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Evaluation of Selection Criteria for School Buildings in Canada Using AHP and MAUT

O.S. Alshamrani[1], K. Galal[2], and S. Alkass[3]
[1] Department of Building Engineering, College of Architecture and Planning, University of Dammam, Dammam, Kingdom of Saudi Arabia
[2&3] Department of Building, Civil and Environmental Engineering, Concordia University, Montréal, Québec, Canada

Abstract: The construction of any building's structure and envelope has become easy to achieve, yet the selection of a favourable, most-suitable alternative from sustainability and LCC points of view has become the new challenge. The selection of the structure type or the construction material is often decided based on personal experience or perception, or it could be accomplished by a random untested method that is not evaluated for high performance and sustainability. Two groups of criteria are investigated in this paper; The first group of criteria is life-cycle costs, including the initial costs, running costs (operating and maintenance costs), environmental impact costs, and salvage values while the second group contains expressions of sustainability principles. Decision makers' opinions in Canadian school boards were gathered by designing a web-based questionnaire to determine the relative weights for the various selection criteria that could govern the selection of structure and envelope types for new school buildings. These weights are determined using the Analytical Hierarchy Process (AHP), applied with the Eigen-vector technique. The second objective of the survey is to determine the preference utility values for the different criteria by applying the Multi Attributes Utility Theory (MAUT) approach. The result of the conducted evaluation indicates that running costs represent the most significant criterion, followed by initial costs and then sustainability.

1. Introduction

Greenhouse gases and energy extraction, production and consumption contribute to polluting the environment, and have led to climate change and global warming, now ranked as one of the top priorities on the United Nations' environment agenda (Kyoto protocol). In the United States and Canada, the building sector represents the third-largest domain of total energy consumption, after the industrial and transportation sectors. In Canada and the United States alone, close to 80 million students, teachers and staff spend at least eight hours a day in schools (Kate, 2006). There is a growing demand to construct sustainable schools designed to provide more healthy, comfortable and productive learning environments as well as to reduce energy consumption and building costs. Tis paper details the development of a Selection Framework that enables school boards to select sustainable and cost-effective structure and envelope types for new school buildings. The selection is performed based on an evaluation of the sustainability and life-cycle costing criteria using experts' opinions, and applying AHP and MAUT techniques.

1.1. The Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a structured technique that is applied in complex decisions. The AHP assists decision makers in selecting the decision that best suits their requirements according to their understanding of the problem. Applying the AHP to a decision-making process begins by establishing the hierarchy structure of the problem through the building of the relationships of the goal, criteria, sub-criteria and alternatives. Once the hierarchy of a problem has been established, the decision makers evaluate and compare its different elements to each another. In making the comparisons, the decision makers can use their judgments about the elements or they can use real data, (Saaty, 2008). The AHP utilizes pair-wise comparison matrices consisting of various factors. The relative importance of each category and sub category are based on a 1-9 scale. The AHP converts each different evaluation to numerical values that can be easily processed and compared over the whole range of the problem. (Contributors, 2010)

1.2 Multi-Attribute Utility Theory (MAUT)

MAUT technique is a quantitative comparison method applied to various criteria such as time, cost, safety and benefits, which have dissimilar measurement units along with different stakeholder and individual preferences, and turns these into high-level, cumulative preferences. Utility functions are the foundation of MAUT, which converts different criteria to one unified measurement scale identified as the multi-attribute "utility". For example, the utility functions convert different attributes' dimensioned scores such as dollars, pounds, feet, gallons per minute, etc. to a dimensionless utility score that varies between 0 and 1. Once utility functions are built, an alternative's raw data -whether they are subjective or objective- can be transformed to unified utility scores (Baker, 2001). The various criteria are weighted based on their degree of importance, as with other techniques. Each decision criterion has a utility function created for it through the building of its own graph, which can be created based on the data for each criterion. The utility scores are weighted by multiplying the utility score by the weight of the decision criterion, which reflects the decision maker's values and the experts' opinion and is summed for each alternative. The preferred alternative is the one that reaches the highest score (Baker, 2001).

2. Methodology

2.1. Selection Framework Development

The Selction Framework is developed using the Analytical Hierarchy Process (AHP) and the Multi Atribute Utility Theory (MAUT). These techniques are applied on the experts' opinions gathered through the distribution of surveys to school boards. Figure 1 presents the developmnet process of the selection framework. The first step in developing this framework is measuring the performance of each alternative on each selection criterion. These measurements include the outputs of the LCC forcasting model, the sustainability assessment model, and the computed LEED scores for existing sustainable school buildings.

Selection criteria such as initial costs, running costs, environmental impact costs, salvage values and sustainability are evaluated and given relative weights by experts by means of pairwise comparison and AHP techniques. Utilitiy curves for the selection criteria are developed in the next step using the judjment of experts based on the measured performances of the variouse alternatives. In this step, the various measurement scales are converted to a unified scale (utility score).

The measured performance of each alternative in each criterion is plotted in the developed utililty curve and the utiltiy score is computed accordingly. The obtained utility score is multiplied by that criterion's weight and the score is estimated. This process is repeated for all alternatives and criteria. The total scores are computed for each alternative and compared. The final selection is made based on the highest total obtained score. Total score values are calculated using the developed framework which can be illustrated by the following mathematical model:

$$Vi\ (X) = \sum Wi\ Ui =$$

$$(W_{IC}\ U_{IC}) + (W_{RC}\ U_{RC}) + (W_{EIC}\ U_{EIC}) + (W_{SV}\ U_{SV}) + (W_{SUS}\ U_{SUS})$$

Where:

Vi (X)	= Total Score Value
Wi	= weight of criteria
Ui	= Utility score
W*IC*	= Importance weight of initial costs
U*IC*	= Utility score of initial costs
W*RC*	= Importance weight of running costs
U*RC*	= Utility score of running costs
W*EIC*	= Importance weight of environmental impact costs
U*EIC*	= Utility score of environmental impact costs
W*SV*	= Importance weight of salvage values
U*SV*	= Utility score of salvage values
W*SUS*	= Importance weight of sustainability
U*SUS*	= Utility score of sustainability

3. Development

A selection framework is developed in this paper based on developing LCC forecasting models as well as collecting data from experts in school boards and ministry of education in Quebec via questionnaires. The survey has two main objectives. The first objective is to collect decision makers' opinions to determine the relative weights for the various selection criteria that could govern the selection of structure and envelope types for new school buildings. These weights are determined using the Analytical Hierarchy Process (AHP), applied with the Eigen-vector technique. The second objective of the survey is to determine the preference utility values for the different criteria by applying the Multi Attributes Utility Theory (MAUT) approach. The basic principal of MAUT is the use of utility functions that transform different criteria with various dimensions to a dimensionless scale that can range from 0 to 1 or 1 to 10 or 0 to 100.

3.1. Preliminary Survey (Pilot Study)

A pilot study is conducted by designing a hard copy survey which was then sent to seven school boards in Montreal. This preliminary study is a significant tool to improve the quality and efficiency of the questionnaire prior to conducting a much larger survey. Only one expert participated in this study. Vital modifications were performed to accommodate his comments. The response to the feedback included the following modifications: providing the background of the study, explaining some questions with examples, translating the questionnaire into French, and distributing electronic pre-formatted surveys.

3.2. Main Survey (Large Study)

A web-based survey was developed according to the pilot study feedback and distributed to about 250 school boards in Canada. This study was conducted in eight different provinces and distributed in both English and French. Building managers in the Ministry of Educations in Quebec, directors of materials and resources departments, as well as facilities management supervisors were targeted in this study. Only 27 responses were received: five from Quebec, seven from Alberta, one from Nova Scotia, one from Saskatchewan, two from Manitoba, one from Newfoundland, five from Ontario and five from British Colombia. The responses were collected mainly from experts through emails sent by the web-based system. The questionnaires were then perused many times and discussed with certain experts.

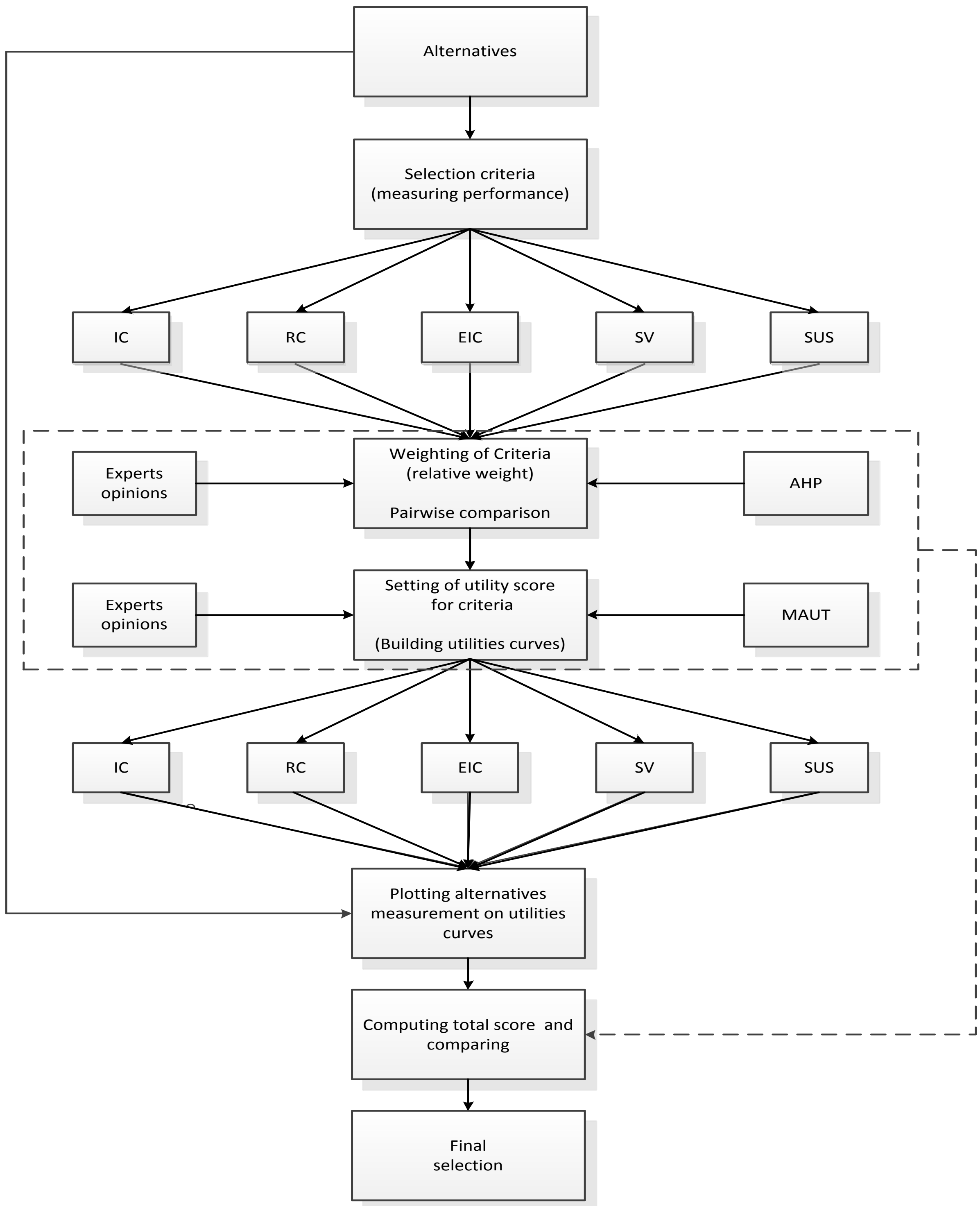

Figure 1 Selection framework development process flowchart

4. Analysis and Results

4.1. Evaluation and Weighting of Selection Criteria Using the AHP

The selection criteria are weighted by the decision makers and experts in school boards using pair-wise comparison matrix and the AHP. The experts are asked first to fill out the matrix using the AHP decision making method. This method helps to quantify the relative weights for a given set of criteria with regards to a priorities scale ratio from 1 to 9. The relative weights are calculated based on the pair-wise matrix and the scales provided by experts. A sample of the calculation matrix is presented for one expert in Table 1. The sample consists of two main tables. The upper table represents the pair-wise comparison matrix of the selection criteria, and the lower table consists of several significant columns, as follows:
Column (A) shows the calculation of the geometric mean for the values in the rows in the pair-wise comparison matrix. Column (B) shows the calculation of the relative weights (Eigenvalue) of a criterion which is equal to the geometric mean of that criterion over the sum of the geometric mean for all criteria. Column (C) shows the vector weight for criteria, which is equal to the sum of multiplying the relative weights by the values in each matrix's row. Column (D) represents the value of λmax, calculated by dividing the vector weight by the relative weight of each criterion.

The calculation of the consistency ratio, shown in columns (E) and (F), is calculated by dividing the consistency index value (CI) by the random consistency index value (CR = CI / RI). The CI is calculated as follows: CI = (λmax – n)/ (n -1), while the RI value is obtained from table 2 using a size n matrix. Expert is judged to be unacceptable when CR exceeds 0.10, which indicates inconsistency in the judgment matrix. Some of responses are eliminated due to their high consistency ratio.

Table 1: Pair-wise comparison matrix and computing of the relative weights

Selction criteria	IC	RC	EIC	SV	SUS
IC	1	2.00	9.00	3.00	5.00
RC	0.5	1	8	2	3
EIC	0.1111	0.125	1	0.125	0.1666
SV	0.3333	0.5	8	1	3
SUS	0.2	0.3333	6	0.3333	1
A	B	C	D	E	F
Geometric Mean	EV wieght	Aω	λ	CI	CR
3.06	0.43	2.23	5.19		
1.89	0.26	1.35	5.10		
0.20	0.03	0.15	5.35		
1.32	0.18	0.96	5.20		
0.67	0.09	0.49	5.28		
7.14	1.00		5.22	0.06	0.05

Table 2: (R.I) Random Inconsistency Index (Saaty 1980)

RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48
n	1	2	3	4	5	6	7	8	9	10	11	12

Thirteen responses passed the consistency test, as shown in table 3. The relative weights of the selection criteria are computed for every respondent and the mean, median, mode, and standard deviation are calculated accordingly. The relative weights of the selection criteria are computed based on the mean. The average resulted relative weights are computed as: 25% for initial costs, 33% for running costs, 13% for environmental impact costs, 10% for salvage value, and 19% for sustainability principles.

4.2 Reliability Analysis of Responses

Cronbach's alpha approach is used to perform the reliability analysis of the experts' responses. Cronbach's alpha is a coefficient of reliability that tests internal consistency or reliability of a psychometric test score for a sample of examinees. It describes how well a set of variables measures a single uni-dimensional latent construct. This coefficient is equal the ratio of the true variance to the total variance of a measurement and is a function of a number of observations, variance and covariance. The reliability analysis of data can be assessed using Cronbach's alphas follows:

$$C\alpha = \frac{n}{n-1}\left(1 - \frac{\Sigma Vi}{\overline{V}}\right) \quad \text{(Equation 2)}$$

where:

$\overline{V}$ = sum of variance of overall points

Vi = variance of values for each point

n = number of points

Table 3: Resulted relative weights for the various selection criteria

Selection Criteria	IC	RC	EIC	Sv	SUS	TOTAL
1	0.43	0.27	0.03	0.18	0.09	1.00
2	0.177	0.316	0.269	0.070	0.168	1.00
3	0.115	0.221	0.140	0.065	0.459	1.00
4	0.209	0.276	0.276	0.079	0.159	1.00
5	0.276	0.168	0.200	0.058	0.299	1.00
6	0.387	0.356	0.115	0.030	0.112	1.00
7	0.25	0.52	0.07	0.08	0.08	1.00
8	0.23	0.31	0.13	0.03	0.30	1.00
9	0.300	0.350	0.080	0.120	0.150	1.00
10	0.32	0.35	0.10	0.08	0.15	1.00
11	0.12	0.39	0.03	0.29	0.18	1.00
12	0.17	0.45	0.14	0.07	0.17	1.00
13	0.24	0.28	0.16	0.12	0.19	1.00
Median	0.24	0.32	0.13	0.08	0.17	0.93
Mean	0.25	0.33	0.13	0.10	0.19	1.00
Mode	N/A	0.35	N/A	N/A	0.15	
STDEV	0.094974421	0.092792238	0.078593018	0.070277924	0.10422834	0.44086594

Cronbach's alpha coefficient of reliability has scale value that ranges from 0 - 1. The lower the score, the less reliable is the data. The acceptable reliability range varied between 0.70 and 1.0. A commonly accepted rule of thumb for describing internal consistency using Cronbach's alpha.The reliability analysis for internal consistency is performed in this study using the SPSS software. The result shows that the data has an excellent reliability according to Cronbach's Alpha (0.908), This value could be further increased by eliminating some responses, such as number three, to get α=0.925

4.3 Preference Utility Values using the MAUT

The second part of the questionnaire is designed to determine the preference utility values for the selection criteria. This section provides the acceptable and preferred ranges of utility scores for all the weighted criteria described in the first part of the survey. Experts are asked to assign a preference cost value for each utility score on a scale of 0 – 1.0 for various criteria that govern the selection of structure and envelope type. The best values (the extremely-preferred values) are assigned a utility score of 1.0 while the worst values (the least-preferred values) are assigned a utility score of 0. These scores are used in developing the utility curves for the different selection criteria. The developed utility curves include initial costs, running costs, environmental impact costs, and salvage value, as presented in table 4. Five decision makers participated in building the utility curves.

Table 4. Preference utility values of selection criteria for high schools

Criteria	**Utility scores**					
	Respondents	**0.0**	**0.25**	**0.5**	**0.75**	**1.0**
Initial Costs ($/ft²)	1	362	295	222	180	150
	2	344	279	236	190	155
	3	355	286	262	175	150
	4	325	275	250	225	200
	5	300	275	225	200	120
	Avg.	**337.2**	**282**	**239**	**194**	**155**
Criteria	**Utility scores**					
	Respondents	**0.0**	**0.25**	**0.5**	**0.75**	**1.0**
Running costs ($/ft²)	1	110	100	80	70	60
	2	120	100	90	80	70
	3	130	110	100	90	80
	4	110	100	90	80	70
	5	130	120	110	100	75
	Avg.	**120**	**106**	**94**	**84**	**71**
Criteria	**Utility scores**					
	Respondents	**0.0**	**0.25**	**0.5**	**0.75**	**1.0**
Enviro. Impact costs ($/ft²)	**1**	3.25	2.25	2.0	1.25	0.65
	2	3.0	2.5	1.75	1.0	0.75
	3	3.5	1.75	1.5	1.0	0.5
	4	3.0	2.25	2.0	1.5	0.75
	5	3.0	2.75	2.5	1.75	0.5
	Avg.	**3.15**	**2.3**	**1.95**	**1.3**	**0.63**
Criteria	**Utility values**					
	Respondents	**0.0**	**0.25**	**0.5**	**0.75**	**1.0**
Salvage Value ($/ft²)	**1**	10	25	40	50	60
	2	0	20	50	60	80
	3	10	20	30	55	80
	4	0	30	50	70	80
	5	0	20	40	50	70
	Avg.	**4**	**23**	**42**	**57**	**74**

The utility function values of initial costs, running costs, environmental impact costs, and salvage values for elementary and high school buildings are presented in Figures 2-5. The utility curves are developed by determining of the preferred cost values at each predetermined utility score (0, 0.25, 0.5, 0.75, and 1.0). The best-fitted lines are drawn for each utility function and the equations of the lines are developed accordingly, as shown in the utility graphs.

The utility function values of initial costs for elementary school are illustrated in figure 2, where the experts determined their preference values and the acceptable range of initial costs ($153- $332/ft^2).

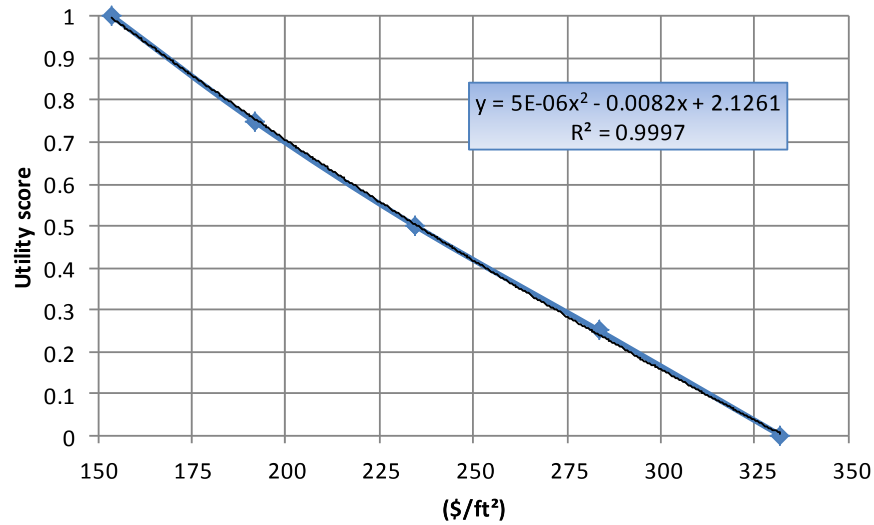

Figure 2: Utility values for initial costs in elementary schools

The utility function values of running costs in present value (PV) for elementary schools are illustrated in figure 3, where the experts determined their preference values and the acceptable average range of running costs ($75- $126/ft^2).

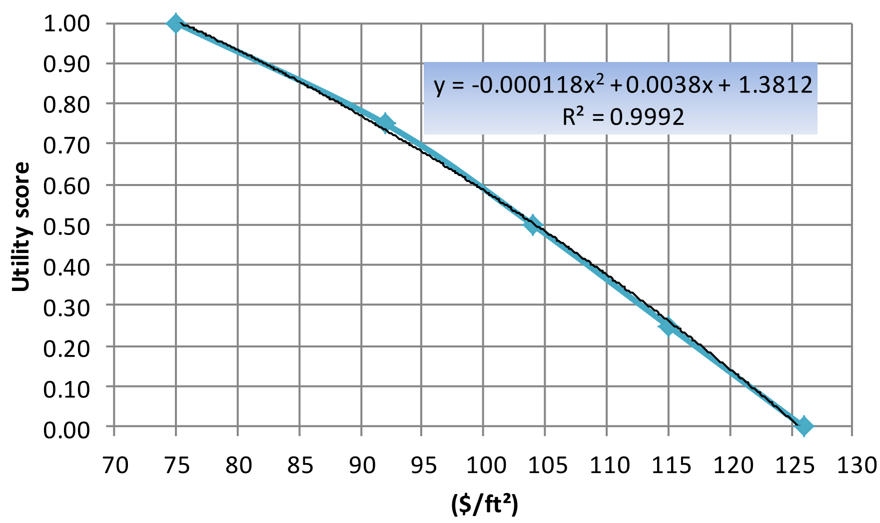

Figure 3: Utility values for running costs in elementary schools

The utility function values of salvage value in PV for school buildings are illustrated in figure 4, where the experts determined their preference values and the acceptable average range of salvage value ($4-$74/ft^2).

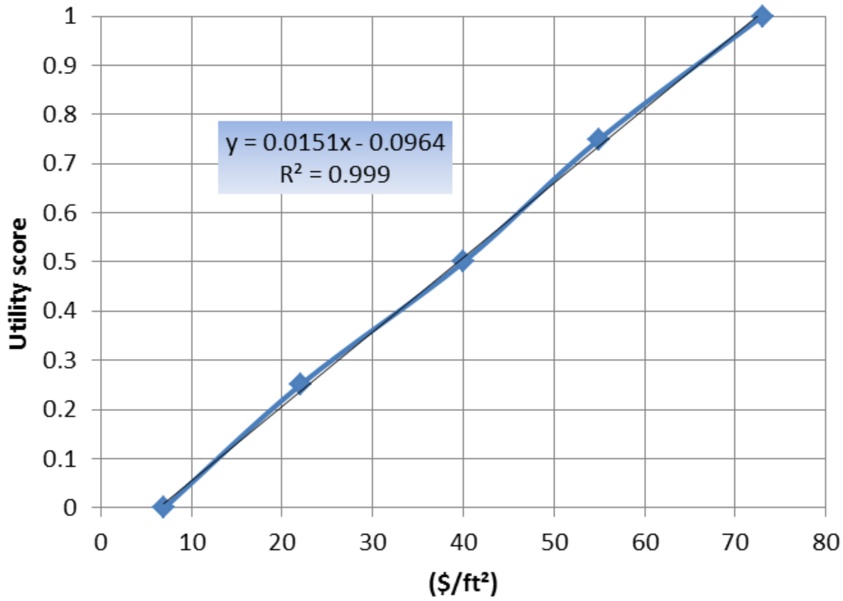

Figure 4 Utility values for salvage values in school buildings

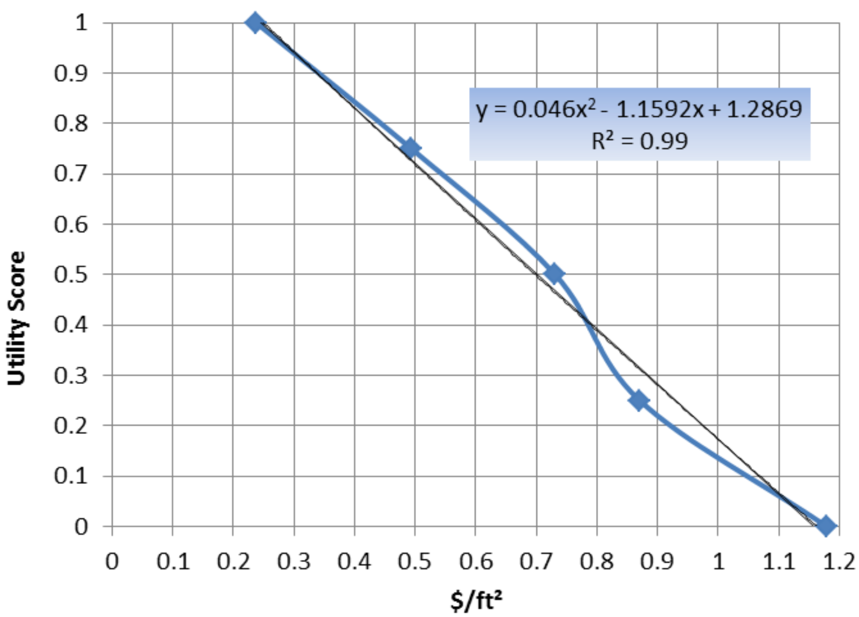

Figure 5: Utility values for environmental impact costs

The utility function values of environmental impact costs in PV for school buildings are illustrated in figure 5, where the experts determined their preference values and the acceptable average range of environmental impact costs ($0.23- $1.17/ft^2).

5. Conclusions

This paper developed a Selection Framework to assist decision makers in school boards to select the best structure and exposure types of new school buildings based on LCC and sustainability criteria. The selection framework was developed using the AHP and the MAUT, based on experts' and decision makers' opinions that were gathered using a web-based questionnaire. The selection is performed based on the alternatives' performance in significant criteria, such as initial costs, running costs, environmental impact costs, salvage values, and sustainability principles (the LEED rating system).

The averages of the relative weights of criteria are computed based on experts' opinions as 25% for initial costs, 33% for running costs, 13% for environmental impact costs, 10% for salvage value, and 19% for sustainability principles. Finally, this developed Framework is a powerful tool that converts the various complicated values into a simplified measurement value, so the decision makers can easily make well informed selections.

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