modeler's bias on building energy outcomes. To study the potential effect of modeler's bias on the rating we studied how sensitive the PI is to random effects of modeler's bias. For this reason, we assume a random modeler's bias effect of X% around the outcome of the dynamic simulation. We compare these values with the EPC results. Different from the preceding approach, the case buildings are categorized into 7 performance classes. This is done to check whether a certain level of uncertainty in the simulation results (classified into 0%, 10%, 15%, 20%, and 30% random errors) will lead to a re-classification of the design in an adjacent performance class. This method is inspired by the similar study reported in Kokogiannakis et al. (2008). Obviously, a random change of class will lead to a different LEED score and is therefore the ultimate measure of the acceptability of a scoring method. In order to make a valid class-to-class comparison between EPC and PI, the reference value for EPC is adjusted such that the EPC classification has maximum correspondence with the original PI classification. Table 6 shows the intervals of PI and EPC in each class. For instance, a building in class 4 will correspond to a PI improvement between 30% and 40%, and an EPC value between .8 and .65. It should be noted that we chose to use equidistant class sizes on both sides, which is a crude way of classification. Any difference in class size between PI based and EPC based classification of the 119 cases has therefore limited significance. We are more interested in the role that modeler's bias plays in potential re-classification as this will cast doubt on the robustness and fairness of the method. First, we study the reclassification that would result from modeler's bias. shows the average number of change in PI classifications by one or more classes as a result of modeler's bias. Around the 15% bias point half of the cases would change one or more classes.

Table 6 PI and EPC categorization

CLASS	PI	EPC
1	10%	1.1
2	20%	0.95
3	30%	0.8
4	40%	0.65
5	50%	0.5
6	60%	0.35
7	70%	0.2

It is also relevant to compare the mismatches between PI and EPC classifications as is, and as result of increasing modeler's bias. This is shown in Table 8. Table 8 shows the number of matched/unmatched cases among the 119 buildings and the number of cases that have one (Diff=1) or more than one (Diff>1) class change caused by modeler's bias. The results show that a modeler's bias of X≥15% shows a large number of unmatched cases (61) in comparison to zero bias than we find in comparison to the normative calculation (53). Both tables confirm the intuition that classification (of scores) based on simulation based outcomes is very sensitive to random uncertainty. This makes a case for a method where random uncertainty is kept to a minimum.

Table 7 The number of reclassifications

MODELER'S BIAS	0.0	0.1	0.15	0.2	0.3
Diff. = 0	119	77	58	47	29
Diff. = 1	0	41	55	60	58
Diff. >1	0	1	6	12	32
Total	119	119	119	119	119

Table 8 The number of cases in matched and unmatched rating categories

MODELER'S BIAS	EPC (0.0)	0.1	0.15	0.2	0.3
Matched	66	77	58	47	29
Unmatched	53	42	61	72	90
Total	119	119	119	119	119
Diff. = 1	47	41	55	60	58
Diff. > 1	6	1	6	12	32

CONCLUSION

This paper examines two building energy rating methods, LEED-EAc1 and EPC with a parametric analysis. It examines the correlations between both outcomes and their impacts on the respective ranking of a set of case buildings by both methods. It is analysed whether one method has distinct advantages over the other.

Under the constraints posed by the current study, that is to say only one building type (office building) and one climate zone (3A), the results from a parametric study are analysed from two points of view: the features of the calculation methods and the outcomes, in particular the relative rankings that they produce.

First, in the calculation practices, the actual values of EUIs from different methods fall within a maximum difference of 20%. Notwithstanding this range, the EUI results from both calculation methods are strongly correlated, with a R^2 of 95%. Finally, the building rankings from both sets of results show that there is no statistically significant difference in the rankings that both methods produce.

Secondly, the results show that replacing the baseline in ASHRAE 90.1 with a fixed reference value does not affect the rating results in any major way. When comparing PIs with EPCs it shows 77% correlation in a regression analysis, and there was no statistical difference in building ranking. Even though more study is necessary to extend to other building types and climate zones, we conclude therefore that introducing a single reference value would be a good alternative to replace the time consuming baseline simulation in the ASHRAE 90.1 Appendix G method.

Furthermore, whenrandom errors, i.e. due modeler's bias, are introduced in the simulation results, we found that any bias larger than 15% leads to unacceptable number of reclassifications, whereas the normative calculation is by definition not affected by modeler's bias. Starting from ad-hoc classification of PI and EPC classes it is found that at the level of 15% or more the reclassifications of PI exceed the initial mismatch between PI and EPC classifications. This would indicate that, unless modeler's bias can be kept under 15% there is no legitimate reason to prefer the PI approach over the EPC approach.

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REFERENCES

de Wit, S. and Augenbroe, G. 2002. Analysis of uncertainty in building design evaluations and its implications, Energy and Buildings 34, 951-958

Corrado, V. and Mechri, H. E. 2009. Uncertainty and Sensitivity Analysis for Building Energy Rating. Journal of Building Physics 33(2) 125-156

EIA. 2005. 2003 Commercial Building Energy Consumption Survey. Washington, D.C., www.eia.doe.gov/emeu/cbecs/cbecs2003/introduction.html.

Hunn, B. D., Conover, D. R., Jarnagin, R. E., McBride M., and Schwedler, M. March 2010. 35 years of Standard 90.1. ASHRAE Journal March 2010, 36-46.

IES VE-Navigator for ASHRAE 90.1 (LEED Energy). http://www.iesve.com/software/ve-pro/analysis-tools/ve-navigators/nav-ashrae901

ISO. 2008. 13790:2008 Energy performance of buildings – Calculation of energy use for space heating and cooling.

Kleinhenz, P., Seryak, J., Schreier, C., Sever, F., & Raffio, G. 2012. How the culture of inefficiency is out-foxing LEED, ASHRAE, and Efficiency programs in the Midwest, 2012 ACEEE Summer Study on Energy Efficiency in Buildings, 185-196.

Kokogiannakis, G. and Strachan, P.A. (2007) Modeling of double ventilated facades according to CEN Standard 13790 method and detailed simulation. Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st century, 2nd PALENC Conference and 28th AIVC Conference. Heliotopos Conferences.

Kokogiannakis, G., Strachan, P. and Clarke, J. 2008. Comparison of the simplified methods of the ISO 13790 Standard and detailed modelling programs in a regulatory context. Journal of Building Performance Simulation, 1(4), 209-219.

Lee, S.H., Zhao, F. and Augenbroe, G. 2011. The use of normative energy calculation beyond building performance rating systems. Twelfth Conference of International Building Performance Simulation Association, Sydney, 2753-2760.

Newsham, G. R., Mancini, S., and Birt, B. J. 2009. Do LEED-certified buildings save energy? Yes, but…Energy and Buildings 41 (2009) 897-905.

Norusis, M. J. SPSS 17.0 guide to data analysis. Prentice Hall Press, 2008.

SBEM v3.1, 2008. Simplified Building Energy Model. BRE, UK. http://www.ncm.bre.co.uk/

SPSS Inc., 2008. SPSS Statistics for Windows, Version 17.0. Chicago: SPSS Inc.

Standard, A. S. H. R. A. E. "Standard 90.1-2007.(2007)." Atlanta: ASHRAE

US Green Building Council. LEED for new construction v2009. US Green Building Council, 2012.

Zweifel, G. 2007. New EPBD related European Standards and their relation to building and HVAC system simulation. Proceedings Building Simulation. Vol. 7.