International Journal of Civil Engineering and Technology (IJCIET)
Volume 8, Issue 10, October 2017, pp. 1821–1828, Article ID: IJCIET_08_10_183
Available online at http://http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=8&IType=10
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

DEVELOPMENT OF FUZZY RATING MODEL FOR RESIDENTIAL GREEN BUILDINGS BASED ON PRE-OCCUPANCY & POST-OCCUPANCY PARAMETERS

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ABSTRACT

As 'sustainable development' has become a global focus, ''Green Building'' or ''Sustainable Building (SB)'' is the need of the day. These buildings not only reduce negative environmental impact but also improve human comfort and safety. Sustainable Buildings need to be assessed by 'Assessment tool' for checking its overall contribution towards achievement of 'sustainability'. In this paper an attempt is made to develop a user friendly computer based evaluation programme. The beauty of the model is such that evaluator can do the rating of building according to its predicted performance in the design phase as well as during post occupancy phase of the building. The model is given the name from ***F****uzzy* ***Ra****ting* ***M****odel for* ***Re****sidential* ***B****uildings as* ***'FRAMREB'****.* ***'FRAMREB' is*** *a comprehensive one with flexible and easy to calculate scoring system. It covers non-controllable factors along with negative scoring system. Results can be utilized in the coming years to prepare a comprehensive 'GBAT' for developing country like India.*

Key words: Green Residential Buildings, Fuzzy Model, Post occupancy, Pre occupancy

Cite this Article: D. A. Pastagia and J.E.M. Macwan, Development of Fuzzy Rating Model for Residential Green Buildings based on Pre-occupancy & Post-occupancy Parameters. *International Journal of Civil Engineering and Technology*, 8(10), 2017, pp. 1821–1828.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=10

1. INTRODUCTION

Buildings are found to be contributing about 36–45 % of the carbon dioxide emissions and between 25 and 48 % of the sulphur dioxide emissions in the UK and the US. Thus, to say that buildings are the single largest source of terrestrial and atmospheric pollution is not an overstatement. Throughout the world, the construction industry is responsible for high levels of pollution, resulting from the energy consumed and during the extraction, processing and

transportation of raw materials. This has led to the emergence of a sustainable design agenda. According to the researches, buildings are major contributors to environmental deterioration. Sustainable construction is considered as a way for the construction industry to contribute to the larger effort of achieving sustainable development (SD). 'Sustainable Buildings (SB)' are described as buildings which are energy efficient, healthy, comfortable, and flexible in use and designed for longer life. Performance of SBs are assessed by building assessment tools. It has been noted that initial building assessment tools focused only on environmental performance but there is a discussion required on the need to bring sustainability concerns into the tools. This includes economic and social concerns as well as environmental aspects of sustainability. Economic, social and cultural issues are not considered as major issues by many of the countries till date while performing building assessments. The main emphasis is on ecological impacts to the environment. So, there is a need of a paradigm shift in the approach as: earlier construction industry was emphasizing on three factors: cost, quality and time. Then new approach emerged which added: resources, emissions and biodiversity to protect environment. Now, global need for SD calls for addition of new factors as: social equity and cultural issues, economic constraints, service quality and safety aspects.

The present research is having objective to develop a user friendly computer based evaluation programme. The beauty of the model is such that evaluator can do the rating of building according to its predicted performance in the design phase as well as during post occupancy phase of the building.

2. MODEL DEVELOPMENT

After development of criteria scoring system for all 68 criteria in GB assessment model, last step is to develop final building assessment model. Here, a model is developed which includes global weights for each criteria (derived by AHP technique) and fuzzy based score which can be generated from fuzzy logic inference system of each criterion. For each criterion, fuzzy score calculation can be performed from MS Excel itself by using the link set up between MS Excel and MATLAB 2007. The concept of assessment model is given in Figure 1.0.

The model is given the name from **F**uzzy **Ra**ting **M**odel for **Re**sidential **B**uildings as **'FRAMREB'**. First of all, evaluator has to collect the performance data for the particular criterion from the building authority. This value is called as 'basic crisp'. Range of this value would be large. Then by using fuzzy evaluation model of that criterion, the performance value (Basic Crisp) of criterion will be converted in to fuzzy value (In between 0 to 1) through fuzzy evaluation file.

This operation can be carried out through fuzzy logic by aggregation of input value into different fuzzy sets. This fuzzy score gets converted into 'modelled crisp score' through fuzzy logic approach. It is the output of fuzzy logic. Range of this value is from 0 to 5. This scale is designed to encourage those involved in green building projects to achieve better design results. 0 to 5 will be the output of the fuzzy model of each criterion. The output value is multiplied by global weight of that criterion (derived by AHP technique) which is derived in earlier phase of this research. Thus, evaluator can get weighted score of criterion. Likewise, evaluator has to do assessment of each criterion in different worksheets. Result of 'Star Rating' of building is given in one out of four different levels. If the performance score is in between 1.5 to 1.99, building will be rated as one star. If the total score of building is in between 2 to 2.99, it will be rated as two stars. If the performance is in between 3 to 3.75, it will get three stars and if it achieves more than 3.75 score, it will be rated as four stars.

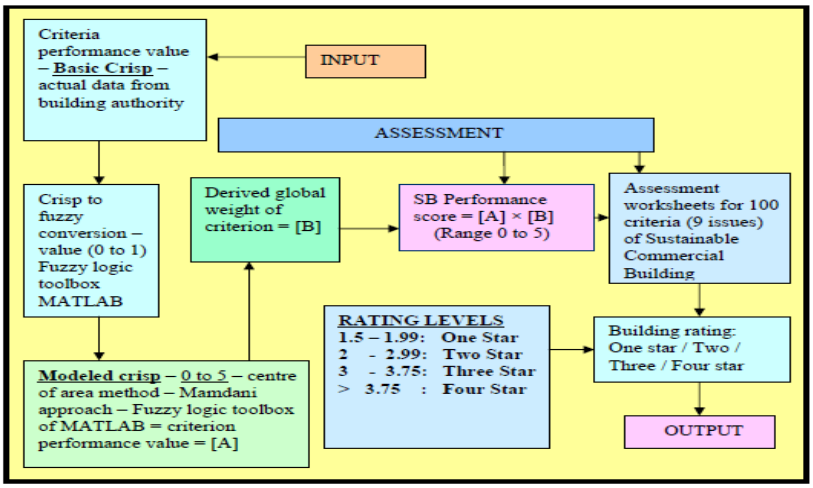


Figure 1 Schematic diagram of 'FRAMREB'

'FRAMREB' assessment model contains 15 different worksheets. First worksheet covers general information about the project such as name of project, contractor name, architect name, year of construction, address, area of building etc. Second worksheet contains numeric value to establish relative importance in the form of global weights of each criterion of the model. It covers total 68 criteria. Third worksheet covers assessment module of first issue – sustainable site – in two different categories: site selection & site development. Fourth worksheet covers assessment module for project planning related criteria. Fifth worksheet includes assessment module for innovation in design related issues. Sixth worksheet covers assessment module for materials and other resources issues. Seventh worksheet includes an assessment module of Social & Economical Aspects related criteria. Eighth worksheet includes assessment module for environmental loading related criteria. Ninth worksheet covers assessment module for Environmental Loadings issues. Tenth worksheet includes assessment module for cultural issues and eleventh worksheet includes assessment module for indoor environment quality issues. Twelfth worksheet includes assessment module security & safety issues. Thirteenth worksheet includes assessment module building operation & maintenance issues. Fourteenth worksheet includes assessment module flexibility & adaptability issues. Fifteenth worksheet shows the result of the assessment. At the end of each worksheet; evaluator will get a weighted sum of the building's score under that category of assessment. Weighted score of building's performance will be transferred from worksheet no. 3 to 14 to worksheet no. 15 through link.

1	GROUP A SUSTAINABLE SITE: SITE SELECTION, PROJECT PLANNING & URBAN DEVELOPMENT						
2	SR NO	NO	CRITERIA	GLOBAL WEIGHT	PERFORMANCE INPUT	FUZZY SCORE	WEIGHTED SCORE
3	A	SUSTAINABLE SITE					
4	A.1	SITE SELECTION					
5	1	A.1.1	Pre-development ecological value or sensitivity of land - flora and fauna of site land	0.0049	0	4.58	0.0225
6		Intent	To discourage the use of land with prior high ecological value				
7		Indicator	Ecological value or sensitivity of land used for construction as determined by competent authority				
8		Assessment method	Review of a site analysis report by an Ecologist				
9		Scoring Method	INPUT MBP: very limited- 0-0-30, limited - 0-30-60, same as adjacent - 30-60-90, wide- 60-100-100 OUTPUT MBP: Low Green - 0-0-1.75-2.75, Medium green- 1.75-2.75-3.75, High green- 2.75-3.75-4.75, Excellent green- 3.75-4.75-5-5				

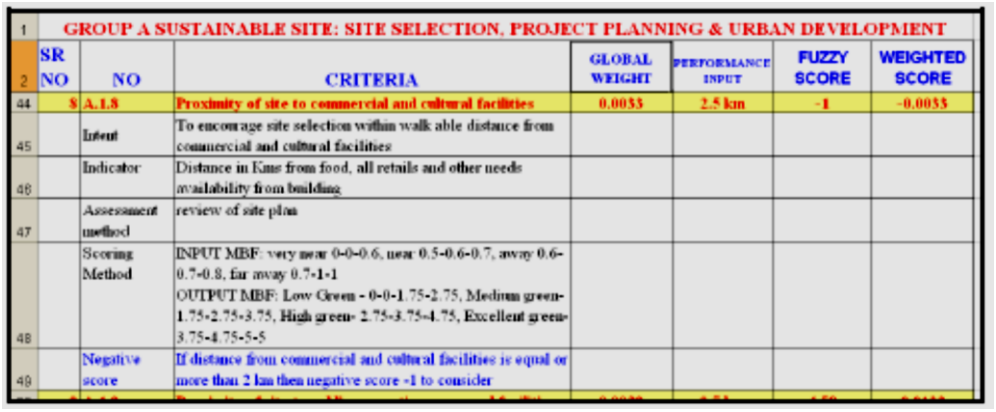
Figure 2 Schematic diagram of assessment module of GB assessment model

Figure 2 explains the theme of working for each assessment module in a separate worksheet. For each criterion, its intent, indicator, assessment method and fuzzy based scoring method (input MBF and output MBF) is given in four rows. The intent of criterion explains the purpose of that criterion. Indicator and assessment method gives information about how to work out criterion performance value. Scoring method includes input and output membership functions (MBF) for all fuzzy sets. Output fuzzy sets are common for all criteria. For each criterion, four columns are given for assessment. The first column is of global weight. Global Weight column shows numerical value of criterion which was derived by AHP technique in third phase of this research. 'Performance Input' column is actual data regarding building's input value for that criterion. Say for example, for a particular site, selected land is having no ecological value, so '0' input was selected. 'Fuzzy Score' column gives criterion performance score conversion in to modelled crisp value in between 0 to 5. For'0' input, fuzzy score is 4.58 through fuzzy logic technique. It is derived by using a fuzzy model of that criterion in fuzzy logic toolbox of MATLAB. 'Weighted Score' is the last column of evaluation sheet which gives criterion's performance value. Stepwise evaluation procedure for criteria is given below:

- Evaluator has to enter criterion performance value according to input MBF range in 'PERFORMANCE INPUT' column worksheet. Then he has to open criterion's fuzzy inference system file. This can be done through 'evalstring' command (to execute MATLAB command by using interlink between MS Excel & MATLAB software) available in MS Excel which will open MATLAB 2007 software. By entering performance value in the rule viewer command, he can get defuzzified output.
- This output score would be in between 0 to 5, which evaluator has to enter in 'FUZZY SCORE' column of the worksheet.
- After entering the fuzzy based score, it is multiplied by AHP based numeric global weight value to generate the criterion weighted score. Weighted score of criterion = 'Global Weight' of criterion × 'Fuzzy Score' of criterion (For above figure, weighted score = 0.0049 × 4.58 = 0.0225)
- Each worksheet gives a total weighted score by building under that issue. This weighted score is transferred to 'Result worksheet' through link and building score is displayed in the last worksheet (out of '5') with rating under any one category (One star, two stars, three stars or four stars).

3. CRITERIA WITH NEGATIVE SCORING

Negative implications are as valuable as positive ones. The supporters of negative scoring considered that this would give an incentive to building owners, developers and decision makers to achieve higher sustainability scores. The current rating systems does not account for negative scoring to reflect unsustainable performance of buildings. It would be better for such aspects to penalize the building authority within the system of assessment (Alwaer and Clements-croome, 2009). Hence in 'FRAMREB', negative scoring effect is considered for 24 out of total 68 criteria as per the opinion of experts'. Figure 3.0 shows criterion A.1.1 (Proximity of site to commercial facilities) with negative scoring effect.



1	GROUP A SUSTAINABLE SITE: SITE SELECTION, PROJECT PLANNING & URBAN DEVELOPMENT						
2	SR NO	NO	CRITERIA	GLOBAL WEIGHT	PERFORMANCE INPUT	FUZZY SCORE	WEIGHTED SCORE
44	8	A.1.8	Proximity of site to commercial and cultural facilities	0.0033	2.5 km	-1	-0.0033
45		Intent	To encourage site selection within walk able distance from commercial and cultural facilities				
46		Indicator	Distance in Kms from food, all retails and other needs availability from building				
47		Assessment method	review of site plan				
48		Scoring Method	INPUT MBF: very near 0-0-0.6, near 0.5-0.6-0.7, away 0.6-0.7-0.8, far away 0.7-1-1 OUTPUT MBF: Low Green - 0-0-1.75-2.75, Medium green-1.75-2.75-3.75, High green- 2.75-3.75-4.75, Excellent green-3.75-4.75-5-5				
49		Negative score	If distance from commercial and cultural facilities is equal or more than 2 km then negative score -1 to consider				

Figure 3 Criteria A 1 1 – Proximity to commercial facilities with negative scoring effect

24 criteria (12 for Pre occupancy & 12 for Post occupancy) are considered for negative score due to its importance according to current Indian conditions and as per opinion of experienced Architects' and Developers' (Phase 2 survey findings supports negative scoring). For a negative performance by building, '-1' score is to be considered for that particular criterion. Weighted score of that criterion will be also negative (For Figure 4.0, weighted score of criterion = 0.0033 × -1= -0.0033). Table 79 shows all 35 criteria which are considered with negative score effect in FRAMREB.

This research was intended to provide a scale where the focus in sustainability assessment is based on more positive than negative attributes. Alwaer and Clements- Croome (2009) also used '-2 to +5' scale while developing an assessment model for sustainable intelligent buildings. For above criterion A.1.8, based on experts' opinion it was decided that if distance of commercial and cultural facilities is more than 2 km (2.5 km in this case) from building site, then '-1' score shall be considered. In that case, this particular criterion's weighted score will be negative (-0.0033 in this case). So, for the poor performance of criterion, the evaluator does not need to refer its fuzzy model, but directly he or she shall put '-1' score. The final rating of the building will be given as per Table 1.0.

Table 1 GB assessment model evaluation levels

Sr No.	Score Range	% of score to be achieved	Evaluation level of certification
1	1.5 to 1.99	30 to 39.9	One Star
2	2.0 to 2.99	40 to 59.9	Two Star
3	3.0 to 3.75	60 to 75	Three Star
4	Above 3.75	Above 75	Four Star

The final result worksheet of assessment model is given in table 2.0. Weighted score for issues from sustainable site (worksheet no. 3) to flexibility & adaptability (worksheet no. 14) will be transferred to last worksheet's column named 'SCORE' through link in programme. The next column shows the maximum possible score a building can achieve under that particular issue. The last column of result worksheet shows the % of scores achieved by the building out of the maximum possible score. The total score of the building will be reflected at the bottom of all issues; which will be out of 5.

Table 2 Result worksheet – 'FRAMRAB'

RESULT - FRAMREB				
SR NO	**ISSUE**	**SCORE**	**MAX POSSIBLE SCORE TO BE ACHIEVED**	**% OF SCORE ACHIEVED IN CATEGORY**
A	SUSTAINABLE SITE	0.1056	0.5464	19.3222
B	PROJECT PLANNING	0.0918	0.7740	11.8631
C	INNOVATION IN DESIGN	0.3353	0.9741	34.4243
D	MATERIALS AND RESOURCES	0.5421	0.7953	68.1620
E	SOCIAL & ECONOMICAL ASPECTS	0.2110	0.8505	24.8102
F	ENVIRONMENTAL LOADING	0.1108	0.9666	11.4592
G	INDOOR ENVIRONMENT QUALITY	0.3625	0.8819	41.0983
H	HEALTH & WELL BEING	0.0943	0.5597	16.8509
I	WASTE MANAGEMENT	0.6667	0.9815	67.9211
J	SECURITY & SAFETY	0.1148	0.8521	13.4726
K	BUILDING OPERATION & MAINTANANCE	0.1270	0.9219	13.7808
L	FLEXIBILITY & ADAPTIBILITY	0.2591	0.9164	28.2744
	TOTAL SCORE OF BUILDING	3.0209	10.0204	30.1480
	RESULT - GB PERFORMANCE		EVALUATION RANGES	
	THREE STAR		SCORE RANGE	LEVEL OF GREEN
			1.5 -1.99	ONE STAR
	***		2.00 - 2.99	TWO STAR
			3.00 - 3.75	THREE STAR
			Above 3.75	FOUR STAR

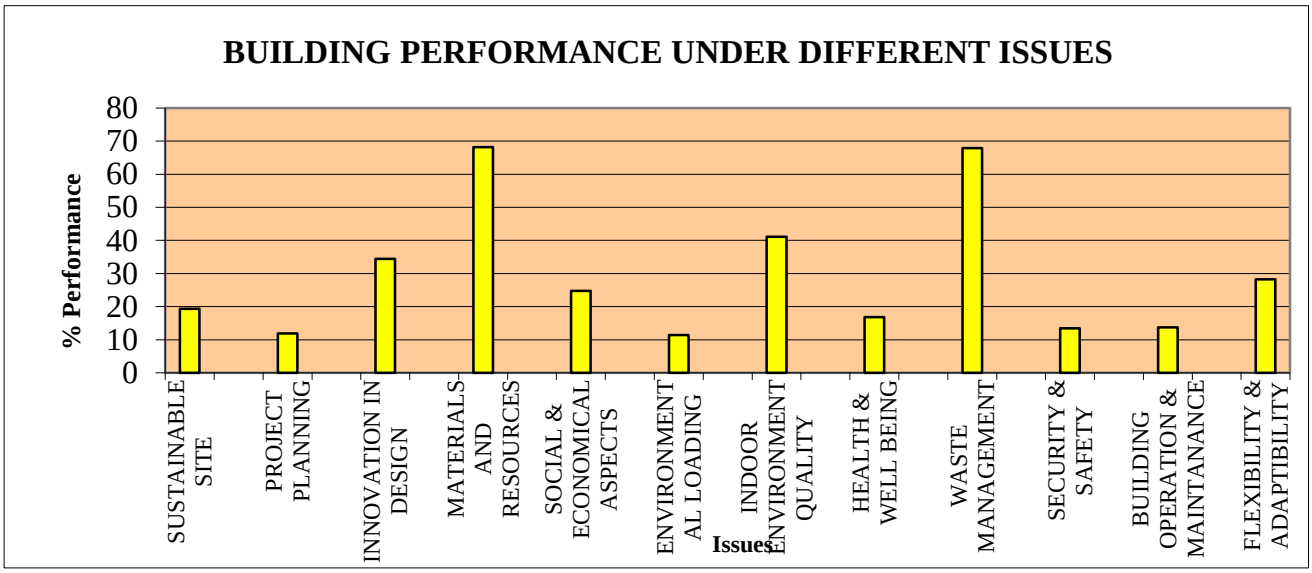


Figure 4 Building Performance under Different Issues

'Four stars' are awarded to the building with highest sustainability performance. The star rating will automatically reflect in the result worksheet. The graph of building's performance under 12 issues will be generated at the lower end of result worksheet. From this graph, evaluator can get idea about lack of building's performance under certain issue. Say for example, for building results shown in above figure, under material resource & reuse performance is good (68.16 %). For environmental loading issue its performance is poor (11.46%). For Building operation & maintenance (13.78 %) & security &safety (13.47) issues

performance is also poor. Further evaluator can suggest corrective measures to improve its performance under environmental loading, Building operation & maintenance & security & safety issues.

'FRAMREB' is an assessment model to assess residential green building in pre occupancy & post occupancy phase. It depends on two types of parameters: Endogenous (Constants-global weights of criteria) and Exogenous (Variables - performance value of building for the criterion). Building's assessment score is the interplay between above two parameters. 'FRAMREB' will make the evaluation of building a most realistic one, as relative importance of criterion is taken into consideration in the process of assessment. If building's performance is good for set of criteria having higher global weights, then that building will get higher rating. Performance evaluation is fuzzy logic based, so every effort of building authority will get converted in to some score. Criteria are covered from environmental to social issues with wide range. Mathematically the model considers 8 digits accuracy after the decimal which is also one of the highlighting features of this model.

4. MODEL COMPARISON

In this section 'FRAMREB' is compared with LEED INDIA 2011 and GRIHA on various aspects.

Table 3 Comparison of evaluation scheme of different systems

Level of Evaluation	LEED INDIA 2011		GRIHA		FRAMREB	
	% of Score to Achieve	Rating Level	% of Score to Achieve	Rating Level	% of Score to Achieve	Rating Level
FIRST	40 – 49	Certified	50 – 60	One Star	30 – 39.9	One Star
SECOND	50 – 59	Silver	61 – 70	Two Star	40 – 59.9	Two Star
THIRD	60 – 79	Gold	71 – 80	Three Star	60 – 75	Three Star
FOURTH	>80	Platinum	81 – 90	Four Star	>75	Four Star
FIFTH			91 – 100	Five Star		

Table 3 gives comparison of the evaluation scheme of FRAMREB with LEED INDIA 2011 and GRIHA. Lowest level (One star) of building evaluation under 'FRAMREB' is kept lower than other two existing models: LEED INDIA and GRIHA (30% instead of 40% of LEED INDIA and 50% of GRIHA). This is due to the reason that 'FRAMREB' covers more number of criteria compared to other two systems. Hence, the first level of certification is kept lower. Highest level of building evaluation was kept at 75% threshold level instead of 80% level of LEED INDIA and GRIHA. This is also due to the fact that 'FRAMREB' includes 68 criteria instead of 46 criteria of LEED INDIA and 34 criteria of GRIHA.

5. SUMMARY

'FRAMREB' relies on a fuzzy logic approach for criteria evaluation. The complexity of the assessment process overcomes the crisp nature of the present evaluation methodology of LEED INDIA and GRIHA. Building authority gets advantage with this model to convert every possible effort towards 'greenness' into a performance score. A building evaluated through this model is likely to achieve higher rating compared to other present systems due to 'fuzzy approach' o evaluation. Hence, comfort of decision makers is surely enhanced in the early stage of designing and planning itself. In this chapter, fuzzy based criteria evaluation models and AHP based weights were taken as reference. Further, GB Assessment Model was developed in this chapter. The model is computer based and works on its own after entering

the criteria performance value. It gives the rating of residential green building in pre-occupancy & post occupancy phase. The rating is given from 'one star' to 'four stars' with a score range from 0 to 5. Comparison of evaluation results shows that the newly developed model works well. It evaluated the building comprehensively by covering 68 criteria. The negative scoring effect is considered for 24 crucial criteria. The features of 'FRAMREB 2016' are compared with other tools.

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