LA-UR-09- 00280

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Title:	An applied study using system engineering methods to prioritize green system options
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Draft

Los Alamos
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EST.1943

FORM 836 (7/06)

Abstract

For many years, there have been questions about the effectiveness of applying different green solutions. If you're building a home and wish to use green technologies, where do you start? While all technologies sound promising, which will perform the best over time? All this has to be considered within the cost and schedule of the project. The amount of information available on the topic can be overwhelming. We seek to examine if Systems Engineering methods can be used to help people choose and prioritize technologies that fit within their project and budget. Several methods are used to gain perspective into how to select the green technologies, such as the Analytic Hierarchy Process (AHP) and Kepner-Tregoe. In our study, subjects applied these methods to analyze cost, schedule, and trade-offs. Results will document whether the experimental approach is applicable to defining system priorities for green technologies.

Introduction

In residential construction, the homeowner has to allocate resources based on importance to the project as a whole while making acceptable tradeoffs among goals such as cost and design appeal. We are currently in a "green" trend, where the public has a renewed interest in energy efficiency and impacts on the environment. An explosion of information and advertising exists for materials and technologies that tout themselves as "green" alternatives. Which best meet that customer's needs for the project? How does one decide?

Furthering the problem, although consumers say they're concerned about the environment, they're not necessarily willing to pay for "green" alternatives. In Design News magazine, Vol. 63, Nov. 03 2008, the comment titled "Consumers Won't Pay for Green" states that "According to research firm Yankelovich, fewer consumers are willing to pay for green products despite continued interest in the environment."

In order to help reluctant and overwhelmed buyers, we attempted to develop a Systems Engineering strategy to guide their decision-making process. Our goal is to help a buyer address the construction process and select energy alternatives at the same time. This paper gives examples of Systems Engineering techniques used in our test scenario.

Background

The current interest in energy-efficiency isn't a new trend, but a renewed trend. There was a similar trend in the mid-1970's, and others before that. In the 1970's, research was done in passive solar energy. In 1976, [ref X], Dr. J. Douglas Balcomb discussed the first effort sponsored by the Federal Government, by General Electric, to apply solar energy to mobile homes. A follow-on project at Los Alamos National Laboratory incorporated

active and passive solar to a manufactured building. Dr. Balcomb is still active in the field of solar energy today.

Looking even further back, we can find cultures that harvested the sun well before electricity provided an alternative heating method. Passive solar was employed by the Ancestral Pueblo People as far back as 1200 – 1500 A.D. A hike in Bandelier National Monument near Los Alamos takes the hiker along rows of caves built in the South-facing cliff, absorbing the winter sun. Park archeologist, Rory Gauthier, says:

> "The cavates found in Bandelier National Monument and throughout the Pajarito Plateau were used at the same time as the large, freestanding masonry pueblos. This leads many to question what the cavates were used for. The most compelling argument is they were used seasonally, primarily in the winter, because nearly all have a southern exposure and appear to be sited to take advantage of the low winter sun angle. Snowfall quickly melts away from these south facing structures but will remain for several months on the canyon floors and the north facing canyon slopes."

Figure X.X Cavates at Bandelier National Monument, New Mexico

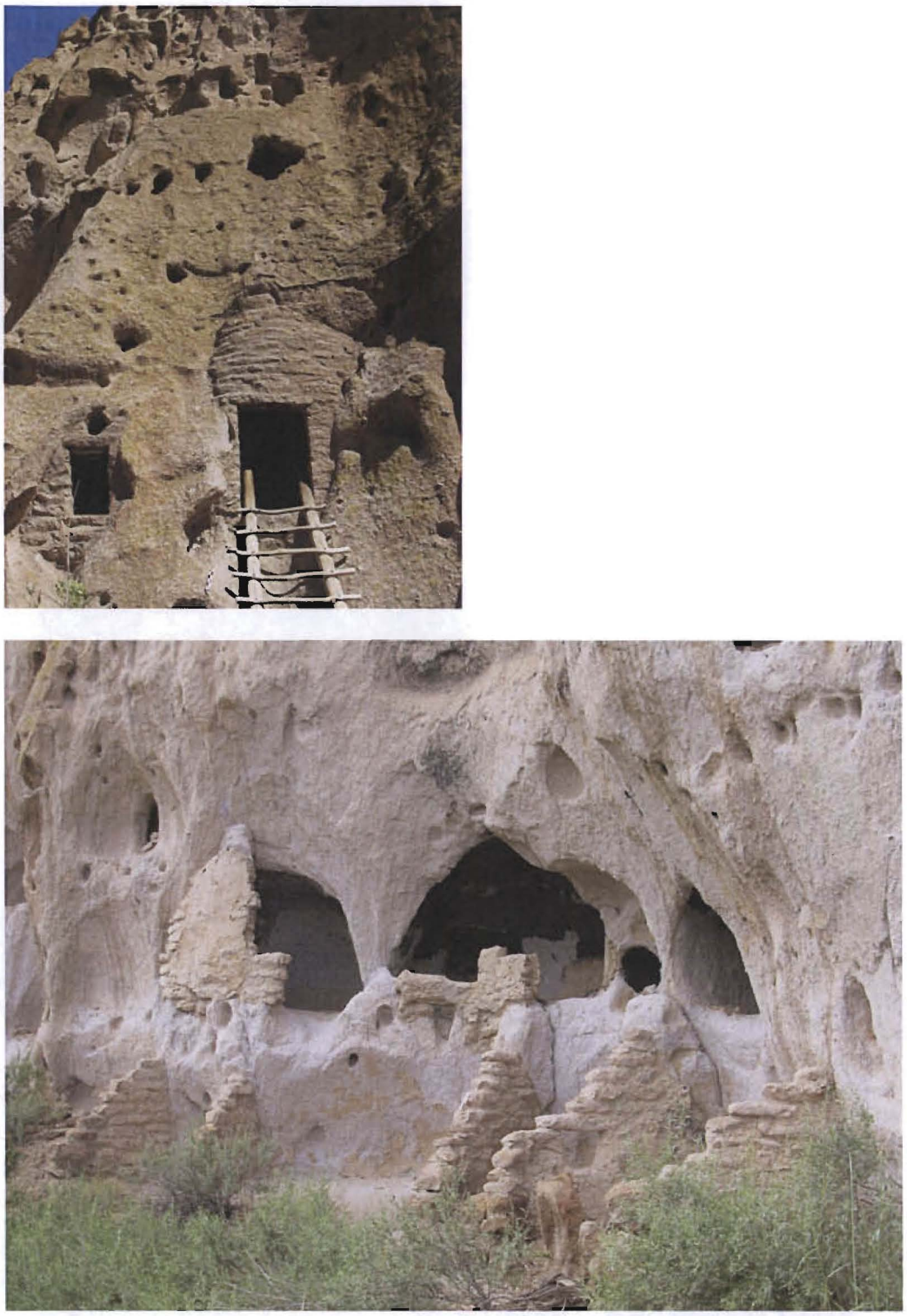


Figure X.X Ancestral Pueblo Dwellings with Southern Exposure

Back to the 1970's, an example of the alternative energy trend can be found in a community near Taos, New Mexico. "Earthships" were designed by Mike Reynolds and

aimed to be sustainable, off the grid, and economically feasible. These homes employ many types of energy-efficient systems, such as water collection, grey water re-use, alternative toilets, windturbines, earth berms and other systems. However, the novel architectural designs limited interest in earthships.

Picture

In the 1970's, even modest passive solar designs faced a similar problem as they do today. Congress was told that solar homes weren't popular with buyers, and home-builders didn't like to experiment.

We should take a page from history if we wish to encourage homeowners to build homes that save energy and have less impact on the environment. Buyers are reluctant to build homes that seem out of the ordinary to them. The study described in the rest of this paper experiments with the idea that Systems Engineering methods can be used to help homeowners make construction choices according to their personal preferences, within their comfort zone. By making choices among the wide range of possibilities, they can then focus their research on specific systems. These architectural and engineering details can be communicated to the builder. This should help with the secondary problem that builders may be wary of trying new materials, techniques, or systems.

Assessment Approach

Our decision process employs guidance from the Department of Energy's publication, "Guidebook to Decision-Making Methods," Dec. 2001. Our assessment is limited in scope in order to be accomplished within 45-minutes. The decision process is shown in the diagram below.

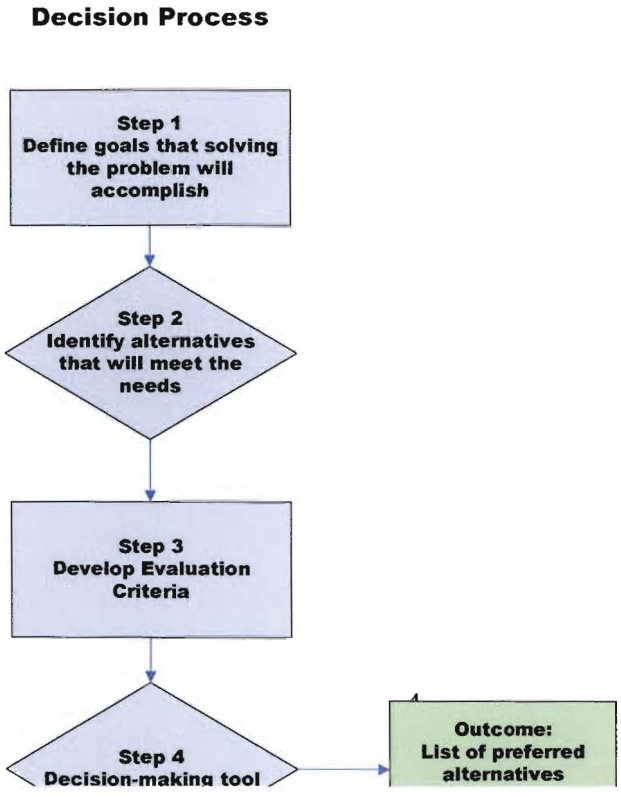


Figure X.X Steps of Decision-Making Process in the Assessment

The strategy of our study applies three Systems Engineering (SE) techniques. Our goal is to allow the person's individual preferences guide the information they analyze during the construction design process. The individual chooses the energy-saving alternatives as well as the evaluation criteria. From this, information on preferences is developed into weighting factors used for tradeoff decisions. The SE methods applied in our assessment are shown in the next diagram.

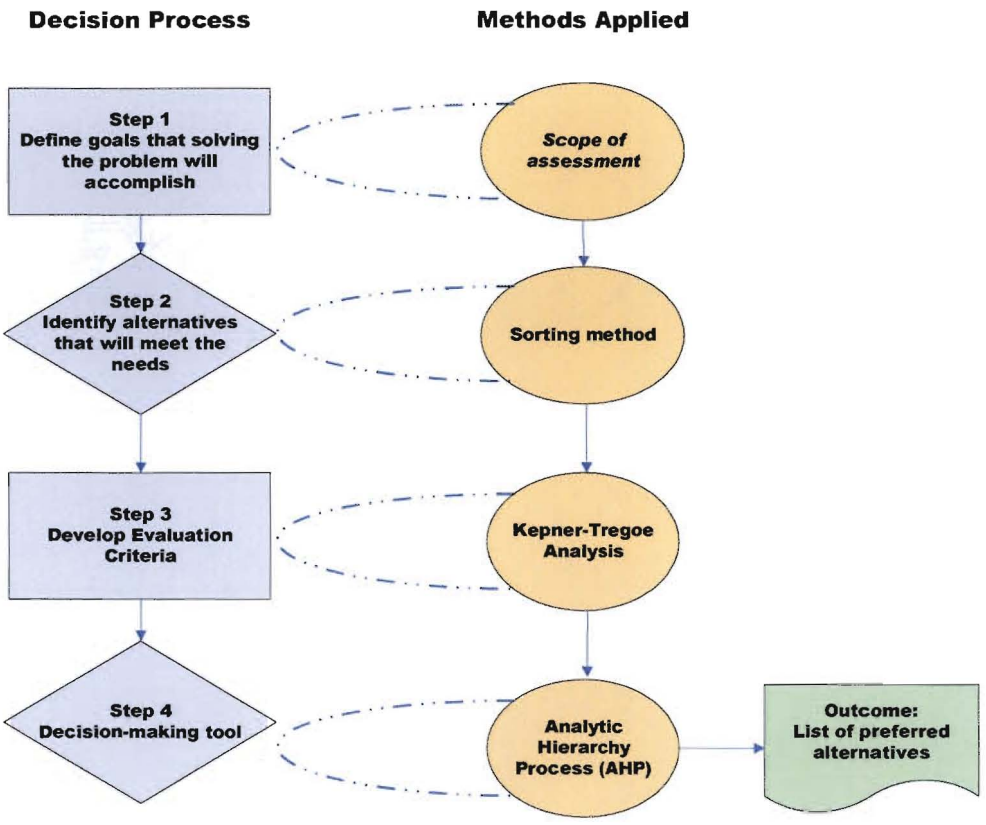


Figure X.X Applied Systems Engineering Methods

Our study used the following approach. The problem statement was formulated for the construction scenario. During the course of the exercise, the subject creates 2 lists of preferred energy-saving construction features. The first list is off-the-cuff, decided without using SE techniques. The second list is created with the use of SE techniques. Following the exercise, we compare the lists and interview the subject about the usefulness of the SE techniques.

We then interview the subject to determine if the SE techniques were helpful in choosing energy options. The elements of the exercise are:

1. Limited-scope scenario (45-minutes)
2. Subject studies green solutions
3. First cut – identify preferred options
4. Apply Systems Engineering techniques to evaluate options
5. Second cut – Identify preferred options a second time
6. Survey about perceived usefulness of techniques

To limit the scope to an exercise that can be completed within 45 minutes, we selected concepts in the area of passive solar energy. The "blind list" of energy-saving features is created by asking the subject their preferences. The subject, or "homeowner," is given five minutes to study websites with information about energy-saving options. Then they list their preferred options. At this point in the exercise, we move into applying SE techniques to the decision process.

In the next sections, we give an overview of the applied techniques, then describe each one in more detail with examples from our study.

Overview of Systems Engineering Techniques Applied in the Assessment

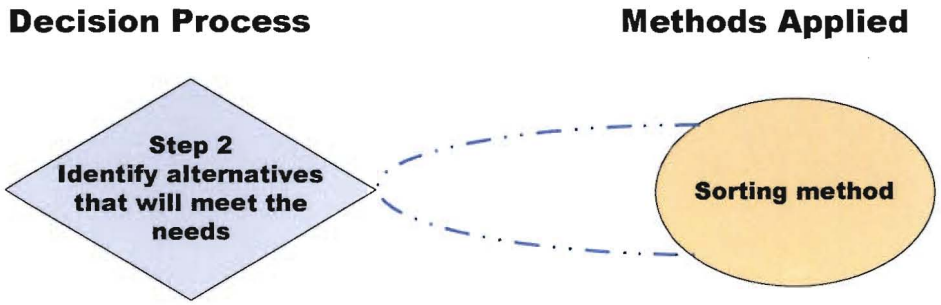
The purpose of the first SE method is to narrow the scope of the decision criteria and energy-saving options to be analyzed. Using a sorting technique from Cognitive Anthropology, we begin to merge construction factors with specific alternative energy systems. The subject uses his or her own cognitive schema and preferences to rank technologies for a given criteria. For example, they sort a heating system according to their perception of initial installation cost.

The second SE method is the Kepner-Tregoe Analysis.

Taking us to the third step in the decision process, the Kepner-Tregoe technique uses the criteria from the previous step to evaluate alternative green technologies. In this step, the homeowner refines his or her decisions.

Narrowing Possibilities with the Sorting Technique

If you're building a home and wish to use green technologies, where do you start? The amount of information available on the topic can be overwhelming. We believe information overload is one reason consumer spending for alternative energy doesn't match what they say their interest is in the environment [ref XX]. We need to aid the homeowner in picking a feasible set of options to begin analyzing.



We began by sorting options into general categories. Our first step applied the relational hierarchy method from Cognitive Anthropology. One of the goals with these sorting methods is to allow the subject to develop for themselves which categories are most meaningful. We were constrained in our assessment and were not allowed to be as free-choosing as some of the sorting techniques would permit us to be, so instead, we provided the categories. Our intent is still to allow the subject to have input on their personal preferences, and to apply their own personal knowledge to the task.

In our assessment, the homeowner sorted domain elements (green solutions) into fixed categories, which are a scale from low to high for each criterion. In a step-wise fashion, the homeowner ranks each feature for each criterion.

The criterion we selected were:

1. Initial cost
2. Maintenance effort
3. Energy savings per year
4. Impact on environment
5. Historical performance
   - How well this feature has performed over time
6. Design
   - How innovative
   - Livability, comfort and aesthetics

A scale was developed for each criterion. The examples are shown below. Each "box" along the scale is a sorting category. The homeowner sorts the listed features into the categories.

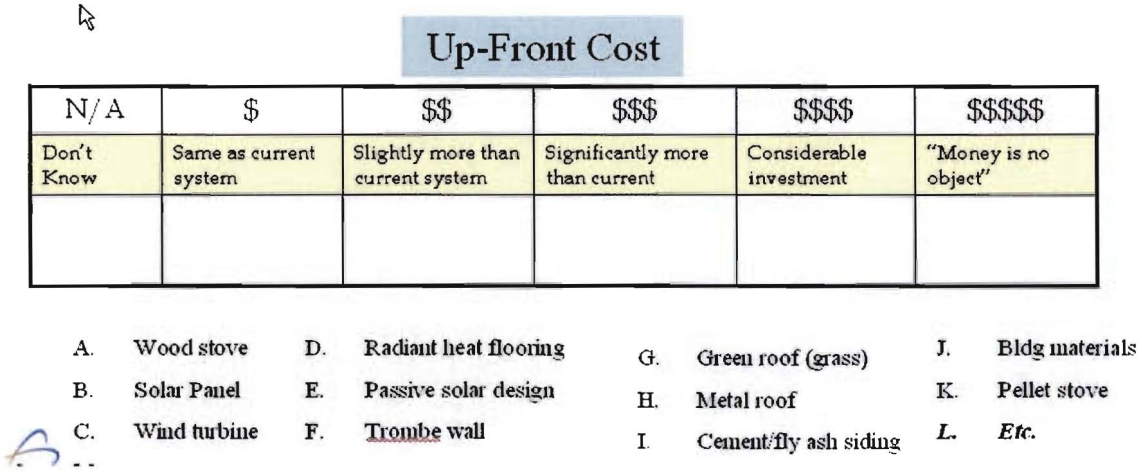


Figure X.X: Example Sorting Categories for Initial Cost Criterion

Design

N/A	1	2	3	4	5
Don't Know	Basic Today, Conventional	Contemporary, Original	Innovative	Departure	"Really Out there"

A.	Wood stove	D.	Radiant heat flooring	G.	Green roof (grass)	J.	Bldg materials
B.	Solar Panel	E.	Passive solar design	H.	Metal roof	K.	Pellet stove
C.	Wind turbine	F.	Trombe wall	I.	Cement/fly ash siding	*L.*	*Etc.*

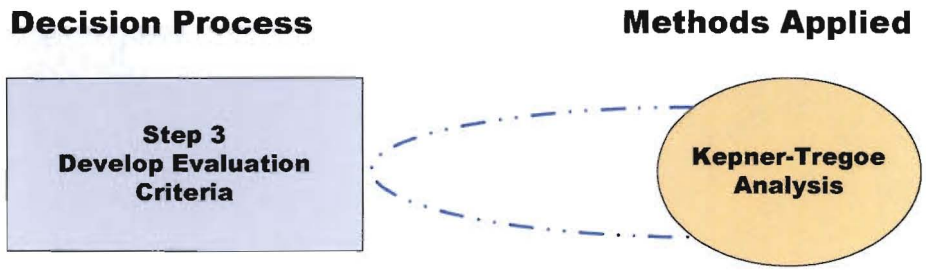
Figure X.X: Example Sorting Categories for Design Criterion

When the homeowner has finished ranking the technologies and design features for each criterion, they're now asked to narrow the field to be considered. For each criterion, he or she picks only two of the six possible ranking categories. This selection narrows the field of possibilities to be further analyzed. It also allows the homeowner to preserve their buying preferences. For example, some homeowners might be conservative in their architectural design options, and would eliminate any features that are too far a departure from the customary home.

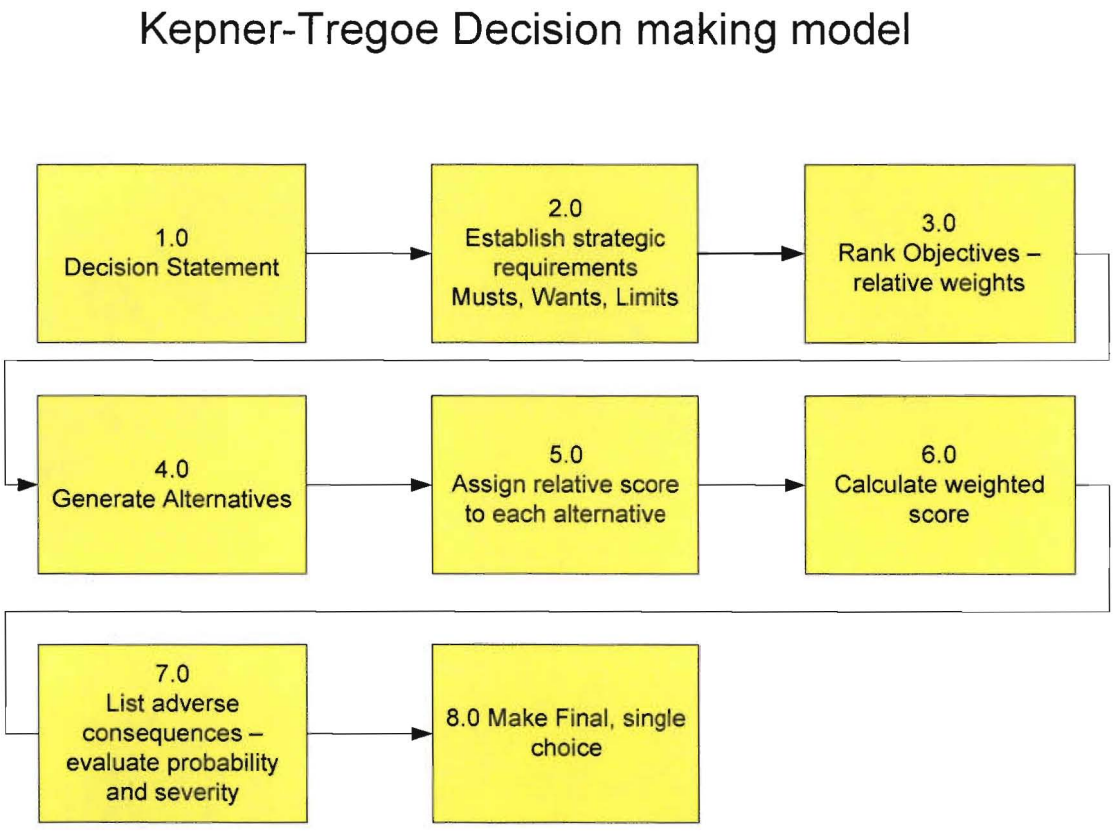
This final cut still yields a range of possible energy-saving features included in the 12 groupings. In our assessment, we needed to accomplish the study within a few minutes, so we further restricted the choices. We did this by ordering the energy-saving features by the number of times they appeared in the 12 categories, then selecting the top (most frequent) XX candidates.

Weighing Options with the Kepner-Tregoe Analysis

The next step is to identify alternative that will meet the homeowner's goals. How does the homeowner stay within project scope? We want to continue screening out alternatives that are out-of-scope for homeowner's project. The Kepner-Tregoe Decision Analysis is used to help the homeowner make choices. It begins by letting the homeowner weight the criteria according to their personal preferences.



The figure below shows the steps of this applied technique.



From the Sorting techniques just finished, we have a rough idea of the goals and objectives. The Kepner_Tregoe (K-T) technique refines this by assigning weights. At this stage, the K-T gives us a systematic approach to begin comparing alternatives. Although this can also be accomplished with the Analytic Hierarchy Process technique

(next), this step is useful because it gives an intuitive and easy way to begin the comparisons. It is especially useful in comparing "apples and oranges" to help the homeowner choose between systems with dissimilar functions. For example, in one assessment, this helped the subject compare WHAT and WHAT.

As described in the DOE Guidebook to Decision-Making Methods [ref XX],

> "In K-T parlance each evaluation criterion is first scored based on it's relateive importance to the other criteria (1 = least; 10 = most)....The alternatives are scored individually against each of the goal criteria based on their relative performance."

Some cases studies described in literature use SE techniques to allow a team to form consensus on system priorities. In our assessment, we instead use the K-T technique to highlight an individual's preferences. We seek to determine if SE methods can help a non-expert consumer move forward in making decisions that will fit their personal lifestyle and goals. If the techniques are helpful in the simple construction scenario of our assessment, then they can also be applied to more complex construction projects, and a wider range of green solutions.

EXAMPLE ONLY FOR DRAFT PAPER

A	B	C	D	E
Criteria Want objectives	**Criteria Weight**	**Energy-Saving Feature**	**Alternative Score**	**Total Score**
		Heating alternative 1		
Same as current	10	Feature has desirable cost	10	100
Energy Savings per year	10	Feature gives desirable savings	10	100
Questionnaire Information				
Geothermal system	7	Not selected on Questionnaire	0	0
Pellet stove	10	Selected	9	90
Wood stove	10	Selected	10	100
Solar panel	5	Selected	5	25
Radiant heat flooring	10	Selected	7	70
Passive solar design	10	Selected	10	100
Trombe wall	8	Selected	8	64
Green roof	7	Not selected on Questionnaire	0	0
Cost/ROI	10	100K/.97	10	100
		Total		**749**
		Heating alternative 2		
Contemporary, original	8	Feature has desirable design	0	0
Energy Savings per year	8	Project is not deemed M	0	0
Questionnaire Information				
Geothermal system	7	Not selected on Questionnaire	0	0
Pellet stove	10	Not selected on Questionnaire	0	0
Wood stove	10	Not selected on Questionnaire	0	0
Solar panel	10	Not selected on Questionnaire	0	0
Radiant heat flooring	10	Not selected on Questionnaire	0	0
Passive solar design	10	Not selected on Questionnaire	0	0
Trombe wall	8	Not selected on Questionnaire	0	0
Green roof	7	Selected	5	35
Cost/ROI	10	5500K/.002	1	10
		Total		**45**

Refining Decisions with the Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) provides a framework for helping our homeowner choose amongst overall architectural designs. The results can provide the general contractor with a better understanding of the degree to which a particular solution needs to satisfy customer desires. AHP was used to evaluate the relative importance of the criteria, help in comparing building and system alternatives, and making a final decision.

TBD

Study Results

TBD

Considerations for Future Efforts

TBD

A useful criterion for comparing energy-saving options would be historical performance. While all technologies sound promising, which perform best over time? This aspect would involve actual savings, maintenance, and overall return on investment.

As mentioned in the beginning of this paper, Passive Solar is an ancient concept, and has been the focus of trends in the past. A homeowner interested in passive solar might wish to research how designs have evolved over time, and why. As a brief illustration to compare concepts in passive solar over time, we created two tag cloud diagrams. Tag clouds show the relative strength of words based on frequency of occurrence in an excerpt. These diagrams were created from the "Wordle" website [ref XX]. This website uses technology developed at IBM. The first tag cloud is developed from a 1976 paper by Dr. Douglas Balcomb, titled "Solar Energy Systems for Manufactured Housing," Los Alamos Scientific Laboratory. In 2008, the same author wrote "*reference*" and an excerpt from this was used to make the second tag cloud.

Figure X.X: Passive Solar concepts from a 1976 paper.

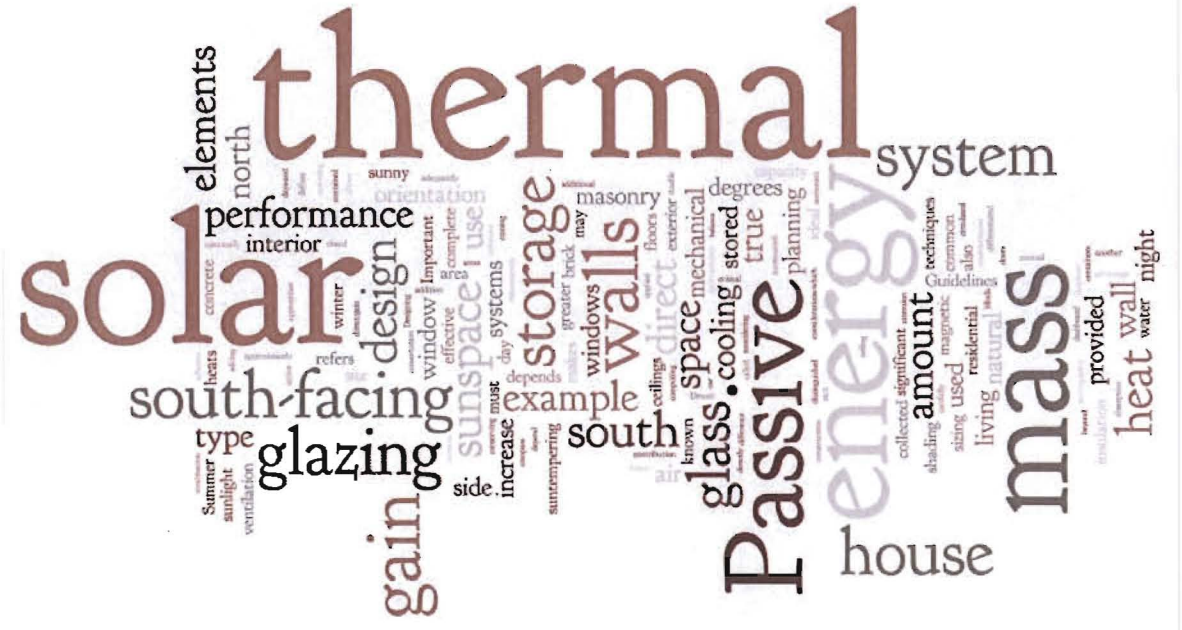


Figure X.X: Passive Solar concepts from a 2008 paper by the same author.

These tag clouds depict changes over time for the same energy concept. It would be useful to know how and why systems have evolved, and which features have stood the test of time. However, in general, this information isn't readily available. The information may exist in computer simulations, especially for industrial buildings, but it's difficult to determine quickly for residential systems. Follow-on work to this study could

look at providing consumers with the historical performance information to be considered at appropriate times in their decision-making process.

Summary

In this assessment, we sought to determine if Systems Engineering techniques are beneficial to helping the average consumer move forward with decisions to implement alternative energy solutions. The XX subjects evaluated energy-saving features for a residential construction test scenario. The decision-making aids that were applied were a Sorting technique, Kepner-Tregoe Analysis, and the Analytic Hierarchy Process (AHP).

Results TBD