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EVALUATION OF DOMESTIC SOLAR WATER HEATING SYSTEM IN JORDAN USING ANALYTIC HIERARCHY PROCESS

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Abstract—In addition to the solar water heating (SWH) system, other domestic water heating systems used in Jordan were considered in terms of benefits and costs using the Analytic Hierarchy Process. In terms of cost, the SWH system was the least expensive. On a percentage basis, the SWH cost about 13% compared to the most expensive heating system, LPG, of about 28%. In terms of benefits, the SWH was also the most beneficial. Approximately, the SWH benefits were about 31%, while the least benefits were obtained from the kerosene water heating system, which is about 9%. By considering both cost and benefit (i.e. cost-to-benefit ratio), solar was also the least expensive, about 7%, with kerosene being the most expensive, over 30%. © 1997 Elsevier Science Ltd.

Water heating   Solar water heating systems   Analytic hierarchy process

1. INTRODUCTION

Domestic solar water heating systems are widely used in Jordan. About 12% of dwellings in Jordan use solar systems for water heating. The financial evaluation of solar water heating systems in comparison with other types of conventional water heating systems is usually based on the price of the fuel [1]. The financial evaluation of solar water heating systems is conducted using one of the most known conventional methods, such as Net Present Value (NPV) or Internal Rate of Return (IRR). The socio-economic evaluation makes assessments to all gains (benefits) and all losses (costs) of solar water heating systems which include the financial, social, cultural and ecological impacts [2]. The most widely used method in socio-economic analysis is the cost-benefit analysis [3]. Although the assessment of socio-economic benefits and costs depends first of all on the data provided by the cash flow sheets, it is supplemented by socio-economic impacts from the field of welfare economics.

In a review of existing surveys on financial evaluation methods and cost-benefit analysis for solar water heating systems, a few limitations were observed:

1. The problem of calculating revenues.
2. The determination of interest rate for discounting.
3. The problem of cost calculations for solar water heating systems.
4. Estimation of lifetime of solar water heating components or of the system itself.

The Analytic Hierarchy Process (AHP) can be used as a practical approach for addressing these cost-benefit-benefit application issues.

2. THE ANALYTIC HIERARCHY PROCESS (AHP)

The AHP has been effective in structuring many types of complex multi-criterion problems. For example, the AHP has been applied to business decisions [4], choosing areas of R & D programs [5], the estimate of the economy's impact on sales, the problem of traffic congestion, real estate investment [6], and water policies [7]. The AHP enables decision makers to structure a problem

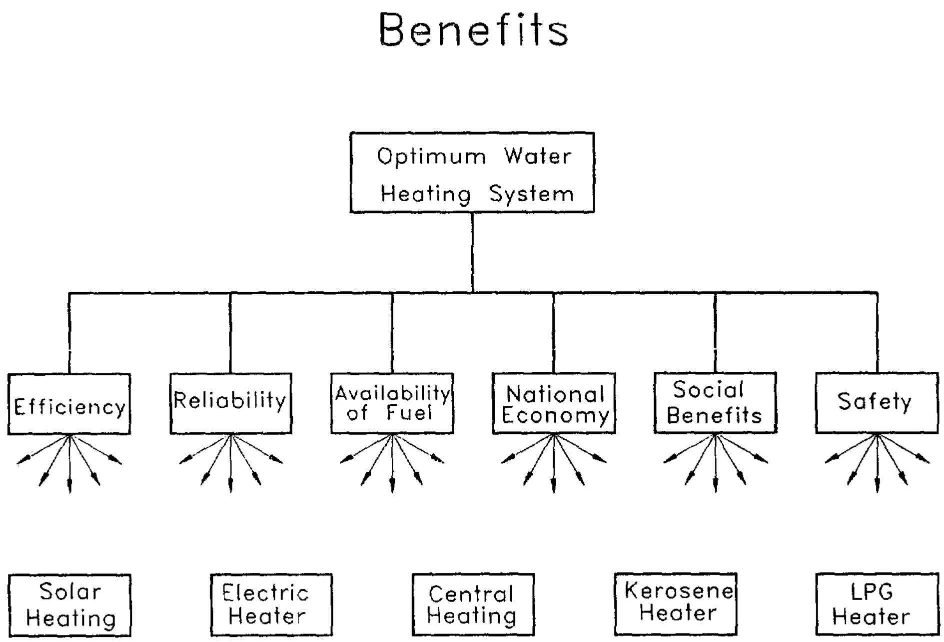

Fig. 1. Benefits hierarchy diagram.

in the form of a hierarchy of preferences through a series of pairwise comparisons of relevant factors or criteria.

There are five basic steps in applying the AHP in practice [6]:

1. Structuring the decision hierarchy.
2. Collecting data by pairwise comparisons.
3. Checking consistency of material judgments.
4. Applying the eigenvector method to compute weights.
5. Aggregating the weights to determine a ranking of decision alternatives.

Applying the AHP approach to cost-to-benefit analysis requires separating costs from benefits and constructing separate hierarchies for benefits and costs. The benefits hierarchy assigns decision

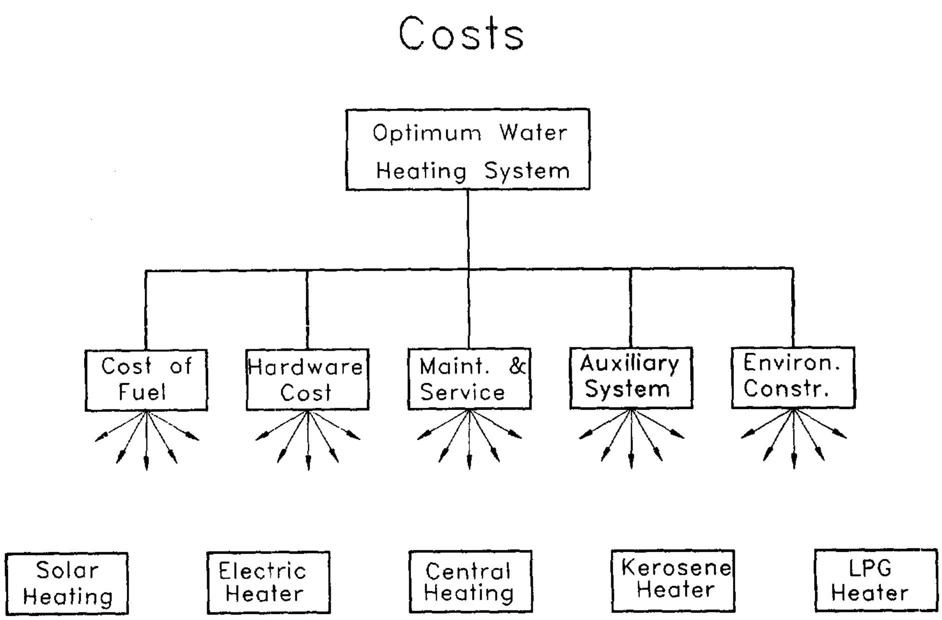

Fig. 2. Costs hierarchy diagram.

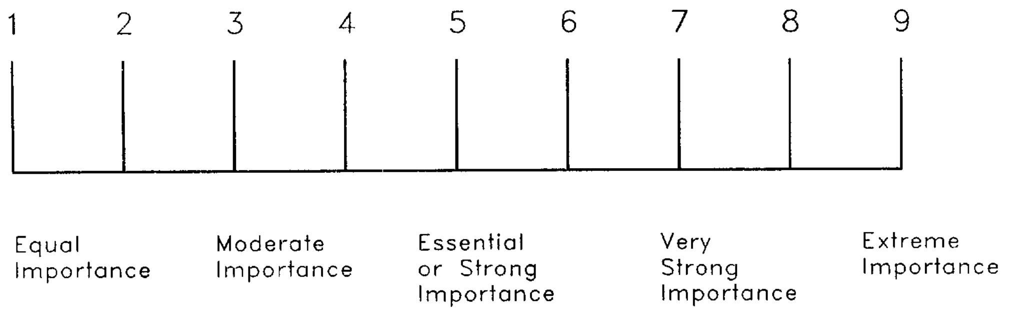

Fig. 3. The pairwise comparison scale (after Saaty [6]).

Table 1. Relational scoring and relative weights of water heating systems with respect to benefits

(a) Efficiency:

Cost of fuel	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	1/7	1/5	1/2	1/6	0.044
Electric heating	7	1	3	5	2	0.415
Central heating	5	1/3	1	3	1/3	0.164
Kerosene heater	2	1/5	1/3	1	1/5	0.071
LPG heater	6	1/2	3	5	1	0.306

(b) Reliability:

Hardware cost	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	1/4	1/7	1/3	1/5	0.044
Electric heating	4	1	1/4	3	1/3	0.148
Central heating	7	4	1	5	3	0.467
Kerosene heater	3	1/3	1/5	1	1/4	0.084
LPG heater	5	3	1/3	4	1	0.256

(c) Availability of fuel:

Maintenance & service	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	4	6	6	6	0.564
Electric heating	1/4	1	2	2	2	0.169
Central heating	1/6	1/2	1	1	1	0.089
Kerosene heater	1/6	1/2	1	1	1	0.089
LPG heater	1/6	1/2	1	1	1	0.089

(d) National economy:

Auxiliary system	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	9	9	9	9	0.692
Electric heating	1/9	1	1	1	1	0.077
Central heating	1/9	1	1	1	1	0.077
Kerosene heater	1/9	1	1	1	1	0.077
LPG heater	1/9	1	1	1	1	0.077

(e) Social benefits:

Environmental constraints	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	5	4	2	4	0.436
Electric heating	1/5	1	1/2	1/3	1/2	0.071
Central heating	1/4	2	1	1/2	1	0.121
Kerosene heater	1/2	3	2	1	4	0.264
LPG heater	1/4	2	1	1/4	1	0.108

(f) Safety:

Environmental constraints	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	5	4	2	4	0.436
Electric heating	1/5	1	1/2	1/3	1/2	0.071
Central heating	1/4	2	1	1/2	1	0.121
Kerosene heater	1/2	3	2	1	4	0.264
LPG heater	1/4	2	1	1/4	1	0.108

criteria. The category weight is used to adjust the overall weight of each benefit criterion. After alternatives are evaluated with respect to all benefit and cost criteria, an overall benefit weight and a cost weight are determined for each alternative. Benefit cost ratios are formed to facilitate the final selection of alternatives. Using this approach to cost-to-benefit analysis can improve this type of decision-making tool by employing the pairwise comparison scale to quantify non-financial factors.

The primary advantage of the basic AHP approach is its simplicity; once the criteria are agreed upon, and supporting data are collected for each alternative, the AHP analysis can be processed. Sensitivity analysis can be used to test the solution, and examine how changes in criterion weights would alter the weights and rankings of the individual alternatives.

3. FORMULATION

The decision regarding the selection of an optimum water heating system in Jordan was evaluated according to its benefits and costs. The benefit and cost hierarchies were considered separately, and cost-to-benefit ratios were obtained. The benefit and cost hierarchies were constructed as shown in Figs 1 and 2, respectively. The overall objective for both hierarchies was to select an optimum water heating system. As shown in Fig. 1, the benefits hierarchy includes all possible benefits that may be derived from various water heating systems. The benefit criteria at level 2 are efficiency, reliability, availability of fuel, national economy, social benefits, and safety.

Thus, the measurement of potential benefits from a particular water heating system exceeds, in scope, the financial return on that system and encompasses its contribution to the overall benefit of the nation. These socio-economic gains are represented by the criteria of the national economy and social benefits.

Figure 2 shows the cost hierarchy. The cost criteria at level 2 are cost of fuel, hardware cost, maintenance and service, auxiliary system, and environmental constraints. All items in the cost criteria can be related in terms of cost or money-value, apart from one item which is very difficult to quantify in terms of money, namely, environmental constraints, which measures the effect of a water heating system on the environment, directly or indirectly. The third level of the benefit and cost hierarchies represents the most common systems used for heating water in Jordan. The selections of these alternatives were based on the results of an energy consumption survey conducted by the Ministry of Energy [1]. These alternatives are solar energy, electric, central heating, kerosene fuel, and LPG water heating systems.

In order to establish the priorities (weights) of the alternatives in both the benefit and cost hierarchies, pairwise comparisons were necessary i.e. to compare the alternatives in pairs against a given criterion. Figure 3 shows the scale developed by Saaty [6] for a pairwise comparison. It defines values 1–9 assigned to judgments in comparing pairs of level 3 against a criterion in the second level of both the benefit and cost hierarchies. Table 1 shows the relational scoring and relative weights for the different water heating systems considered with respect to the benefits. The relative weight of each benefit criterion is obtained for all heating systems. Table 2 represents the relational scoring for all benefit criteria with respect to each other, as well as the relative weight scorings of each benefit criterion. This is the pairwise comparison matrix of the goal defined at level 1: the optimum water heating system. The last column gives the relative weight of their priorities, which indicates that the reliability of the system is the most important, followed by availability, efficiency, national economy, safety and social benefits. All five entries in the vector

Table 2. Relational scoring and relative weights for optimum benefits against each other

Optimum water heating system	Efficiency	Reliability	Availability of fuel	National economy	Social benefits	Safety	Relative weights
Efficiency	1	1/3	1/2	1	3	2	0.136
Reliability	3	1	2	4	5	3	0.365
Availability of fuel	2	1/2	1	2	4	4	0.240
National economy	1	1/4	1/2	1	2	2	0.120
Social benefits	1/3	1/5	1/4	1/2	1	1/2	0.055
Safety	1/2	1/3	1/4	1/2	2	1	0.084

Table 3. Overall relative weights for optimum benefits

Optimum water heating system	Efficiency		Reliability		Availability of fuel		National economy		Social benefits		Safety		Relative weights
Solar water heating	(0.044)(0.136)	+	(0.044)(0.365)	+	(0.564)(0.240)	+	(0.692)(0.120)	+	(0.436)(0.055)	+	(0.506)(0.084)	=	0.307
Electric heating	(0.415)(0.136)	+	(0.148)(0.365)	+	(0.169)(0.240)	+	(0.077)(0.120)	+	(0.071)(0.055)	+	(0.251)(0.084)	=	0.185
Central heating	(0.164)(0.136)	+	(0.467)(0.365)	+	(0.089)(0.240)	+	(0.077)(0.120)	+	(0.121)(0.055)	+	(0.134)(0.084)	=	0.241
Kerosene heater	(0.071)(0.136)	+	(0.084)(0.365)	+	(0.089)(0.240)	+	(0.077)(0.120)	+	(0.264)(0.055)	+	(0.044)(0.084)	=	0.089
LPG heater	(0.306)(0.136)	+	(0.256)(0.365)	+	(0.089)(0.240)	+	(0.077)(0.120)	+	(0.108)(0.055)	+	(0.066)(0.084)	=	0.178

Table 4. Relational scoring and relative weights of water heating systems with respect to cost

(a) Cost of fuel:

Cost of fuel	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	1/8	1/6	1/5	1/7	0.034
Electric heating	8	1	3	5	3	0.452
Central heating	6	1/3	1	2	1/3	0.153
Kerosene heater	5	1/5	1/2	1	1/3	0.102
LPG heater	7	1/3	3	3	1	0.259

(b) Hardware cost:

Hardware cost	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	2	3	5	1/2	0.243
Electric heating	1/2	1	2	5	1/5	0.150
Central heating	1/3	1/2	1	2	1/6	0.081
Kerosene heater	1/5	1/5	1/2	1	1/7	0.047
LPG heater	2	5	6	7	1	0.480

(c) Maintenance and service:

Maintenance & service	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	1/2	1/8	1/5	1/3	0.054
Electric heating	2	1	1/6	1/5	1/4	0.068
Central heating	8	6	1	1/2	1/3	0.247
Kerosene heater	5	5	2	1	2	0.362
LPG heater	3	4	3	1/2	1	0.268

(d) Auxiliary system:

Auxiliary system	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	9	9	9	9	0.692
Electric heating	1/9	1	1	1	1	0.077
Central heating	1/9	1	1	1	1	0.077
Kerosene heater	1/9	1	1	1	1	0.077
LPG heater	1/9	1	1	1	1	0.077

(e) Environmental constraints:

Environmental constraints	Solar water heating	Electric heating	Central heating	Kerosene heater	LPG heater	Relative weights
Solar water heating	1	1/4	1/7	1/6	1/3	0.044
Electric heating	4	1	1/6	1/5	1/2	0.091
Central heating	7	6	1	2	3	0.429
Kerosene heater	6	5	1/2	1	3	0.305
LPG heater	3	2	1/3	1/3	1	0.131

of priorities obtained in each of the six matrices are weighted by the priority for that corresponding criterion. An overall relative weight factor is then obtained from the results of Tables 1 and 2. These weights are of the overall relative properties of the five different water heating systems against the six benefits criteria, as they are presented in Table 3.

Similarly, the same procedure was repeated for the cost hierarchy, where Table 4 shows the vector of priorities of the five different water heating systems with respect to each cost criterion. Table 5 shows the pairwise comparison matrix of the cost criteria with respect to the goal defined

Table 5. Relational scoring and relative weights for optimum costs

Optimum water heating system	Cost of fuel	Hardware cost	Maintenance cost	Auxiliary system	Enviro'l constraints	Relative weights
Cost of fuel	1	3	3	4	5	0.440
Hardware cost	1/3	1	1	3	4	0.205
Maintenance cost	1/3	1	1	3	4	0.205
Auxiliary system	1/4	1/3	1/3	1	1/2	0.070
Environmental constraints	1/5	1/4	1/4	2	1	0.082

Table 6. Overall relative weights for optimum costs

Optimum water heating system	Cost of fuel		Hardware cost		Maintenance cost		Auxiliary system		Environmental constraints		Relative weights
Solar water heating	(0.034)(0.440)	+	(0.243)(0.205)	+	(0.054)(0.205)	+	(0.692)(0.070)	+	(0.044)(0.082)	=	0.128
Electric heating	(0.452)(0.440)	+	(0.150)(0.205)	+	(0.068)(0.205)	+	(0.077)(0.070)	+	(0.091)(0.082)	=	0.256
Central heating	(0.153)(0.440)	+	(0.081)(0.205)	+	(0.247)(0.205)	+	(0.077)(0.070)	+	(0.429)(0.082)	=	0.175
Kerosene heater	(0.102)(0.440)	+	(0.047)(0.205)	+	(0.362)(0.205)	+	(0.077)(0.070)	+	(0.305)(0.082)	=	0.159
LPG heater	(0.259)(0.440)	+	(0.480)(0.205)	+	(0.268)(0.205)	+	(0.077)(0.070)	+	(0.131)(0.082)	=	0.283

at level 1 of the cost hierarchy. Table 6 shows the overall priorities for the different water heating systems with respect to the costs.

4. RESULTS AND DISCUSSION

The benefit hierarchy results show that, based on efficiency and reliability, the solar water heating system was the least efficient and reliable (see Table 1). However, in terms of availability of fuel, national economy, social benefits and safety, the solar heating system was the most beneficial among all other heating systems. Reliability and availability of fuel were the two highest factors in determining the benefits factor. They have values of 36.5% and 24%, respectively, as shown in Table 2. In terms of overall benefits or returns, the solar water heating system was the most beneficial and had the highest returns.

The cost hierarchy shows that the solar water heating system would have the highest hardware cost, and it has the highest need of an auxiliary system (see Table 4). However, in terms of cost of fuel, maintenance and service, and environmental constraints, solar energy costs the least. The cost hierarchy shows that, in any water heating system, the cost of fuel counts the most, about 44%, as shown in Table 5. Hardware cost and maintenance cost follow with about 20% each. Table 6 shows that the solar heating system is the least expensive system (about 13%).

The overall cost priorities (weights) were divided by the overall benefit weights to obtain cost-to-benefit ratios. These ratios were also normalized to give new weights, as shown in Figure 4. The figure clearly shows that, even though the cost of the solar water heating system was the least

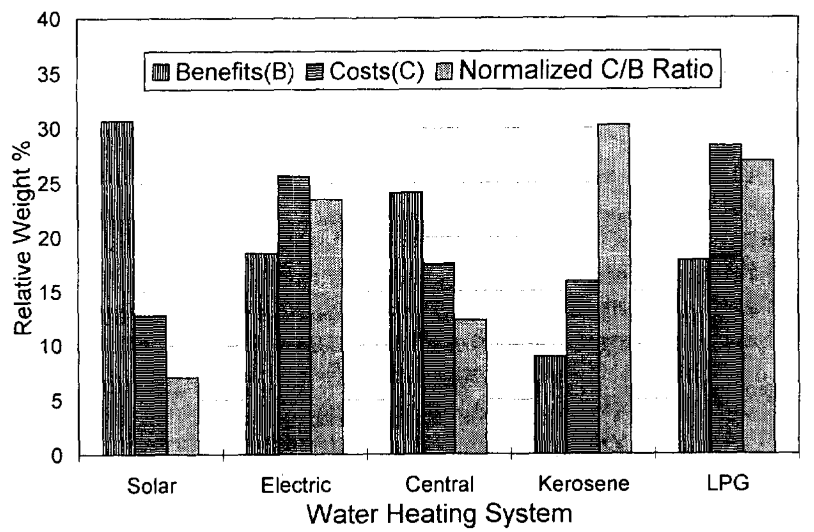

Fig. 4. Comparison of benefits, costs, and cost-to-benefit ratios.

expensive (approximately 13%) based on the cost hierarchy, it is even lower (about 7%) based on both the cost and benefit hierarchies. Other systems were affected. For example, based on the cost hierarchy, kerosene heaters come second (about 16%). However, based on the cost and benefit hierarchies, it was the most expensive of all systems (i.e., the worst choice, approximately 30%). Kerosene was the most expensive because it had the lowest percentage of benefits.

5. CONCLUSIONS

Based on the Analytic Hierarchy Process, the solar water heating system was the most inexpensive type heater in domestic use. By considering cost-to-benefit hierarchies, the solar water heating system was still the most inexpensive, but with more convincing results. In conclusion, we can say that the solar water heating system is the most desirable system to be used in Jordan.

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