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INVESTIGATING THE WEIGHTING MECHANISM IN BREEAM ECOHOMES

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The Building Research Establishment's Environmental Assessment Method for Housing (BREEAM EcoHomes) is a commonly used sustainability assessment method in the UK. Initial investigations highlighted concerns among EcoHomes assessors with the weighting mechanism. The effect of the weights was investigated by a questionnaire sent to housing professionals to gauge the relative importance of each of the EcoHomes issues. The responses were transformed to weights using the analytical hierarchy process (AHP). The results showed that there is a remarkable consistency between respondents on the level of the weights which should be applied. Additionally there are some notable differences between the sets of weights produced by the respondents. However, further research demonstrated that the effect of these weights on the EcoHomes score is small. This indicates that the weighting mechanism is not as important an issue as it was perceived to be and that there may be other issues which are more important.

KEYWORDS: AHP; BREEAM; sustainability assessment; weighting

INTRODUCTION

Sustainability addresses social, economic and environmental considerations. The impact of the construction industry and buildings is substantial on all three of these. The actual impact of the built environment varies in the published data, but all agree it is considerable. In the environmental context buildings account for around half of carbon emissions, and one third of landfill waste (Department for Business Enterprise and Regulatory Reform, 2007). Socially, poor physical conditions have been of detriment to communities (Egan, 2004). It is not surprising that in an attempt to meet in particular carbon emission targets buildings have been a principal focus. One of the main areas for this has been in the housing sector where the Government aim is for net zero carbon homes by 2016 in England and Wales (CLG 2007). One of the tools used to measure delivery of this is the Code for Sustainable Homes (The Code) (Communities and Local Government, 2007). The Code is to a large extent based on the BREEAM (Building Research Establishment's Environmental Assessment Method) for housing – EcoHomes. EcoHomes was first developed in 2000 and added to a family of BREEAM assessment which had previously existed for non-domestic buildings (Rao *et al.*, 2000). BREEAM was the first simplified environmental certification scheme of its kind in the world when it was developed in 1990 (Howard, 2005). EcoHomes underwent revisions in

2003, 2005, 2006 and was the main environmental assessment method for housing in the UK until The Code was introduced. Since May 2008 there has been a mandatory requirement for all new homes in England to be assessed under The Code (CLG 2008). In Scotland the standard remains EcoHomes 2006. The BREEAM non-domestic schemes, EcoHomes and The Code all function in similar fashions. A range of indicators is measured under a set of headline issues. The scores achieved in each issue are transformed to a single score using a relative weighting of each issue. The weights are set by the current revision of the schemes.

Prior to the research presented in this paper a workshop was held at which the shortcomings and potential improvements to EcoHomes was discussed. There were six key risk areas which emerged from this process. These were 1) Indicators are omitted from the process; 2) Unnecessary indicators are included; 3) Weighting Mechanism is ambiguous/wrong; 4) Sub-total for each indicator creates an additional weighting; 5) Uncertainty in the values of the fixed parameters specified by the process (eg. water use for an appliance); 6) Unable to make allowance for regional variations. There was agreement at the workshop that the third, the weighting mechanism, provided the biggest risk in getting a wrong measurement of sustainability. These findings were confirmed by over 60% of EcoHomes assessors who, when questioned, assigned "Moderately Important", "Important" or "Very Important" to the risk. Among the six risks this ranked the highest. It is the purpose of the research presented in this paper to investigate the importance of the weighting mechanism. EcoHomes 2006 was selected as a test scheme, firstly, because it is familiar to the assessors who have worked over the last eight years with the scheme. Secondly, the focus was kept on housing because of the introduction of mandatory assessments under The Code, significantly increasing the amount of assessments taking place. This is especially important as the quantity of the housing stock needs to be increased following the recommendations of the Barker Review (Barker, 2004). Thirdly, the similarities between the BREEAM programmes and The Code will assist with the transferability of the results. This research investigates whether the weights which are used in EcoHomes differ from the levels which would reflect the preferences of those working in the housing construction sector. If there are differences this research aims further to investigate the impact of these on the measure of sustainability. The work presented in this paper discusses EcoHomes 2006 unless otherwise stated.

THE WEIGHTINGS

EcoHomes scores are calculated on a site-wide basis. All the dwellings in a development are awarded a combined score from eight issues. These are i) Energy; ii) Transport; iii) Pollution; iv) Materials; v) Water; vi) Land Use & Ecology; vii) Health and Wellbeing and viii) Management. Under each of the issues a set of points is awarded. These are then calculated as a percentage of the total available for each issue. The score achieved from the credits for each issue is then multiplied by the weight. This provides a weighted score. The weights have been defined through industry consultation, and are normalized to sum to one (Rao *et al.*, 2000). The weights for each of the eight issues are shown in the third column of Table 1. The sum of these weighted scores provides the overall EcoHomes score. An example is provided demonstrating this process in Table 1. As can be seen in the table, Energy, for instance, scored 41.67%. The Energy issue carries a weight of 0.22, which produces a contribution of 9.17% from this issue to the overall score of 53.08%.

The EcoHomes assessment method sets thresholds which define ratings for housing developments. The five ratings are 'Fail' (0%); Pass (36%); Good (48%); Very Good (58%), Excellent (70%). The numbers in brackets refer to the threshold levels. It can be seen that for

the example in Table 1 a 'Good' rating would be obtained; the score of 53.08% is approximately in the middle of the good banding.

Table 1: Example of a BREEAM EcoHomes assessment

	Issue Achieved for Issue (%)	BREEAM EcoHomes Weight	Weighted Score- (Issue Score x weight) (%)
Energy	41.67	0.22	9.17
Transport	75.00	0.08	6.00
Pollution	36.40	0.10	3.64
Materials	87.10	0.14	12.19
Water	50.00	0.10	5.00
Land Use & Ecology	11.10	0.12	1.33
Health & Wellbeing	62.50	0.14	8.75
Management	70.00	0.10	7.00
		EcoHomes Score	53.08%

QUESTIONNAIRE

The entire population of 409 EcoHomes assessors was sent a questionnaire. It was noted that the population did not have many assessors in Scotland. To ensure responses were received from Scottish organisations the private and public housing sectors were also issued with a questionnaire. This was sent to all of the Registered Social Landlords (RSLs) in Scotland and all member organisations of Homes for Scotland (HfS). Homes for Scotland members produce 95% of the new built homes for sale in Scotland (Homes for Scotland, 2007). RSLs are landlords provide social rented accommodation and are registered with Communities Scotland (2007). To ensure coverage of the public sector the sustainability managers of the local authorities in Scotland were also sent the questionnaire.

The size of the populations sent the questionnaire is shown in column A of Table 2 for the different groups. The number of responses is given in column B, along with the corresponding response rate in C. Several organisations stated that they were unable to complete the questionnaire due to a lack of time or knowledge, or the address was unknown. Account of this was taken by modifying the response rate using equation 1 (Bryman, 2004). This is given in column E of Table 3.

$$\text{Modified Response Rate (E)} = \frac{\text{Number of Responses (B)}}{\text{Number Sent(A)} - \text{Number Unable to Complete(D)}} \quad \text{Equation 1}$$

Table 2: Population and response rate from questionnaire

	Sent (A)	Replied (B)	Response Rate (C)	Cannot Complete (D)	Modified Rate (E)
EcoHomes	409	76	18.6%	30	20.1%
RSL	159	16	10.1%	2	10.2%
Homes for Scotland	90	9	10.0%	1	10.1%
Local Authorities	38	6	15.8%	13	24.0%
Overall	696	107	15.4%	46	16.5%

The Analytical Hierarchy process

To determine the relative importance of the eight issues in EcoHomes it is necessary to use a prioritisation method. The analytical hierarchy process (AHP) is a multi-criteria decision making method of assigning weights to different criteria to facilitate complex decision making (Saaty, 1980). For the research at hand each of the eight issues are defined as the criteria, and the AHP is used to define the relative importance of each one. The AHP requires a pair-wise comparison between each of the eight issues. This results in 28 individual comparisons. Comparisons are carried out on a nine-point scale (Saaty, 1980). The scale ranges from "equally important" (1) to "absolutely more important". These values relate to a score of 1 and 9 respectively, with seven intermediary levels. Inverse relationships (ie. "less important" rather than "more important") are imputed simply by inverting the result of the original score. For example "absolutely less important" scores 1/9.

The scores for each of the comparisons are collected into a matrix. An example for a three issue (A, B and C) assessment is given. A is weakly more important than B (3); A is absolutely more important than C (9); and B strongly less important than C (1/5). This is presented on the left of Figure 1. The inverse of these values are given for the alternative comparison in the matrix, as demonstrated on the right hand side of Figure 1.

	A	B	C
A		3	9
B			1/5
C			

(1) Pair-wise comparisons are included in matrix

	A	B	C
A	1	3	9
B	1/3	1	1/5
C	1/9	5	1

(2) Inverse values are included for the alternative comparisons

Figure 1: The AHP Matrix

There are a range of mechanisms available to determine the weights from the matrix and possibly the most effective is by iteration of the matrix Eigenvector (Saaty, 1980). This process squares the matrix on the right-hand side of Figure 1, and then calculates the Eigenvector. This provides the set of weights. However, to ensure that the most appropriate solution is reached, the squared matrix is itself squared, and a new Eigenvector of weights

calculated. When there is no change in value between subsequent Eigenvectors these iterations stop. The Eigenvector is normalised to one to calculate the weights.

The AHP has been used by previous researchers for application to sustainability assessment (Lombardi, 2007). The examples cited by Lombardi make use of the ability to compare different options on a quantitative scale. There is little published information on the method used by the Building Research Establishment (BRE) to determine the weights for BREEAM EcoHomes. A BRE report published in 2000 (Dickie and Howard, 2000) outlined a weighting process which was undertaken for environmental issues. Experts were provided with 20 points which were to be 'spent' across a range of issues. A second process allowed themes of sustainability to be ranked subjectively and were then weighted using an objective process, but there are no details as to what this was.

RESULTS

Range of Weights

The weights for each respondent from the questionnaire were calculated using the AHP. The responses from all the respondents were averaged for each issue. The effect of the inconsistent results was compared also, firstly by removing the inconsistent results from the analysis and subsequently by including them. The level for each of the issues for these two new sets of weights is given in Table 3. In total there were 96 responses with usable weights; 63 of these remained when the inconsistent values were removed.

Table 3: Mean values of AHP weights from Questionnaire

			Without Inconsistent			With Inconsistent		
	Original Weight	Rank	Mean	St Dev	Rank	Mean	St Dev	Rank
Energy	0.220	1	0.225	0.115	1	0.216	0.112	1
Transport	0.080	8	0.096	0.069	7	0.100	0.069	6
Pollution	0.100	5	0.141	0.073	3	0.142	0.070	3
Materials	0.140	2	0.104	0.042	4	0.108	0.051	4
Water	0.100	5	0.146	0.072	2	0.144	0.070	2
Land Use & Ecology	0.120	4	0.102	0.046	6	0.099	0.046	7
Health & Wellbeing	0.140	2	0.104	0.054	5	0.104	0.055	5
Management	0.100	5	0.083	0.058	8	0.086	0.059	8

The results presented in Table 3 were tested for statistical differences between the weights. All tests were undertaken at a 95% level of confidence. Firstly a Spearman Rank Correlation was calculated to determine differences between the rank orders of the weights. This demonstrated that there was no difference in order between the inclusion and exclusion of

inconsistent values. However, both of these lists differed in rank order to the original weights. To investigate these further a Student's t-test was used to determine the differences between the mean of the values obtained from the AHP and the original weights. This was performed in turn for each of the eight issues and showed that the hypothesis that energy and transport had the same mean could not be rejected. However, for the remaining six issues, the alternative hypothesis that the means were not equal was accepted.

The level of the weights was investigated further by reviewing the responses for five UK regions. These regions differentiated between Scotland and four English areas (North England; Midlands; South West England and South East England), defined by Regional Development Agency boundaries. Weights could not be calculated for Wales because there was only one response. Each respondent was placed in the region defined by the region of their postal address. The average weights for each issue were calculated from the respondents in each region. The values of these regional weights are given in Table 4 together with the differences from the original weights.

Table 4: Derivation of regional weights

	Mean Weights for Each Region (% Change from Original EcoHomes Weight in Brackets)					
	Original Weight	Scotland	North England	Midlands	South West England	South East England
Energy	0.220	0.185 (-15.9%)	0.29 (31.8%)	0.204 (-7.3%)	0.248 (12.7%)	0.213 (-3.2%)
Transport	0.080	0.122 (52.5%)	0.096 (20%)	0.075 (-6.3%)	0.093 (16.3%)	0.097 (21.3%)
Pollution	0.100	0.163 (63%)	0.126 (26%)	0.144 (44%)	0.117 (17%)	0.143 (43%)
Materials	0.140	0.114 (-18.6%)	0.079 (-43.6%)	0.106 (-24.3%)	0.12 (-14.3%)	0.106 (-24.3%)
Water	0.100	0.132 (32%)	0.164 (64%)	0.136 (36%)	0.137 (37%)	0.161 (61%)
Land Use & Ecology	0.120	0.101 (-15.8%)	0.084 (-30%)	0.118 (-1.7%)	0.100 (-16.7%)	0.092 (-23.3%)
Health & Wellbeing	0.140	0.098 (-30%)	0.087 (-37.9%)	0.122 (-12.9%)	0.100 (-28.6%)	0.103 (-26.4%)
Management	0.100	0.084 (-16%)	0.074 (-26%)	0.095 (-5%)	0.085 (-15%)	0.086 (-14%)

Statistical tests, again at a 95% confidence level, were carried out to determine the differences in weights among the five regions. Statistically the range of values produced demonstrated a remarkable consistency. In the tests it was not possible to reject the hypothesis that the means were the same in almost all of the cases. The only significant

differences occurred in Energy between Scotland and the North of England; Transport between Scotland and the Midlands; Materials between Scotland and the North of England and again in materials between the South West and the North of England.

In a comparison with the original weights defined by BRE, these mean values of regional weights again showed a remarkable consistency. The small differences were: Transport in Scotland was demonstrated as being different, and Pollution in Scotland, South East and the Midlands. Finally the weights across all of the regions for Water differed significantly from the 10% applied by BRE. To investigate again the effect of the rank order of the regional weights the Spearman Rank Correlation Co-efficient was used. This demonstrated that there were no differences between the rank orders of the six regions. However, all six regions differed in rank order from the BRE weights.

Inconsistency, however, existed in comparison of the mean values of the weights to the original weights. It can be seen from Table 4 that differences in excess of 60% from the original weight were possible. The effects of these changes to the level of the weights will be investigated further.

The Effect of the Weights

Further investigation applied each of the regional weights in Table 4 to 30 past examples of EcoHomes assessments, obtained from 11 licensed EcoHomes assessor organisations. All 30 were compared with a reference value using the score from the original EcoHomes weights. The difference between the two was measured using the mean accuracy. This is done in two stages. Firstly, the difference in the measurement as a percentage of the original score was calculated. Secondly, the mean value of this error was calculated across each of the six regions. In addition to the six regions and the UK average weights given in Table 4, an equal weighting of one eighth was applied for comparison. The average difference for eight sets of weights is given in Table 5. The largest differences are +1.15% and -0.66% from the original scores.

Table 5: Difference from original scores when regional weights are applied

	% Difference from Original EcoHomes Score						
	Scotland	North England	Midlands	South West England	South East England	UK Average	Equal
Mean	1.15%	0.89%	-0.66%	0.89%	0.72%	0.42%	1.03%
St Dev	0.038	0.032	0.023	0.020	0.028	0.027	0.040
Max	8.94%	8.24%	4.57%	5.50%	7.38%	6.76%	10.52%
Min	-7.59%	-5.90%	-4.24%	-3.50%	-5.26%	-5.25%	-7.55%

While the absolute value of the score is important, the measure commonly used is the descriptive rating. Thus the effect of the different weights on the weighting was investigated. For each of the 30 cases the original BRE weighting was determined, as was the rating using each of the regional and equal weights. The two ratings were compared for each region. The rating was changed in four cases or less for four out of five regions. For the North of England

the rating changed in seven out of thirty cases. The UK average weights and the assumed equal weighting resulted in a change of rating three and five out of thirty times respectively. Where the rating was affected this was generally due to the case being close to the threshold. The application of weights thus moved the score below the threshold and changed the rating accordingly.

DISCUSSION OF ECOHOMES WEIGHTING MECHANISM

The process of investigating the weights has utilised the AHP. The AHP has allowed the relative importance of each of the eight issues in BREEAM EcoHomes to be re-calculated. The benefits of using the AHP are two-fold. Firstly, due to the pair wise comparisons which are carried out the respondents cannot readily determine the outcome of the relative importance. Secondly, the inclusion of a consistency index allows the effect of responses which are inconsistent to be identified. However, these advantages are offset by a relatively complex response form required.

The overall response rate to the questionnaire was 16.5%. From the weights which were derived from these responses it was shown that there are differences between the mean weights across the UK and the weights set by EcoHomes for six of the eight issues. Further the rank order for these new scores and the original scores is different. This implies that there are differences between the levels of the weights which have been set by BRE in the EcoHomes 2006 process and the perception of the assessors and others working in the housing sectors.

When the weights were calculated for each of the six UK regions there was considerable consistency between the regions. This was partly due to the spread of the weights being relatively large for the means, accounting for the apparently large differences in the values for each issue. This finding was further confirmed by the rank correlation co-efficient, which demonstrated no statistical differences between the regions. The more concerning finding in this process however was that while there was general consistency between all of the weights obtained from the questionnaire and the weights set by BRE, the rank order of these differed significantly. In addition to this all of the regions deemed water to be significantly more important than the value set by BRE. However, despite these differences in rank order and magnitude of the weights the effect on the overall scores was seen to be relatively small. The application of each of the regional weights to 30 examples demonstrated that the score achieved for the assessment difference by a maximum mean value of 1.15% in Scotland to a minimum of -0.66% in the Midlands. Regionally, there were extremes of values which occurred when the new weights were applied. These were all within +9/-8% of the original score defined by BRE. This number is not considered to be large by itself, and the standard deviation of the score shows it to be within a reasonable range. The UK mean weights had the smallest effect on the average difference in score, again demonstrating a consistency between the weights defined by BRE and the general view of assessors across the UK. Interestingly, when the BRE scores were compared with applying an assumed equal weighting to each of the eight issues the score are within an average of 1% of the original score. However, an equally weighted score has a larger spread in the differences than the regional weights, and has a maximum difference of 10.52%. This is also the largest absolute difference from the original score at 5.72 percentage points.

What is potentially more important for users of EcoHomes is the effect on the rating. Frequently money and effort will be spent on increasing the score by a few points for this to

be improved. All of the changes resulted in scores that were within six percentage points of the original. However, across most of the regions this only affected the rating in four or less out of thirty cases. These were generally due to a rating threshold being exceeded by only a small amount. The application of different weights thus moved the score below the threshold. This would imply that, although only by a small amount, the regional weights result in a lower score and hence a tighter awarding of sustainability points than is the case using the present EcoHomes version. This is most obvious in the North of England case which resulted in seven different ratings. This would suggest there are differences in the weights applied in this region on the issues which have been the focus in increasing the rating. This is confirmed by the differences which occurred between some of the regions and the North of England in the mean scores. Significantly there were differences between materials and energy issues. Under the BRE weights these are the topmost with 22% and 14% of contribution respectively. However, within the North East, Energy is the most important at 29%, with this score being higher than all of the other regions. In contrast, Materials is the second lowest at 7.9% with the score for this issue being lower than all of the other regions, and nearly half of the original weight. This can therefore be accounted for in the examples which aimed to reach the appropriate thresholds by increasing the scores in the two issues with the largest weights (Energy and Materials). When the regional weights are applied the effect of the materials score is reduced, hence reducing the score below the threshold.

CONCLUSIONS

The research presented in this paper has shown that the weightings used in BREEAM EcoHomes are generally robust. There are some differences between the weights obtained from assessors across the UK and the weights set by BRE, and the rank order of these is different. However this has been demonstrated to have a minimal effect on the scores. A relatively small range of scores is obtained when different weights are used. Further investigation has shown that there are some differences in the absolute values of the weights when the UK is split into regions. However, the effect of these on the overall score is minimal. Similarly, there is only a small effect on the scores when it is assumed that each of the issues is of equal importance. This research confirms the findings which were originally published by BRE in 2000 showing consistency among those involved in the weighting process. This is further confirmed that where there are inconsistencies these do not substantially affect the overall EcoHomes score.

While the research presented in this paper has been demonstrated on EcoHomes 2006 there is no reason to believe that the findings would not be equally transferrable to The Code or the non-domestic BREEAM schemes. The practical significant of this piece of research in relation to the assessment methods is in demonstrating that since the weights do not have a large affect on the overall score, assessors should not be unduly concerned by them. However, the weights do potentially have an impact in directing the focus of designers who give higher weighted issues more attention if a higher rating is required.

Overall it has been shown that the weighting mechanism is not a significant issue in BREEAM EcoHomes. This is in contrast to the perspectives of those assessors questioned. The findings in this research should increase confidence in using the EcoHomes. However, there are other potential issues with the process as a sustainability assessment method which should be considered. Most significantly, the assessment only takes account of the environmental and a small amount of social issues. No account is taken of the economic

dimension of sustainability. The impact of these on sustainability assessment should be considered.

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