AN ANALYSIS OF SELECTED SOLAR ENERGY SYSTEMS OF APPROPRIATE TECHNOLOGY FOR THE KINGDOM OF NEPAL

By

SOMA SHEKAR ADIGA

Bachelor of Engineering (Mechanical)

University of Mysore, India

Mysore, India

1970

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
July, 1985

AN ANALYSIS OF SELECTED SOLAR ENERGY SYSTEMS

OF APPROPRIATE TECHNOLOGY FOR

THE KINGDOM OF NEPAL

Formal Report Approved:

John L. Briggs
Report Adviser

Linda M. Vincent

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

The Kingdom of Nepal, where I was born and bred, is landlocked and has very few natural resources. Being among the poorest countries in the world, Nepal is facing several problems. Acute shortage of fuel wood is one of them. Village poor in approximately 29,120 villages in the country are hard hit by this shortage. This study was an attempt to analyze some "low temperature" appropriate solar energy systems as alternatives to fuel wood for the village people.

There are many who have contributed to the completion of this work. My special thanks to all of them.

To my committee I express my sincere gratitude and appreciation for their guidance throughout this academic endeavor. First to Dr. John L. Baird, Committee Chairperson, for his constant encouragement, guidance, and assistance throughout this work and my other academic activies. Dr. Baird's experience in academic areas and in leadership, and his warm and outstanding personality, have benefited me. He has also influenced my philosophy both professionally and personally. His belief in my abilities has led me to have confidence in myself. I also appreciate his personal concern for my overall career development. I am also grateful to the late Dr. Lloyd L. Wiggins, and to Dr. Cecil W. Dugger, currently in Jamaica, and to my committee member, Dr. Linda M. Vincent, for their interest and assistance during this work and my stay at Oklahoma State University.

I would not have completed this work without the help of Mrs. Dianne Wimberley and Mrs. Marie Roe. As I was always worried about my poor English language, Dianne helped me by editing and Marie helped me by typing. I am grateful to both of them for their input, support and suggestions.

Finally, I extend my special thanks to my wife, Neeru, and to my friends, Mohan and Hirendra. Their life experience in Nepal contributed to practical aspects of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Kingdom of Nepal, with a population of fourteen million and growing at 2.4 percent annually and a per capita income of only $120 per year, is facing a double energy crisis. The net oil imports constitute 85 percent of the total commercial energy demand, which is very costly in foreign currency for a poor country like Nepal, and the country is faced with an acute shortage of fuel wood. Other sources of energy are limited in that there are no fossil fuels available and hydroelectric power systems are not yet fully developed. Nepal derives half or more of its total energy from wood and agricultural or animal waste.

Hayes (1977) writes:

> While dreadfully low, energy use in the world's poorer countries is higher than official statistics suggest. Data are usually compiled only for fuel commonly used in the industrial world and in many third world countries such conventional sources count for only a small fraction of total energy use . . . the typical American uses 957 times as much energy as the average Nepalese (p. 31).

According to Earl (1975), firewood accounts for an estimated 96 percent of the fuel used in Nepal. When all energy is counted, the average American uses about 40 times as much energy as the Nepalese.

The average Nepalese family consumes one and one-half tons of fuel wood per year, and 85 percent of the country's heating and cooking energy. Twenty years ago, nearly 60 percent of Nepal's landmass was blanketed with thick forests. That figure has dwindled to 19 percent, according to

State Planning Commission of Nepal estimates, and it continues to decline despite recent acceleration of forestry schemes and other efforts to curtail felling of trees. Continued use of fuel wood at the current rate will produce deforestation and resultant erosion that could lead the country to other serious problems including change of land cover and possible conversion to desert conditions.

Essential elements to a solution, in the longer term, are alternate energy sources and improved energy efficiency. If solutions are not implemented in a timely manner, the current practices may thrust the country into conditions of irreparable damage.

The solutions are, in the longer term, local application of solar, biomass and other renewable forms of energy that hold promise of more abundant energy in rural societies at lower economic and environmental costs.

In recent years, several technologies have been developed which have been tested in developing countries. Appropriate technology societies reporting on testing activities which deal with energy technology application in small villages and among peasant farmers, reveal that developments are on a small scale. A worldwide survey (Jequier and Blanc, 1983) of appropriate technology activities conducted during 1978 shows Nepal under poor coverage.

The Research Center for Applied and Science Technology, Kathamandu, (Jequier, 1979) the only local organization working in this field, is faced with obstacles to technology diffusion due to lack of competitiveness relative to traditional technologies, lack of technical support, and lack of skilled manpower. Its scale of activities in appropriate energy technology is not specified though it is currently engaged in the development of village-level technologies in food storage and preservation, low-cost building materials, solar energy, and the utilization of agricultural and industrial wastes. However, the work of this organization is at present limited.

Problem Statement

In Nepal, technology transfer has been unsuccessful for several reasons, and technologies have proved unsuitable due to lack of realization of the real needs of the people. There remains a question of why Nepal has not effectively used readily available solar energy for its rural community development. A study to analyze some appropriate systems was deemed timely.

Purpose

The major purpose of this study was to select solar components for rural development projects in Nepal to meet household and community needs with small, low cost, locally operated energy systems. Analysis required a move beyond purely technical solutions to an approach based on a much broader range of considerations, including cultural, social, political and economic factors. Applying low-grade solar energy technology entails a number of quality and cost considerations. The technologies discussed here are based on well established scientific principles and could probably soon be applied.

The objectives of this study were threefold:

1. To examine selected solar energy systems for their overall appropriateness (based on the author's experience in Nepal and expertise as a mechanical engineer and within the possible range of criteria stated

below) for rural community development in the kingdom of Nepal.

2. To rate the selected solar systems on criteria explained in Chapter III.

3. To examine the selected solar systems to determine feasibility for course development in trade school curriculum in the Kingdom of Nepal.

Assumptions

In analyzing solar energy systems the following assumptions were made:

1. That people could and would work together collectively to bring improvements to their communities, though in Nepal region and cast feeling still prevails.

2. That all the systems selected for analysis did not involve patents, royalties, consultant fees, import duties, shipping charges, and practical plans could be obtained free or at low cost.

3. That user ability to understand the technology was equal, though in reality it varies from community to community.

4. That the work of the Research Center for Applied Science and Technology, Tribhuran University, Nepal, was not included.

Limitations

1. The thermodynamic aspects of design were not taken into account.

2. Due to lack of money and time, site visits to examine the solar energy systems were not attempted.

3. While analyzing system bureaucracy, attitudes of political leaders and inadequate legislation could not be involved.

Scope

1. This study would be useful for information and documentation for further research.

2. This study would help to develop employable skills in trade schools in Nepal.

CHAPTER II

REVIEW OF LITERATURE

Solar energy reaches the earth via a mixture of sunny, overcast, and partly cloudy days. In order to control the flow of solar energy to meet the requirements of most end uses, a mechanical (active) solar system is generally employed. The purpose of an active solar system is to match the available solar input to the temporal energy demand of the particular end use.

The temperature requirement and magnitude of the load, as well as the correlation between instantaneous load and available solar radiation, would affect long-term solar system performances. Different weather statistics were important for prediciting the performance of different combinations of system of load.

In this study, Nepal has been divided from north to south into four climatic zones: (1) the mountains, (2) the foot hills, (3) the Kathamandu Valley, and (4) the tarai region.

The mountain climate is unsuitable for the application of solar energy and has a very small population. Therefore, this region has not been included in future discussions. The population density of the rural section of the valley, found most suitable for this study, was estimated to be about 1,150 per square mile and the average village population in one village of approximately 29,120 villages in the country was estimated to be 335 (Harris and Giddens, 1973).

The maximum and minimum temperatures for the Kathamandu Valley, the foothills,and the tarai were taken from the climatic tables for Kathmandu Airport, Pokhara Airport, and Bhairawa Airport (Takahashi and Arakawa, 1981), as displayed in Table I.

Approach to System Analysis

Introduction of energy in rural areas should be gradual. Sudden infiltration of advanced technology in a primitive rural environment would not help. A technology that recognizes the economic boundaries and limitations of poverty is the one that is most likely to succeed. Such technology goes by the generic name 'intermediate technology' or 'appropriate technology' (Ramkumar, 1976). A definition of appropriate technology would include the following concepts:

1. Appropriate technology should be compatible with local culture and economic conditions; that is, the human, material and cultural resources of the community.

2. The tools and processes should be under the maintenance and operational control of the population.

3. Appropriate technology, wherever possible, should use locally available resources.

4. If imported resources and technology are used, some control must be made available to the community.

5. Appropriate technology should, wherever possible, use local energy sources.

6. It should be ecologically and environmentally sound.

7. It should minimize cultural disruptions.

8. It should be flexible in order that a community will not lock

TABLE I

REGIONAL CLIMATIC CONDITIONS RELEVANT TO THE USE
OF SOLAR ENERGY

Region	Latitude	Longitude	Elevation	Temperature Range
1. Kathamandu Airport (Valley)	27° 42'N	85° 22'E	1,336m	Maximum Daily January - 16.6°C
				Maximum Daily May - 27.7°C
				Minimum Daily December - 2.1°C
				Minimum Daily July - 19.8°C
2. Pokhara Airport (Foothills)	28° 13'N	84° 0'E	827m	Maximum Daily January - 18.8°C
				Maximum Daily April - 29.8°C
				Minimum Daily February - 6.0°C
				Minimum Daily August - 21.0°C
3. Bhairawa Airport (Tarai)	27° 31'N	83° 26°E	110m	Maximum Daily January - 22.2°C
				Maximum Daily May - 36.6°C
				Minimum Daily January - 7.6°C
				Minimum Daily August - 25.1°C

itself into a system which later proves inefficient and unsuitable.

"Appropriate Technology" or self-help development with small scale factories and village industries has been suggested as a more rational system of development for countries like Nepal than the introduction of sophisticated centralized industries largely supported by foreign capital and dependent on foreign "know-how." Appropriate technology allows for the generation of wealth within the country and the gradual establishment of industrial traditions with a pool of local technicians. Such a system allows for individuality and the adaption of equipment to local needs. Solar enegy systems could be produced by the methods of appropriate technology and could be a contribution to industrial development.

A solar device selected under appropriate technology could be an add-on to human and animal energy. In this circumstance, the initial cost must be low, maximum use of local material has to be made, and the level of technology should be in harmony with the lifestyle of the user. It would be necessary to avoid fragmentation of efforts and aim for integration, not only of investigation but also of functional goals of different devices, for successful energy utilization.

Topology of the village, geoclimatic conditions, socioeconomic and demographic data, local energy resources, consumption patterns, availability of local infrastructure, and skills of existing village industries and services are the major factors to be studied and analyzed before implementation of solar technologies for rural development (Gururaja and Ramachandran, 1979). While developed countries foresee a dominant role of solar thermal technologies for residential heating and cooling purposes, developing countries, Nepal in this study, require thermal energy more for essential activities such as cooking, pumping water, and post-harvest operations.

The energy requirements for the rural poor in Nepal were considered similar to the energy requirements for the village of Kayar in Africa, of which a detailed energy demand analysis was available (Sloop and Gordon, 1979). Categories of application were cooking, lighting, cold storage, cooling, domestic water pumping, communications, and other village operations. The energy demands are displayed in Table II.

Energy requirements for an individual in a rural community in Nepal were approximated on the basis of data available from an estimation made for a village household person in India (Kedia, Saksena, and Mitra, 1978). These requirements are shown in Table III.

From the above analysis, it was evident that a large portion of energy was utilized in cooking, water heating, crop drying, water pumping, and space heating. Hence, systems were analyzed on "selected low grade solar energy" for rural development projects to meet household and community needs with a small, low cost, locally operated approach.

The main problem in the design of solar appliances is the absorption of a maximum percentage of solar radiation incident and the use of the surface area in such a way that the total calories absorbed are sufficient to do the work required, such as cooking food, boiling water, or drying grain. Thus, the basic principle can be displayed as in Figure 1. Without going into details on the thermodynamic aspects of design, this section explores additional information on the existing systems for cooking food, boling water, and drying grain to determine their suitability for application in the rural sections of Nepal.

TABLE II

DAILY ENERGY DEMANDS FOR A RURAL VILLAGE

Energy Demands	KWh/Day
Lighting	125
Cooking	290
Cold Storage	23
Domestic Water Pumping	12
Cooling	22
Communications	12
Other Village Operations	9
Total	493

TABLE III

DAILY ENERGY DEMANDS FOR A RURAL INDIVIDUAL

Requirements	Time Period	Fuel Required	Cost/Qty of Fuel Required
Hot Water Bath	Oct. - Feb.	Firewood	2-3 kg/day
Space Heating	Oct. - Feb.	Firewood/ Kerosene Oil	10 kg/day
Animal Food Heating (Household)	Whole year	Firewood	6 kg/day
Lighting	Whole year	Kerosene Oil	1-1 1/2 litre/ day
Drinking Water	Not Available		
Cooking Food	Whole year	Firewood	2-3 kg/day
Drying of Vegetables	Not Available		
Drying of Crops	Not Available		

Useful Heat Collected = Incident Radiation Absorbed − Heat Losses Due to Conduction, Convection, and Radiation

Figure 1. Basic Thermodynamic Principle

Solar Cookers

Walton and Bomar (1979) wrote:

> Although efforts to develop solar cookers had been actively pursued for more than 100 years, they had never found general acceptance at the village level. It appeared that lack of acceptance was not simply a matter of economic, technological or social/cultural problems per se but rather a complex mix of all three. An additional problem also has been identified which was related to inadequate programs of instruction, interaction and follow-up between the sociologist/technologist and the villagers themselves. Finally, there had been very little if any involvement of the villagers in determining the type of cookers which would meet their requirements and in seeking their participation in the design, development and fabrication of the cooker (p. 1465).

Hoda (1978) described various types of box type solar cookers. He provided information test results conducted by the Appropriate Technology Development Association (India) on those cookers and found that reflector type solar ovens were very effective, but box type were easy to handle and much cheaper, although it took a longer time to cook using the box type cooker. Hoda discussed box type cookers, parabolic type cookers, lens type cookers, and steam type cookers in detail. Kisan cookers and reflector type cookers were models of the box type cooker, discussed by Hoda, whereas Tabor (1966) modified a solar cooker of the reflector type. Tabor made the cooker suitable for local production at a national or regional rather than a village level. It has long life with maintained performance; it is simple to use and it requires negligible maintenance. Tabor assumed that a non-portable cooker would be acceptable in most cases provided its durability was so high that it could be left out of doors throughout the year. Though not the cheapest, the high durability stove that Tabor expected to design would compensate for the additional cost.

The performance evaluation of the five solar cookers (Garg, Mann, and Tanvi, 1978) that were fabricated and tested at the Central Arid Zone Research Institute, Jodhapur, were found useful for this study. The study was undertaken to determine the cookers' potential usefulness. Two of them were reflector type, two were of hot box type and one used the flat type reflector. Of these five cookers, the hot box type solar cooker (solar oven) showed the greatest promise due particularly to its efficiency, ease of operation, ease of construction with local techniques and materials, and simplicity.

Khan (1964) found an absorption-type solar cooker suitable for rural use with certain modifications. He adopted an "air-lock" arrangement to minimize the loss of heat through the window. The problem of constant focusing irrespective of the motion of the sun has not been solved in a cheap and practical manner. Jeness (1960) felt that the improved cooking pot design, rather than further refinements in the reflector construction, offered the opportunity for the advancement of solar cooking in nonindustrial regions. The cooking pot, with a selective black bottom surface and convection-shielding skirt, could improve solar cooking efficiency.

Bhattacharya and Kapur (1978) attempted to explain that the reason behind the failure of solar cookers to gain popularity was the fact that these were essentially outdoor cookers. Their attempt to develop indoor solar cookers by using a two-phase thermosyphon to transport solar energy from an outdoor collector to a hotplate located inside the kitchen proved expensive for village use.

Solar Water Heaters

Certain essential features in common for domestic solar water heaters (McVeigh, 1983) were the collector plate, insulating material at the back and sides of the plate, one or two sheets of glass or translucent plastic in front of the collector plate, a casing, and a hot water storage system. Several systems were developed for installation. Feasibility studies were carried out on the basis of cost effectiveness, simplicity in construction, and efficiency.

Bachmann and Shakya (1978) provided some information on their work on solar water heaters designed and installed in Nepal. Pipe grid solar water heaters used galvanized iron materials instead of copper sheets and pipes to reduce cost of manufacturing. Another type of collector, flat plate, was made with two mild steel sheets fixed together with a minimal gap of only six mm or less. This collector had no pipe grid. Another item produced in Nepal, according to the same authors, was a one-piece solar water heater, on which the storage tank was itself the collector, insulated and encased in a mild steel or galvanized iron box. Village solar water, with no water mains and no plumbing, working on the principle of thermosyphon flow, was the latest system under construction in Nepal.

Mohan, Choudhury and others (1978) wrote on water and space heating systems which were designed and developed in the Central Building Research Institute at Roorkee in India. Those works resulted in the production of built-in storage type solar water heaters and large size solar water heaters, the integration of solar water heaters with building, and solar water space heating systems. Gupta, Tyagi and Tiwari

(1978) at Jawaharlal Neharu Agricultural University, Jabalpur, India, designed and constructed a prototype flat plate solar heater to evaluate its capacity to heat the ambient air for future use as a small solar heater to provide comfortable temperature in an office room, utilizing stack effect. The ambition was to make the occupant quite comfortable during the working hours of a day in winter.

Solar Drying

Because of the wide variety of circumstances encountered, the potential economic advantage of solar crop drying was assessed on an individual basis. This depends principally on the size of the crop dried and the prevailing weather conditions. Food loss which occurs between harvesting and consumption, commonly called post-harvest food loss, is a problem which has become increasingly important in rural areas. People in Nepal have limited opportunities to dry harvested grain. The most common and traditional drying method is to spread the grain out on the ground, on mats or plastic sheets, or on concrete or asphalt roads, to dry in the sun. These methods are unsatisfactory for a number of reasons: limited surface area, requirement of prolonged sunshine, susceptibility to damage from insects and foraging animals, covering the crop during rainy periods, and uneven quality of drying.

Morgan and Icerman (1981) explained several crop drying systems that included works from Volunteers in Technical Assistance (VITA). Direct exposure rack dryers, direct exposure chamber dryers, direct exposure preheat air dryers, combined direct and indirect heating models, and indirect heating designs are compared in this book. Similarly, Biswas and Tandon (1978) wrote on exploratory studies initiated at the Indian

Agricultural Research Institute to establish the design parameters of solar dryers. Investigations were carried out on drying of paddy using solar heated air. They used an experimental setup consisting of flat plate solar energy collectors connected to grain bins through air ducts. In a vertical bin type continuous solar grain dryer (Pattanayak, 1978), grain was dried continuously by flow of hot air at right angles to the vertical bed of grain moving downward due to gravity between two perforated sheet chambers.

Concept of Appropriate Technology, Solar Energy Systems, and Additional Load on Trade Schools by Introducing Appropriate Technology Solar Systems

Appropriate technology is no more and no less than a return to, or reaffirmation of, the fundamentals of engineering for the use and convenience of man. It could be argued, therefore. that it is not only wrong but ridiculous to treat it as something separate from the core of technical studies (Committee for Economic Development, 1970). Projects are the key to successful solar energy systems appropriate technology education. Projects could take many forms. They could involve single students or small groups. They could be concerned with research, development, or implementation. They could be closely formulated in advance or they could be "open-started" as well as "open-ended." They could involve field work; the scope is enormous and has been recognized only in recent years.

The operations of trade training on solar energy systems must necessarily provide factual information concerning suitable solar energy components and operating systems for heating, cooling and other purposes for rural people and institutional applications within the Kingdom of Nepal. Such training must also provide information about choice of components, economic evaluation and design of such systems, techniques of installation and maintenance and ways to improve public acceptance and gain overall social, economic, and environmental benefits from such systems.

In the maintenance of working solar systems, the present training provides tradesmen with sufficient knowledge to enable them to identify problems in systems and follow the necessary "trouble shooting" corrective procedures. Understanding the functional relationships of various solar components to the total system is extremely important in understanding the "why" behind the "what" of the system's operations.

The major objective of the proposed technical (trade) schools in the Kindgom of Nepal is to produce skilled workers to fill the need for low-level technical manpower for the country's development. Thus 80 percent of the available funds is allocated to trade education, much of which will be spent on practical activities, although the emphasis will vary for different trades. The solar installation field requires a certain amount of technical training and familarity with the hardware and terminology applicable to such activities.

CHAPTER III

METHODOLOGY

The kingdom of Nepal is landlocked. It has mountains over 15,000 feet high in the north and plains at sea level in the south stretching over 800 miles. Education among communities varies dramatically due to inadequate, difficult transportation and communication facilities. The cast system prevails in Nepal. Cultural background and political influence play major roles in community development. The tendency to resist any change is very high; therefore, criteria to be developed to examine low grade solar energy systems for system's application suitability are required on the basis of individual local needs. However, for this study, essential criteria were developed that should be useful for any community in Nepal. Further, this study is aimed at helping the government to utilize existing interest in development of cottage industries, financial aid to small farmers, and inclusion of rural community development projects in the Five-Year National Plan for selection of solar energy systems as per community needs. Systems which are considered appropriate, based on the author's experience and expertise, appear not to have been examined in any kind of systematic way for implementation suitability in the Kingdom of Nepal. Preliminary selection of available systems appropriateness was done through:

° Library research

- Examination of journals and other literature containing articles with key words in the topic areas of interest
- Mail request for information to institutions and individuals in the U. S. and other countries
- Consulting experts, task forces, and attending technical conferences

Each criteria was carefully written after studying criteria developed in the selection of solar energy systems in and for countries like India, Pakistan, Malawi, Kenya and other African countries, and on basic principles such as:

- Behaviorially appropriate design
- Layman construction technologies
- Responsiveness to local code, site and climate conditions
- Life-cycle conditions
- Post-construction evaluation
- Public awareness activities

The set of criteria thus developed were rated for:

1. Technology complexity

   high -- moderate -- low

2. A state of art review

   high -- moderate -- low

3. Social impact

   high -- moderate -- low

4. Scope for repair and maintenance by nontechnical people

   high -- moderate -- low

5. Manufacturing conditions

   large scale -- medium scale -- piecework

6. Manufacturing mode

   in factory -- in cottage industry -- in trade school

7. Manufacturing cost

   less than Rs150* -- Rs150 to Rs500 -- above Rs500

8. Cost effectiveness in BTU's

   less than 25% -- 25 % to 50% -- more than 50%

9. Use of local materials

   less than 25% -- 25% to 50% -- more than 50%

10. Life cycle cost (for 5 years)

   less than Rs100 -- Rs100 to Rs200 -- above Rs200

*Exchange Rate (1985) US $1.00 = Nepali Rs20.

There were no clear-cut boundaries for accepting or rejecting any of the systems under analysis. It was evident that because of climatic differences and existing facilities, certain criteria that occupied prime importance in one region were not important for another region. Again, no single form of energy could cope with the full range and complexity of rural energy supply. Technologies based on both direct and indirect forms of solar energy suitably combined with conventional energy technologies have the greatest potential for evolving appropriate energy systems for rural situations.

It is also important that the construction and installation of the major part of the solar components and systems require only basic skills in such trades as sheetmetal work, plumbing, carpentry, and brazing. The specific skills could be taught fairly easily to unskilled personnel, making these systems particularly attractive for the rural unemployed poor. The systems could be built by local citizens, thus saving on labor cost and producing employment. Each system was studied separately to examine the specific skills involved and to determine if such skills could be developed through courses in trade school curriculum in the Kingdom of Nepal.

CHAPTER IV

RESULTS

The sun radiates an average of two calories of heat per square centimeter per minute. This is the total heat available for utilization.

To bring one kilogram of water to a temperature of 100°C from a normal room temperature of 30°C requires 70 kilo calories of heat. The surface area to be provided, taking into account the efficiency of the absorber and the heat losses, should be at least 70 calories per kilogram.

In all the systems studied so far the key component is the collector. In the present state of development, even the cheapest sort of solar collector accounts for from 50 to 95 percent of the total cost of any solar device. Thus, the solar collector is the most expensive component in a solar cooker, a solar water heater, or a solar grain drier for the study in progress. Because of this, collectors are undergoing intensive reexamination and rapid development.

Flat-plate collectors or focusing collectors are two types of collectors in common use. Flat-plate collectors consist of flat, blackened surfaces which absorb solar radiation. Transparent covers and back insulation may be provided to reduce or control losses from the plate. On the plate, absorbed solar energy is converted to a desired form of energy, usually heat, and means are provided to remove that energy, usually as heated water. Flat-plate collectors are generally operated in fixed position.

The concept of the focusing collector is a reflector. This is an optical device which focuses the beam component of solar radiation on a receiver. The result is higher energy flux which allows collection of energy at higher temperatures. The ratio of intensity of radiation on the receiver to the intensity of the beam solar energy incident on the optical system may range from 2 to 3 at the low end, to 10,000 to 20,000 at high range. At any but the lowest of these ratios, some degree of "sun tracking" is required to orient the system to allow for the changing direction of the incoming beam radiation.

Flat-plate solar collectors have several advantages over the concentrating type: (a) flat plate collectors can be easily fabricated in any desired sizes; (b) they collect both diffuse and direct solar radiation; (c) their orientation is not critical; (d) their initial and maintenance cost is low; and (e) the collector can be used as part of the roof.

Solar Cookers

Solar cookers can be made available in Nepal at nominal cost with the help of the government. This should bring probable economic advantage to the Nepali family which must now spend an appreciable amount of time gathering fuel wood and animal chips with which to cook its food, thereby wasting potentially productive labor.

Two socioeconomic factors must be taken into consideration in introducing solar cookers into practical use. First, the Nepali housewife does not want to cook out in the sun and secondly, no one she knows cooks on a solar stove. Her mother did not cook on a solar stove and her neighbor has never heard of a solar stove. And so she resists innovation. It will require clever and expensive marketing techniques to put even the most economically sound solar device into widespread use in the face of social inertia.

A solar device is a huge capital investment for the rural poor. They must invest money now to save money later. But the initial capital must be available. Consideration must be given to provide access to capital through the financial structure of the society.

In the following section various solar cookers, solar water heaters, and solar grain driers are described. An analysis is made of the advantages and disadvantages of the various types of units in relation to consideration of their use in rural communities in Nepal.

Kisan Cooker

Specifics: The Kisan Cooker is made at home by digging a 2' x 2' pit in the ground where it is exposed to the sun's rays throughout the day. Insulation is achieved by packing the sides of the pit with straw or paddy husk ash. A blackened tray is placed over the pit which is then covered with a double glass cover. Utensils with food are kept inside the tray for cooking.

Analysis: This is the simplest form of solar cooker and it is the least expensive. Technology complexity is low. This type of cooker can be made by anyone. The only purchase required is the glass cover. Heating efficiency is low. Food in this type of cooker takes more time to cook than in other types of cookers. Food cannot be fried in this cooker. Regular attention is required to protect the pit. It is a stationary type of solar cooker. Some problems may arise during the rainy season.

Box Type Cooker

Specifics: This cooker allows solar radiation to enter through a double-walled glass cover placed inside a blackened box which is well insulated and made airtight. In this box type cooker, the amount of solar energy incident is rather small because only direct rays enter the box.

Analysis: Due to low technology complexity and low manufacturing cost this type of cooker can be made in small workshops as piecework. The manufacturing cost under present circumstances is expected to be within the reach of rural people (estimated cost: Rs300.00). More than 50 percent of construction material is made available locally. Experiments conducted on box type cookers in India indicated that temperatures near 100°C were reached in winter in three hours and in summer in two hours. The cooking time for rice in winter was 3-3 1/2 hours and in summer 2-2 1/2 hours.

Simple Reflector Type Solar Cooker

Specifics: Although a little more expensive and complicated in construction, simple reflector type solar cookers have been made by adding glass reflectors on all sides. This design is efficient and renders cooking time less than in the box type cooker.

Analysis: This type of cooker can be manufactured on a medium scale. The cost is brought down by using local materials and by training local tradesmen in trade schools. This type of cooker does not require sun tracking. The cost may range from Rs400 to over Rs600. Scope for repair and maintenance by nontechnical people is moderate. Technology complexity is rather high for local technical knowledge.

Mirror-Mounted Solar Cookers of the Reflector Type

Specifics: Several copper-backed, silver-glass, plane mirrors of small diameter are used for reflection. The explanation is in the high reflectivity of the glass mirror and the improved absorption by the pot due to the smaller angle of incidence. This is a nonportable cooker of high durability. It can be left out-of-doors throughout the year.

Analysis: Due to the technological complexity and the cost of manufacturing, this type of solar cooker is unsuitable for present use in rural communities in Nepal. However, there are several long-term advantages to using this type of cooker. It is much easier to keep the glass mirror clean. Mirrors are expected to last at least four years. The mounting, rotating frame, and clamp are all of iron and, therefore, can be manufactured on a large scale easily by local blacksmiths once the jig is made available. Trade schools can experiment with this type of cooker in their projects.

Many more ideas are being researched to lower the manufacturing cost of the solar reflector. One such idea potentially suitable for Nepal is to use paper-made reflectors. Several layers of newspaper are glued over the convex paraboloidal die. When the laminate and glue have dried, the shell is removed from the die, and strips of aluminum foil are pasted onto the surface. This can be done by using locally available cheap material and by using native techniques. Trade schools can experiment with this technique.

Experiments on thermosyphon systems for indoor cooking were conducted in India. The technical know-how and the cost will deter the successful implementation of these systems in rural communities in Nepal.

Solar Water Heaters

A primitive method of water heating with solar energy, which is being used in many houses in Nepal, is simply to leave the water container exposed to the sun. This method is very inefficient, and heat losses subsequently cool the water. Covering the water surface to prevent heat losses from the container led to the development of solar water heaters.

Different types of solar water heaters have been developed in Nepal by Balaju Yantra Shala in collabration with the Swiss Association for Technical Assistance. According to the data available, at present more than 18,000 liters of water are heated daily up to temperatures of 60°C or more by the direct use of solar energy in Nepal. Inexpensive solar water heaters installed five years ago at an altitude of more than 4,000 meters have been found working successfully today without much repair and maintenance.

Village Solar Water Heater

Specifics: The village solar water heater requires no water mains and no plumbing. It consists of 100 mm diameter plastic pipe with an inner aluminum tube that facilitates the thermosyphon flow.

Analysis: Details are not available. According to the author, this type of heater is in the experimental stage in Nepal.

Built-in Storage-Type Solar Water Heater

Specifics: With this type of solar water heater, the storage tank is itself the collector, insulated and encased in a mild steel or galvanized iron box.

Analysis: It is very simple to construct; it is very easy to install; and it is much less expensive than other types of solar water heaters. This type of solar heater can be manufactured on a large scale in factories so that the cost can be brought down further. At present, the estimated cost is Rs600 and use of local material is less than 25 percent.

Reflector-Type Portable Solar Water Heater

Specifics: The tank is placed in the main body of the water heater. Pipes are connected for the circulation of water. A mirror, attached on the upper portion of the main body, faces the sun. Wheels are attached to allow transport from place to place.

Analysis: Technology complexity is moderate. Cost is more than for the built-in type but less than for the domestic type. The scope for repair and maintenance by nontechnical people is high. This type of solar water heater can be manufactueed on a large scale as a cottage industry. It can be manufactured by using more than 50 percent local material.

Domestic Solar Water Heater

Specifics: The water heated by solar energy through the absorber flows to the storage tank by a thermosyphon action. Several separate components such as a flat-plate solar collector, storage tank, circulation pipe, and feed water supply arrangement are used in this system.

Analysis: Technology complexity is high. This water heater costs approximately Rs3,500, which is rather expensive for a common man in Nepal. The price is high due to the separate absorber and storage tank.

An improved version of this type using more local material is in progress. The efficiency of this system comes out to be 60 percent. This is an excellent type to use in schools, office buildings, and community health centers. Skill development to design, fabricate, and install this type of solar heater needs to be considered seriously as a trade school activity.

Solar Grain Dryers

The traditional grain drying method in rural Nepal is to spread the grain out on the ground, on mats or plastic sheets, or on concrete or asphalt roads and leave it in the sunshine for several days. This method is very unsatisfactory. It yields losses in the amount, nutritional quality, germination capability, and market value of the grain. Considering the village situation, in present circumstances in Nepal, possession of any type of indirect forced convection dryer is beyond the scope of individuals or single families. Where government investment is very high through different input such as seed, fertilizer and irrigation, government should provide community facilities for drying agricultural products as a protection of their original investment. Government must provide research and development facilities to improve solar drying techniques by using solar energy collectors which will save the cost of other fuel.

Direct Exposure Chamber Dryer

Specifics: The crop is placed in an enclosure covered by a transparent cover and/or side panels. Solar radiation is absorbed directly by the crop and internal surfaces of the chamber to provide heat and convection currents to evaporate the moisture in the grain. The structure can be constructed from bamboo, coconut thatch, rice straw, and polyethylene sheeting.

Analysis: This type of dryer is used primarily for drying rice paddy and may reach internal temperatures of 42° to 54°C. In almost every house in the Tarai belt of Nepal this is the common method of crop drying during the months from May to September. This design is very simple and has remained unchanged over several years of use because it is more economical than most other techniques which have been developed as replacements. Construction cost is about Rs500. Materials can be used repeatedly for two to three years.

Direct-exposure, Preheated Air Dryer

Specifics: A corrugated, galvanized steel solar collector is used in this type of air dryer. The heated air passes into the drying chamber. Removable panels at the back of the drying chamber provide access to crop loading and unloading.

Analysis: The capacity is fixed. Technology complexity is moderate. Ambient temperature, dryness fraction and time of exposure need to be determined with each use. The steel sheet requires regular care and may need replacement once in two years, accounting for about 40 percent of the total cost of the dryer . Cost to build is about Rs 7,500, which is rather high for village people.

Indirect Forced-Convection Dryer

Specifics: The main components of this design are the roof, which serves as the solar collector and is fabricated from corrugated steel sheets blackened with bituminous paint, a plywood air duct, a blower, and a grain bin.

Analysis: Total cost for this system is approximately Rs10,000. It requires blower-motor assembly. Technology complexity is high. This dryer is not within the reach of rural poor in Nepal.

Conclusion

Technology evaluation differs from technology assessment which seeks to predict or project the entire range of intended and unintended impacts of the introduction of a technology prior to its introduction.

Social Assessment of Technology

Due to geographical conditions, several villages in Nepal are simply cut off from the rest of the world. In such areas it is not difficult to find people at the age of forty who have not seen a bicycle. These village people are frightened of change; therefore, introduction of energy systems should be gradual without disrupting their way of life. The failure of the first solar energy system can have an impact on village people to resist further work. Rather than selecting systems high in technology complexity for higher efficiency, systems are chosen which are simple, inexpensive, and suited to the situation.

Children of village poor who are unable to receive high school graduation are likely to attend trade schools to develop employable skills in a short time. Encouraged by trade school training, backed by government financial sources, these students can work to intrduce solar energy systems when they go back to their villages. Among those trained in trade schools, interested young people are provided with assistance to start workshops or cottage industries for further work. This can be a method of bringing energy awareness to a village. This method can create enthusiasm for using solar energy systems in the village elderly people.

Based on past experience in other developing countries, the approach in implementing solar energy systems through trade school activities, like the one stated above, can bring desirable rating changes in all criteria explained in this study.

Financial Assessment of Technology

Manufacturing, transporting, and installing costs for selected solar energy systems vary with the system design, the percentage use of local materials, and the manufacturing mode. Today Nepal has a very poor economic situation. A village person can earn from Rs400 to Rs750 monthly from which he has to feed four to six of his family members. For him to possess a solar energy system with initial cost above Rs500 is out of reach unless government financial support is provided.

More use of local materials and "built-on-site" systems can reduce initial cost of solar energy systems substantially. Systems using local materials like wood, clay, bamboo, used kerosene and oil containers, polyethelene sheeting, polyethelene collapsible tubes, aluminum foil, galvanized iron sheets, and other available local insulating materials are selected. Proper use of selected materials and on-site manufacturing processes of solar energy systems are taught in trade schools through required coursework.

Finally, for any solar energy system to be effective in a village community where ninety-five percent of the population asks "where is the fire?" careful planning, proper approach, and a great deal of patience are required in addition to financial assistance from the government and correct technology selection.

BIBLIOGRAPHY

Bachmann, A. and Gyani R. Shakya. "Solar Water Heaters in Developing Countries." SUN: Mankind's Future Source of Energy vol. 3. New York, NY: Pergamon Press, 1978.

Berrie, T. W. Power System Economics. London, UK: Peter Peregrinus Ltd., 1983.

Biswas, D. K. and S. K. Tandon. "Studies on Performance Character of Solar Grain Drying System.: SUN: Mankind's Future Source of Energy vol. 3. New York, NY: Pergamon Press, 1978.

Bhattacharya, S. C. and V. K. Kapur. "Investigation on the Feasibility of Using a Two-phase Thermosyphon for Solar Storage, Space Heating and Cooking." SUN: Mankind's Future Source of Engergy vol 1. New York, NY: Pergamon Press, 1978.

Committee for Economic Development. Training and Jobs for the Urban Poor. New York, NY: Committee for Economic Development, 1970.

Earl, D. F. Forest Energy and Economic Development. Oxford: Clearendon Press, 1975.

Garg, H. P., H. S. Mann, and K. P. Tanvi. "Performance Evaluation of Five Solar Cookers." SUN: Mankind's Future Source of Energy vol.3. New York, NY: Pergamon Press, 1978.

Gupta, V. K., H. R. Tyagi, and N. K. Tiwari. "Single Room Heating by Solar Radiation." SUN: Mankind's Future Source of Energy vol. 3. New York, NY: Pergamon Press, 1978.

Gururaja, J. and A. Ramachandran. "Characteristics of Rural Energy Demand and Major Barriers and Tasks and Implementation of Potentially Viable Solar Technologies." (Sun II: Proceedings of the Internatinal Solar Energy Society vol. 2. New York, NY: Pergamon Press, 1979).

Harris, George L. and Jackson A. Giddens. Area Handbook for Nepal, Bhutan & Sikkim. Washington, DC: Superintendent of Documents, U.S. Government Printing Office, 1973.

Hayes, Denis. Rays of Hope. New York, NY: World Watch Norton & Company, Inc., 1977.

Hoda, M. M. "Solar Cookers." SUN: Mankind's Future Source of Energy vol. 3. New York, NY: Pergamon Press, 1978.

Jenness, James R., Jr. "Recommendations and Suggested Techniques for the Manufacture of Inexpensive Solar Cookers. Solar Energy, vol. 3-4 (July 1960), pp. 22-24.

Jequier, Nicolas. Appropriate Technology Directory. Paris: Development Centre of the Organization for Economic Cooperation and Development, 1979.

Jequier, Nicolas and Gerard Blanc. The World of Appropriate Technology: A Quantitative Analysis. Paris: Development Centre of the Ortganization for Economic Cooperation and Development, 1983.

Kedia, Y. P, R. K. Saksena, and C. R. Mitra. "A Strategy for the Development of Some Low Grade Thermal Devices." SUN: Mankind's Future Source of Energy vol. 1. New York, NY: Pergamon Press, 1978.

Khan, Ehsan Ullah. "The Utilization of Solar Energy." Solar Energy, vol. 8 (January-March 1964), pp. 17-22.

McVeigh, J. C. Sun Power, 2nd Edition, New York,NY: Pergamon Press, 1983.

Mohan, Dinesh and N. K. D. Choudhury. "Water and Space Heating by Solar Energy." Sun: Mankind's Future Source of Energy vol.3. New York, NY: Pergamon Press, 1978.

Morgan, R. P. and Larry J. Icerman. Renewable Resource Utilization for Development. New York, NY: Pergamon Press, 1981.

Nash, J. M., J. T. Smok, and W. C. Thomas. Modeling, Simulation, Testing and Measurements for Solar Energy Systems. New York: The American Society of Mechanical Engineers, 1978.

Office of the Foreign Secretary. Solar Energy in Developing Countries: Perspectives and Prospects. Washington, DC: National Academy of Sciences, 1972.

Pattanayak, S., P. Sengupta, and B. C. Raychauduri. "Continuous Solar Grain Dryer." SUN: Mankind's Future Source of Energy vol .3. New York, NY: Pergamon Press, 1978.

Ramkumar, R. "Technical and Socio-economic Aspects of Solar Energy and Rural Development in Developing Countries." Sharing the Sun: Solar Technology in the Seventies vol. 9. Cape Canaveral, Florida: The American Section of the International Solar Energy Society, 1976.

Sloop J. L. and Judith J. Gordon. "Solar Energy in Africa: Survey of Needs and Activities: Potential Application of Small Solar Energy Systems." (SUN II: Proceedings of the International Solar Energy Society vol. 2. New York, NY: Pergamon Press, 1979).

Sodha, M. S., S. S. Mathur, and M.A.S. Malik. Reviews of Renewable Energy Resources. New York: John Wiley and Sons, 1983.

Tabor, H. "A Solar Cooker for Developing Coutries." Solar Energy, . Vol. 10, No. 4 (1966), pp. 153-157.

Takahashi, K and H. Arakawa. World Survey of Climatology Vol. 9. New York, NY: Elsevier Scientific Publishing Company, 1981.

Walton, J. D., Jr., and S. K. Bomar, Jr. "Solar Energy Applied to the Needs of Sub-Sahara Africa." (SUN II: Proceedings of the International Solar Energy Society Vol. 2. New York, NY: Pergamon Press, 1979).

VITA

Soma Shekar Adiga

Candidate for the Degree of

Master of Science

Formal Report: AN ANALYSIS OF SELECTED SOLAR ENERGY SYSTEMS OF APPROPRIATE TECHNOLOGY FOR THE KINGDOM OF NEPAL

Major Field: Technical Education

Biographical:

Personal Data: Born in Kathamandu, Nepal, November 1, 1945, the son Subramanya and Sharada Adiga.

Education: Graduated from Board High School, Coondapoor, Karnatak State, India, in 1962; completed pre-university course in Science from Mysore University, India, in 1963; received a Bachelor of Engineering degree in Mechanical Engineering from the University of Mysore, India, in 1970; completed the requirements for the Master of Science degree at Oklahoma State University, Stillwater, Oklahoma, in July 1985.

Professional Experience: Engineer-workshop in charge, Sajha Yatayat (Transport Corporation of Nepal), Nepal 1972-1973; in charge - Training Section, Butwal Technical Institute, Nepal, 1974-1976; Principal, Butwal Technical Institute, Nepal, 1977; Lecturer, Institute of Engineering, Tribhuran University, Nepal, 1978-1982; Assistant Education Officer (Mechanical), Western Region Campus Project, Institute of Engineering, Tribhuran University, Nepal, 1982-1983.

Professional Organization: Nepal Engineering Association, Nepal.