ECONOMIC EVALUATION AND POTENTIAL ASSESSMENT OF SOLAR WATER HEATERS IN URBAN GHANA

A CONTRIBUTION TO AN ENVIRONMENTALLY SUSTAINABLE FRAMEWORK

BY

FORSON DOE KWABLA AMARVIE

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CITATION

Now unto him that is able to keep me from falling, and to present me faultless and joyful before the presence of his glory with exceeding joy, to the only wise God our saviour through Christ Jesus our Lord, be glory and majesty, dominion and power, both now and forever! Amen.

Jude 24 and 25

DEDICATION

This project report is dedicated first to our Lord and saviour Christ Jesus for showing his mercies, guide and guarding, protecting and providing for me throughout my course and finally to my mom and dad Mr. and Mrs. Amarvie for their profound support and encouragement, commitment and devotion throughout my education.

DECLARATION

I with this declare that, no part of this report has been presented to any University to the best of my knowledge for award of any degree, except for references to other people's work which have been duely acknowledged. This work is the result of my own research under the supervision of Professor K.G Adanu and Professor Georg Galster.

....

(AMARVIE DOE KWABLA FORSON)

STUDENT

.... DATE: Feb 5, 1997

(PROFESSOR K.G. ADANU)

SUPERVISOR

....

(PROFESSOR GEORG GALSTER)

CO-SUPERVISOR

ACKNOWLEDGEMENT

I owe first a profound debt of gratitude to the almighty God for seeing me through the course. I am indebted to Professor K.G Adanu, my main supervisor for devoting all his time in supervising my work; I must say I deeply appreciate all his efforts. I profoundly appreciate the contributions made by Dr. Ohene Kunadu of Sociology Department to the successful completion of my research work.

Further more, I am indebted to the entire members of the energy group of the department of Physics in building 309 of Technical University of Denmark for their colossal contribution to the analysis of my data in Denmark, I must say I am grateful and honoured. It is my extreme heart felt desire to express words of appreciation and gratitude to Professor Georg Galster of Department of Physics building 309 and Professor Svend Aag Svendsen of The thermal Insulation Laboratory building 118 all of Technical University of Denmark for the supervisory role played in my data analysis, I must say all their contributions, suggestions and advice have been very much appreciated.

Finally to all those who have contributed in diverse ways but whose names I have not acknowledged I say thank you.

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ABSTRACT

This project work describes the different methods of analyzing the economics of a solar water heating system to determine its economic viability and potential in Ghana. The economic variables in relation to cost that were considered in the analyses are the annual cost of owning the collector, storage unit and associated controls, the annualized life-cycle cost (ALCC) of operating the system, the yearly cost of maintenance, life-cycle savings (LCS), life-cycle cost (LCC), the payback period (PBP).

Based on cost analysis, solar water heaters were found more economical than the use of electric water heaters. A survey conducted in parts of Accra to determine the awareness of the use of solar water heaters, and the affordability of solar water heaters in Ghana, revealed that solar water heaters can be afforded by commercial users (restaurants, hotels, hospitals) and very few private individuals in the medium and high income groups. Critical evaluation of income and expenditure patterns of potential end users revealed that the expenditure pattern of all the income groups is much higher than their corresponding income levels.

A further analysis of the income and expenditure pattern revealed that if all the income is to be used in the installation of a solar water heater, for a family of four in low, medium and high income groups with average income of one hundred and twenty-five thousand, two hundred and fifty thousand, and three hundred thousand cedis respectively, it would take ten, six, and five years respectively to purchase a solar water heater.

An economic and financial viability analyses (see appendices C and D) of a thermosyphon solar water heater were made using an f-chart simulation program, and technical viability using eurosol simulation program for thermal solar water heating systems. The results of the economic analyses revealed that for such a system with an economic lifetime of ten years, the marginal investment is profitable over the economic lifetime and a payback period of eight years.

CHAPTER ONE

1.0 INTRODUCTION

The use of solar energy in its direct and indirect forms is not new in Ghana. However, in recent years there has been an increasing interest in the use of solar energy, and projections suggest that it could provide about 5% of the energy needs of Ghanaians by the year 2010 and more than 10% by 2030 if the necessary technologies are developed Wereko-Brobbey (1993). It is expected that application of solar energy to produce heat on a low temperature level will develop faster than most of the other solar energy conversion methods because of their relatively high conversion efficiencies and their potential to substitute directly for critically limited energy carriers such as oil, fuelwood and gas, which hitherto were employed to provide low-temperature heat. If the above projection proves true, we can expect that many houses in Ghana will have some form of solar water heating system. Nevertheless, the problem is that there has not been much development of solar hardware in Ghana.

Solar energy is abundant in Ghana. It is a gift of nature but appears that the technological expertise is lacking in this regard. Solar energy if well developed would go a long way to meet the energy needs of Ghanaians. The benefits that would be derived from the wide spread use of solar water heaters cannot be over emphasized. Some benefits are as follows:

1. Reduction of the load on limited conventional electrical power,
2. Reduction in the use of woodfuel and fossil fuel,

3. Reduction of green house effect,

4. Conservation of electric power for industrial development.

The conversion of solar energy for useful application requires a considerable initial investment compared with an electrical water heater. Some solar water heaters have a source of auxiliary energy see figures 2.9a and 2.9b page 29 and 30 respectively, making such systems to have both solar and electrical parts to meet the desired load. Solar systems are normally characterized by high initial investment followed by low operational cost. Determining whether such an investment is economically competitive when compared with a conventional electrical water heater is necessary. The economic analyses that were made are based on several figures of merit as defined by Duffie and Beckman (1991) as follows:

I. LEAST-COST OF SOLAR WATER HEATING SYSTEM

The least-cost of solar water heating system applies to a solar water heater for which solar energy is the only energy resource. Solar water heater yielding least cost can be defined as that system showing minimum owning and operational cost over the life of the system. However, the optimum design of a combined solar and electrical water heating system based on minimum total cost of delivering energy will generally be different from that based on least-cost of a solar water heater, and the use of least-cost as criterion is not recommended for systems using solar in combination with other energy sources.

II. LIFE-CYCLE COST (LCC)

The life-cycle cost of a solar water heater is the sum of all the costs associated with the heater over its life time or over a selected period of analysis, and it takes into consideration the time value of money.

The basic idea of life-cycle cost as reported in the Sunset Homeowners Guide to Solar Heating (1979) is that anticipated future cost of the solar water heater is brought back to present cost (discounted) by calculating how much would have to be invested at a market discount rate (the rate of return on the best alternative investment) to have the funds available when they will be needed. To do a life-cycle costing analysis of a solar water heater, that includes predictable expenditures, it is imperative to consider the annual operating costs (the cost of electricity for the pumps, fans, and controls of an active solar water heating system or the cost of fuel necessary to run the conventional electric, gas, or oil appliance of the same heating capacity). Many analyses involve addition of an annual fuel inflation factor to the fuel cost figures to reflect predicted rises in fuel costs over the life-cycle period.

Maintenance costs, such as replacement of mechanical parts with shorter lifetimes than the life-cycle, corrosion inhibitors, polyethylene liners, or any other such equipment of an active solar or passive solar water heating system, and cleaning of conventional equipment, are also figured into the analyses. The analyses must allow for inflation rates, so that annual expenditure for operation and maintenance of the system would reflect predicted annual inflation rates over the chosen life-cycle, and finally subtract from the estimate of the initial cost any local tax deductions, or exemptions available for solar water heater installation. The initial higher-priced solar heating system may end up being the less expensive choice, once the repayment period on loan ends and installation cost and loan interest is recovered through fuel savings.

III. LIFE-CYCLE SAVINGS (LCS)

The life-cycle savings of a solar water heater is the difference between the life-cycle cost of a conventional electric water heater and the life-cycle cost of the solar water heater plus auxiliary energy system.

IV. ANNUALIZED LIFE-CYCLE COST (ALCC)

The annualized life-cycle cost of a solar water heater is the average yearly out flow of money (cash flow). The actual cash flow varies with year, but the sum over the period of an economic analysis can be converted to a series of equal payments in cedis that are equivalent to the varying series.

V. PAYBACK PERIOD

The pay-back period is defined in many ways. Below are some definitions that may be encountered:

(a) The time needed for the yearly cash flow to become positive.

(b) The time needed for cumulative fuel savings to equal the total initial investment; that is how long it takes to get an investment back by saving in fuel. The payback period can be calculated with or without discounting the fuel saving.

(c) The time needed for the cumulative savings to equal the down payment of the solar water heater.

(d) The time needed for the cumulative savings to be zero.

(e) The time needed for the cumulative savings to equal the remaining principal debt on the solar water heater. Definition (b) was adopted in this study.

VI. RETURN ON INVESTMENT (ROI)

The return on investment of a solar water heater is the market discount rate that results in zero life-cycle savings; this is the discount rate that makes the present worth of a solar water heater and a non-solar alternative equal.

1.1 BACKGROUND OF STUDY

The environmental consequences of our daily choice of energy resources, patterns and methods of energy use are among the major factors that are threatening the integrity of both local and global ecological systems. Developing countries are no exceptions. Rapid industrialization in some developing countries, poverty, population growth and urbanization in most developing countries, tend further to intensify the use of non-renewable energy.

Considerations should clearly be given to the choice of energy resources and use of energy in ecologically safer ways. Shifting from non-renewable to renewable energy sources, and efficient and effective use of energy are fields important in this regard. However the remedy to the said ecological problems may lie in the will and commitment of the dwellers of our globe to carry out an environmental sustainable framework where application of energy is planned, such that a sound ecological system will be secured for the present and all generations to come.

If the present level of living standards should be increased rather than decreased in the developing countries, the framework, among others, will call for new technological solutions as alternatives to the conventional ones. In the short run, this is especially important in the high energy-consuming industrialized countries. In the long run, it becomes equally important in the developing countries. New ecology-friendly technologies for conversion, storage, transmission and final utilization of energy in the forms of electrical power, heat, cooling, lighting, etc. are to be developed and put into use.

In the context of developing countries, the new ecology-friendly technologies will have their origin either in the same developing countries or in another country for example in an in dustrialized country. In the latter case, which this project will deal with, the technology has to be transferred to the developing countries before it can be naturally-integrated into the production system in the recipient society. Experience and results from technology transfer cases from industrialized country to developing countries in the past decades, are varying, as far as technological sustainability of the projects are concerned. Some cases have been successful while others less successful or even failures. It is well known that technological sustainability (of the transferred technology) is a precondition for achievement of the contemplated environmental (social and technological) objectives.

This research work seeks to evaluate the economics of a solar water heater, assess the potential of the solar water heater, identify the technological and societal imperatives pertaining to choice and transfer of solar water heating technology to Ghana, with the objective of planning the measures to secure the economics and technological sustainability of solar water heaters. A further objective of the project is to examine the social effect and the economic viability of solar water heaters in urban Ghana.

This research work is focused on the affordability of solar water heaters in urban Ghana as its empirical work field. It is envisaged that hot water will be used in the domestic sector, primarily for dish washing, laundry and bathing. All the electricity supply of Ghana is from hydro-power plants, solar water heaters will not only achieve immediate environmental enefits, but also substituting the use of electricity to heat water. However, with the installation of a thermal power plant and with rising demand of electricity between industries and households the price of electricity will rise tremendously.

It is worth mentioning that in the short run, dissemination of solar water heating technology in Ghana, will not only come to assist households to get access to warm water, but also provide employment and conserving electrical power for use by the growing industrial sector for national development. Seen from an environmental point of view, development and application of ecologically-friendly technologies will be necessary to achieve an environmental sustainable balance.

Economic evaluation and the potential of solar water heaters in achieving a sustainable environmental balance are two main theoretical issues that this project will take up. The technology bears traces and features of its society. For example a technology artist, being an important part of the organizational element of technology, is in constant interaction with his society. He uses the opportunities and resources that the society provides him, while his technological activities are affected and controlled by the limits that the society sets. For example, his products should match the needs and affordability of his clients.

Society is the totality of socio-economic, socio-structural and socio-cultural factors. These factors are mutually affecting each other.

The relationship between technology and society is of a two-way character. These relationships due to their multiplicity and mutual effects, are complex. Identification of these societal factors that are important in the dynamics of technological change would be examined. Thus the mentioned interactions, are so to speak, mainly the interactions between the technological capabilities of a technology actor(s) and the technological capacity of the society. This interaction plays a vital role in technology change process of the society. Seen from an environmentally-sustainable point of view, development and application of ecology-friendly technologies will be necessary to achieve an environmental sustainable balance.

1.2 CONCEPTUAL FRAMEWORK

1.2.1 Definition of the problem:

The Ghanaian energy scene has been dominated for all this time by biomass, (Addo and Hagan 1994). A report by the Ministry of Energy and Mines, 1991 revealed that, biomass consisting mainly of fuelwood and charcoal constitute 71% of the total energy consumed. More than 95% of the energy derived from biomass are consumed by households throughout the country. In the face of significant changes in the vegetation cover of the country, one begins to wonder whether this energy source could be sustained without intervention, considering the rapid growth of the population and the inconsistent nature of our agricultural system, a phenomenon that has contributed immensely to vegetation cover removal and environmental degradation. Any meaningful intervention must be based on reliable knowledge gathered on many factors such as:

A. Environmental threats because of degradation of vulnerable parts of the environment, caused by harmful wastes, emitted from conventional energy systems. Application of new technologies with capability of effective conversion, storage and transmission of renewable and non-renewable energy sources into useful energy forms, can contribute to the solution of this problem.

B. Lack of compatibility between transferred technologies and the technological conditions of the recipient society. To put the new ecologically-friendly technologies (developed in industrialized countries and transferred to developing countries) into application, the socio-technological conditions of the recipient society have to be elaborated, and accordingly, compatible technologies are chosen (or developed). This will contribute to the solution of this problem.

On this background, the project will take up the following sub-problems:

1. Identification of the main characteristics of the energy sector in general, specific solutions to the rising energy demand of domestic sectors of Ghana.
2. Choice of energy-technological solutions for water heating, in the domestic and commercial sectors of Ghana, as related to socio-technological conditions of the society.

3. General implications of problems 1-2 on transfer of energy-technological solutions within the commercial sector and the urban residential sector of Ghana with a focus on solar water heating technology.

The study includes the following topics:

a. Study of the prospective users of solar water heaters as related to the questions of demand, user specifications, social benefits, and affordabilitiy.

These were done through interviews.

b. Study of the Ghanaian energy sector in general, and specifically on the questions of energy supply and price policies. Policies regarding energy technology with a focus on urban households were of special interest. The study was carried out through document studies and interviews with competent bodies in the energy sector.

1.2.2 Hypothesis

In pursuit of the issues raised in 1.2.1, the following hypotheses will be examined:

1. The major household energy used for heating water depends on educational background, and income.
2. The major energy source of commercial end-users for water heating depends on number of customers/guests.

3. The use of electricity by households and commercial end- users for heating water and satisfying any other energy needs is derived from its convenience and availability.

4. The desire in attaining efficiency in the use of energy is based on the desire to reduce consumption cost.

5. Solar water heaters can be afforded only by the higher income group and commercial users.

1.3 OBJECTIVES OF STUDY

1. To assess the hot water needs of the community.
2. To identify the source(s) generally used in Ghana to heat water.
3. To find out the major problem(s) associated with the various source(s) of heating water.
4. To identify specific problem(s) associated with water heating using the various energy sources available.
5. To identify measure(s) taken to solve or alleviate the problem(s) associated with the current energy source(s) for heating water.
6. To examine the social effect of solar water heating on the life style of the community.
7. To examine the economic effect of solar water heating on the community.
8. To determine the economic viability of a solar water heater manufacturing industry in Ghana.
9. To evaluate the cost effectiveness of solar water heaters in urban Ghana.

1.4 METHODOLOGICAL APPROACH

The economic evaluation involves analyses of the pay-back period, life-cycle costing, the annualized life-cycle savings, and net life-cycle savings, and finally the return on investment. The present value method of analysis was used to evaluate the cost effectiveness and the result of this compared with the future repayment (pay-back of initial capital in future) with today's capital. The present value of capital flow arising from investment made now could be obtained by relating the future capital flow with a discount factor. The annual cost of delivering solar energy to water as defined by Duffie and Beckman (1974), that is the cost of ownership, operation, and maintenance of a solar water heater in dollars per year, can be formulated as

$$C_{S,a} = (C_c A_c + C_{sT} + C_E)I + P C_p + C_{MM} + C_{ML} \qquad (1.4.1)$$

Where $C_{S,a}$ is the annual cost of the solar water heater, C_c is the capital cost per unit area of collector as a function of design (number of covers), A_c is the area of collector, C_{ST} is the capital cost of storage (container, and insulation), C_E is the capital cost of equipment, piping, ducts, and control, I is fraction of investment to be charged per year, interest, and depreciation; P is annual solar power requirement for the solar water heater, C_P is unit cost of solar power; C_{MM} is the annual cost of maintenance materials, and C_{ML} is the annual cost of maintenance labour.

1.4.1 SAMPLING FRAMEWORK AND UNDERLYING ASSUMPTIONS

The selection of the survey areas and respondents of this study were based on purposive sampling method where the objectives of the study were taken into consideration. The respondents are husbands/wives for households and head of institutions for commercial users. Five communities namely, Legon, Airport residential area, Labone residential area, Madina, and Achimota were selected in the Greater Accra Region as study areas.

A sample of three hundred questionnaires, made up of forty households and twenty commercial users in each of the five communities, were administered, with the target end- users being homes (private individuals), restaurants, hotels, laundries and hospitals/clinics.

1.4.2 TYPE OF DATA COLLECTED AND ANALYSIS

Two types of data were collected for the study, primary and secondary data. The primary data comprised of the information collected from the respondents during the main field work in the five communities chosen as study areas. These were carried out using structured questionnaires with both direct and open-ended questions. Preliminary work preceded the main field data. The secondary data involve review of existing literature on solar water heaters, the economics of solar water heating, and existing policies towards the utilization of renewable energy resources in Ghana. Data collected in the main field survey were analysed by computerized statistical systems, with quantitative and qualitative assessments. The secondary data provided the basis upon which the main field data were collected. It involves questionnaire- development, reconnaissance survey of some selected study area, pretesting and finalizing of questionnaire.

1.4.3 PRESENTATION OF PROJECT REPORT

The report of the study is structured into five chapters. Chapter one discusses the introduction which involves the general context of study by emphasising on the economic evaluations of a solar water heating system, the background of the study and the conceptual framework. The chapter further outlines the problems for the study and the hypothesis. Other topics that were covered here includes the objectives of the study and the methodological approach .

Review of literature is presented in chapter two. This involves a discussion of the general energy situation in Ghana, by examining the existing government policies on new and renewable energy resources. Policy issues in energy production and utilization and impact on the environment were also outlined in this chapter. A further study of the energy situation brought into focus topics like energy efficiency and conservation, energy pricing, policies on new and renewable sources of energy, domestic energy use and policy. Viability of a solar water heating system, assessment and assessment model of a solar water heater were also reviewed in this chapter. A general description of a thermosyphon and a forced circulation solar water heaters are also presented. The results of the study are presented in chapter three. Chapter four deals with analysis of the results, and finally in chapter five conclusion and principal findings of the domestic and commercial energy sector, project limitation and recommendation are presented.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Review of Energy Situation, Government Policies On New And Renewable Energy

In an effort to provide a coherent national framework and policies for improving the negative impact of the oil crises on the social and economic development Of Ghana, the Ministry of Energy and Mines was established in 1978. In a review of the publication by Karekezi and Mackenzie (1993), Wereko-Brobbey reiterated that the Ministry of Energy and Mines was not only made responsible for formulation, implementation, monitoring and evaluation of Government policies but also exploitation of the energy resources. In a report by the Ministry of Energy and Mines (1990), on the socio-economic Impact Assessment of Public Information and awareness campaign on the conservation, opportunities, practices and benefits, it was reported that the Ministry has continued to prosper during the period of international concentration on environmental issues. The growing international emphasis on environmental issues puts developing countries in sub-sahara Africa in a dilemma. The two goals that appear to conflict are:

1. The urgent need for economic growth and social development in the sub-region.
2. The urgent need to stop the degradation of the natural environment in the sub-region and globally.

In particular, man-made greenhouse gases, threaten to cause rapid and substantial changes in the global climate. The energy sector is a main contributor to these problems. In Ghana, the economy and its development programs depend principally on fuelwood, hydro-power, and petroleum products to meet energy requirements. The two indigenous sources, fuelwood and hydro-power constitute about 80% and 7% respectively of the country's annual energy supply, and the balance of 13% comes from imported petroleum (Wereko-Brobbey ,1993). The demand for energy is expected to increase rapidly in the future as the economy continues to grow; with production and consumption forecast to grow at an average of 10% per annum until the year 2000, and 2% per annum at the corresponding gross domestic product (GDP) growth rate.

I. FUELWOOD

The rapidly deteriorating environment and ecological damage evidenced by perceptibly high rates of deforestation and desertification pose a serious threat to the future availability of fuelwood for human livelihood. Clearing of the forest for agriculture and growing pressure on the high forest region for timber production combine to aggravate the fuelwood resource problem.

II. ELECTRICITY

The bulk of Ghana's electricity is produced from two hydro-electric projects, situated at Akosombo and Kpong, with installed capacities of 912 megawatts and 160 megawatts respectively. The Volta lake, the water source for these Hydroelectric project, has submerged an area of 85,000 square kilometres (5% of the country) and some 78,000 people and 170,000 domestic animals from 700 towns and villages were displaced Karekezie and Mackenzie (1993). There are negative human impacts associated with these schemes such as water-borne diseases (malaria, schistosomiasis, filariasis, and hook worm). In Ghana, the unexpectedly long drought in 1983-1984 led to serious power curtailment of the country's electricity generation and supply. Massive cuts in domestic electricity supply, and a total halt in electricity export, further accelerated decline in

III. PETROLEUM

Crude oil is imported via the Tema harbor and processed at the country's only oil refinery at Tema, which processes a maximum of 28,000 barrels per stream day (BSD) as at 1993. The refinery itself produces, on a relatively minuscule scale, some greenhouse gases. Ghana's consumption of petroleum products Petrol, gas oil, kerosine, and LPG for the year 1991 was 256,981 tonnes, 256,981 tonnes, 274,763 tonnes and 9643 tonnes respectively, with the total consumption emitting about 500,000 tonnes carbon equivalent of carbon-dioxide Wereko-Brobbey (1993). The country's consumption of petroleum products is set to increase into the foreseeable future with a growth rate of about 5% into the twenty-first century Wereko-Brobbey (1988). The opportunities to satisfy this significant growth in the demand for petroleum products will be severely constrained by the country's inability to generate the necessary resources to procure its crude oil needs, unless current exploration activities lead to commercial production of indigenous crude oil.

It is essential that a developing country like Ghana, ensure that the necessary energy required for development is made available without placing undue stress on the environment. One of the most important short-term priorities of meeting the energy demand of Ghanaians is to provide modern energy services to a large section of the population. There exists currently a large range of options for meeting such energy needs, with varying degrees of negative environmental implications. The immediate challenge to policy makers is to select those options that offer the possibility of providing an adequate level of energy service to the population, while minimizing the associated environmental impacts, and without jeopardizing long-term development aspirations.

2.2 POLICY ISSUES IN ENERGY PRODUCTION, UTILIZATION AND ENVIRONMENT

The energy sector programs implementation by the Ministry of Energy and Mines (1990) are based on a strategy with the following principal aims:

Improve productivity and efficiency in the procurement, transformation, distribution and use of all energy resources;

Reduce the country's vulnerability to short-term disruption in energy resources and supply bases;

Ensure the availability and equitable distribution of energy to all socio-economic sectors and geographical regions;

Consolidate and accelerate development and use of the country's indigenous energy sources, especially fuelwood, hydropower, petroleum and solar energy

2.3 ENERGY PRICING

Pricing is one of the many policy instruments which the Ministry of Energy and Mines has utilized in an attempt to achieve its environmental objectives. In this respect, appropriate measures have been taken in a report by the Ministry of Energy and Mines (1990) to set energy prices at realistic levels, based on the principle of full cost recovery of all investments made to secure, produce, process, transport, and market energy service and products. The petroleum price-setting is based on the principle of total cost recovery in the procurement, refining and distribution of petroleum products. Power tariffs are based on the concept of long-run marginal cost (LRMC) Wereko-Brobbey (1990), that is, tariffs reflect the economic cost of supplying electricity so as to promote efficient resource allocation. Economic theory indicates that the benefits (to society) of electricity consumption will be maximized if the output prices are set equal to the marginal cost of supply based on the cost plan Munasinghe, (1989). In practice, prices are adjusted to reflect not only the long-run marginal cost (LRMC) of supply, but also other financial(taxes), social, and political criteria.

Whatever future prices result, they must be compared with prices assumed in making the original demand forecast. If there be any inconsistency then the demand forecast may have adjusted and the investment plan reviewed again. The above consideration indicates that the investment and pricing decisions are closely interrelated.

The impact of this pricing policy is manifested in the reduction in consumption of petroleum products and electricity. There has been until now an indication that this has led to greater efficiency in the utilization of energy, and reduced the emission of carbon dioxide and other noxious gases from petroleum products.

Environmental consideration in the pricing of energy resources is well demonstrated in the pricing of liquefied petroleum gas (LPG). In order to encourage the adoption and use of LPG, several incentives have been built into its price. The price composition of LPG, unlike other petroleum products does not include any taxes; in addition to this, the capital investment required for procuring end-use devices for LPG has been provided by central Government in a revolving fund which is recovered as and when the cylinders are filled. The amortised cost of the cylinder is included in the price of LPG.

Charcoal-pricing however, is outside government control, meaning that prices are determined by market forces. The combination of the lack of formal pricing mechanism and critical supply and environmental problems have made charcoal and fuel wood, the fuel used by the poorest people, the most expensive energy source on a per-unit-delivered energy basis in Ghana as revealed by the survey carried out in parts of Accra as part of the project work. In an effort to redress these problems, and provide further incentive to the promotion of LPG, action has been taken to ensure that the price of LPG, which is lower than charcoal, retains this comparative advantage at all times.

The problem of charcoal production is so grave that a number of districts Administrations have taken the hash measure of banning charcoal production in their districts in an attempt to combat the destruction of the forest. In order to harmonised the activities of charcoal producers with environmental safe-guards, the Ministry of Energy and Mines in collaboration with Ministry of Environment is making efforts to control the situation by encouraging reforestation and better forest management practices. The Ministry of Energy and Mines is currently implementing a programme to organise and assist charcoal producers and other rural communities to undertake reforestation projects. A tax system is also being implemented which will levy taxes on logging operations to provide funding for reforestation programmes in the country.

2.4 ENERGY EFFICIENCY AND CONSERVATION

The Ministry of Energy and Mines has embarked on implementation of projects geared towards ensuring more efficient use of energy and the adoption of environmentally sustainable energy forms in the domestic and industrial sectors. These projects include

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The broad aims of the latter program as reported in Ministry of Energy and Mines (July 1990) are as follows :

1. Promote greater awareness of the opportunities and benefits of energy conservation among all energy users;
2. Facilitate the achievement of savings in per capita energy consumption in all areas of energy use through the application of appropriate energy-conservation measures;
3. Develop indigenous professional capability for the identification and implementation of energy conservation measures;
4. Develop the institutional capability and implementation strategies required for the realization of the potential efficiency improvement in all sectors of the economy.

   It is imperative that Ghana defines a strong institutional base for the management of its major energy sources; formulation and co-ordination of comprehensive programs with other relevant agencies would go a long way to alleviate some of the problems pertaining to our energy resources and environmental issues.

2.4.1 POLICIES ON NEW AND RENEWABLE SOURCES OF ENERGY

It is widely accepted that, renewable energy offers great prospects for attaining the goals of sustainable energy development over the long term. Furthermore promotion of renewable energy has featured prominently in the energy policy of most countries, since the oil crises of the 1970s and 1980s, as a viable means of securing the future supply of energy for most non-oil producing countries. Over the last ten years the Ghana Government, with the goal of attaining a sustainable socio-economic growth of the country has pursued an energy policy which is committed to the development of renewable energy resources of the country Ministry of Energy and Mines (1990).

The short-term broad objectives for the future development of renewable energy resources as detailed in this report are:

i. to improve the efficiency of production, conversion and use of woodfuel in all the socio-economic sectors,

ii. to promote the development of renewable energy industries that have strong inherent prospects.

In the medium to long term, the objectives are:

i. to demonstrate and evaluate renewable energy technologies with the potential to meet the need of prioritized socio-economic welfare objectives.

ii. to provide support for research, development and demonstration of renewable energy technologies with the greatest potential to increase and diversify the country's future energy supply base.

iii. to develop the relevant information base on the stock and status of renewable energy resources, suitable technologies and end-use patterns for the purpose of establishing a planning framework for the rational use of the country's renewable energy resources.

2.4.2 DOMESTIC ENERGY USE AND POLICY

The Government's policy on domestic use of energy is clearly indicated within its other policies on conventional energy resources, new and renewable sources of energy substitution of energy sources, as well as energy conservation and efficiency. The domestic energy policy, as incorporated in these and other policies are summarized in the report by Wereko-Brobbey (1980) as follows:

i. Extension of electricity to all parts of the country, especially to the rural areas under a currently on- going National Electrification Scheme (NES) within the 30 year period : 1989 to 2019;

ii. Expanding the accessibility and reliability of petroleum products (including kerosine) supply and distribution to all parts of the country by removing constraints to existing products distribution and marketing activities, as well as developing new infrastructure to bring products closer to the points of final use;

iii. Decreasing the consumption of firewood and charcoal by promoting the use of improved woodfuel cookstoves;

iv. Expanding the productivity and use of alternative biomass resources such as biogas from organic, animal and municipal waste;

v. Substituting liquid petroleum gas (LPG) for charcoal and firewood in urban households and public institutions such as schools, hospitals, and prisons;

vi. Investigating the pattern of energy consumption and end-uses in households, commercial and public institutional sectors, as well as potential for introduction of energy conservation measures;

vii. Organizing public information and awareness campaigns to educate energy consumers on the opportunities and benefits of energy-conservation.

2.4.3 POLICIES ON SUBSTITUTION OF ENERGY SOURCES

There exist great prospects for the substitution of traditional domestic households fuels by liquefied petroleum gas (LPG). In order to reduce the country's dependence on fuelwood and charcoal, the Ministry of Energy and Mines is promoting the widespread use of liquefied petroleum gas as primary fuel for cooking in households, large institutions and the commercial sectors of the economy. The major objectives outlined in its report (Ministry of Energy and Mines, July 1990) are :

i. To promote an indigenous manufacturing industry of LPG appliances;

ii. To increase public awareness and competence in the safe handling of LPG;

iii. To make it more affordable for firewood and charcoal users to switch to gas by reducing the initial capital investment for LPG appliances.

2.4.4 POLICIES ON ENERGY CONSERVATION

With the positive growth signs being shown in all sectors of the economy of Ghana, there are indications that petroleum and electricity consumption will continue to increase. The high cost of making energy available, coupled with Government's commitment to ensuring adequate energy supply to all geographic regions of the country, necessitate the application of appropriate policy instruments to promote more efficient use of energy in all sectors of the economy. Consequently the Ministry of Energy and Mines is undertaking an energy-efficiency and conservation program with the following specific objectives:

i. To promote greater awareness among all consumers;

ii. To facilitate the achievements of savings in per capita energy consumption in all areas of energy use;

iii. To develop Ghanaian capabilities for identification and implementation of energy conservation measures; and

iv. To develop the institutional capability and implementation strategies required for the realization of the potential efficiency improvements. The renewable energy development program covers a number of specific projects which are grouped under two broad headings of Biomass and Solar Energy.

2.5 SOLAR ENERGY

Solar energy already makes a significant contribution to the country's energy supply, largely for traditional activities such as sun drying of crops, fish, fuelwood and clothing. The Ministry of Energy and Mines has established a National Solar Energy Program (NASEP) to assess, demonstrate and evaluate the technical, economic and social viability of appropriate solar energy technologies and applications which may facilitate the attainment of the major goals of the economic recovery program ERP, especially the development of rural areas.

2.6 BIOMASS ENERGY

To tackle the woodfuel supply and attendant environmental problems, the Ministry of Energy and Mines has implemented a number of projects, some of them pilot, to determine the most effective technological and cost effective solutions for making better use of existing resources, resuscitating degraded areas and increasing the country's bio-energy resource base.

More than 2.5 billion people who live in developing countries constitute majority of the worlds population rely on biomass are their chief source of energy (Munasinghe, 1989). Bioenergy or biomass energy consist of all kinds of plant or animal matter which may be used as energy sources; typical examples include fuelwood, charcoal, agricultural residues, energy crops such as sugar canes, human and animal waste, and muscle power. Bioenergy is basically energy stored from the sun. Plants convert (into biomass) a small fraction of the 170 million gigawatts of solar radiation incident on the earth surface, through the rather inefficient process of photosynthesis. The conversion efficiency varies between about 0.5 and 2.5%.

Munasinghe (1989) further reported that about 10% of gross world energy supplies are obtained from bioenergy, of which the overwhelming part is fuelwood and charcoal. In many African and Asian Countries 60 to 90% of the total energy is supplied from biomass. In a report by the United Nations it is estimated that more than 100 million people, predominantly in the rural areas of developing countries, do not have sufficient fuelwood to meet their basic energy needs, while at least another one billion face actual or potential shortages. It was further reported by the United Nations that the average rural households in developing country needs at least 0.75 to 1 cubic metre of wood per year for cooking; this requirement may double or triple if the fuelwood is also used for heating.

Over-cutting and deforestation has reached alarming levels in many parts of the world. In addition to the immediate local energy for the poor rural masses, potentially more disastrous ecological difficulties have also occurred. The Sahelian situation - Involving desertification, erosion, loss of watersheds, and the catastrophic collapse of the local biosphere's general capability to sustain human life is an extreme example.

In view of these serious problems, the United Nations conference on new and renewable sources of energy , held in Nairobi in 1981, identified improving of existing fuelwood resources through better management. This include giving a higher national priority to fuelwood problems and educating the population in elementary silvi culture.

2.7 VIABILITY OF SOLAR WATER HEATING SYSTEM AND ASSESSMENT

Solar water heating is a technology that has been developed in different countries. Detailed study of design, materials, and efficiency, will not alone provide adequate information for a decision maker. An assessment has to be related to the needs, demands, habits and resources of the end-user. A solar water heating system that is appropriate and feasible from a technical point of view to a particular situation may not be feasible or may be too expensive or socially unacceptable in another situation. A highly sophisticated solar water heating system could be acceptable as long as locally available materials can be used in constructing it.

Assessment of a technology is essential because of scarcity of resources and the lack of information. Assessment is made in order to decide on how to allocate these resources to different purposes. The situation becomes more complicated when new technologies are involved. Information on cost, efficiencies, life times, is usually scarce and less reliable.

This illustrates the problems and risk of making economic financial, technical and social assessment/appraisal of a solar water heating system in general terms. Solar water heater is a proven technology, and currently has a commercial application in various countries. Its viability, naturally, depends on a number of factors.

2.8 ASSESSMENT MODEL

The different steps in the analysis of the viability of a solar water heater as reported by Bjorn (1987) are :

i. Identification of the point of view from which the analysis is to be made (private investor/user or Government body).

ii. Analysis of users' needs and demand for hot water

   Quantity per day

   Temperature

   Consumption pattern

iii. Identification and analysis of an appropriate conventional water heating system (already in operation or as an alternative investment option).

iv. Identification and sizing of a suitable solar water heating system, taking into consideration the information gained in steps i to iii as well as solar intensity and other local conditions.

v. Appraisal of the financial, economic, social and/or technical viability. These include outlining the methodology used, the economic criteria for acceptance of the new technology (based on shadow prices and the national view point), the financial requirements for successful implementation (based on market prices and the private view point) and policy implications of this analyses.

2.9 SOLAR WATER HEATING SYSTEM

The basic elements of most solar water heaters are the flat-plate collector and the storage tank. These are connected to supply a load; an auxiliary energy source, and means for circulation of water and control of the system may be provided. An example of a natural circulation system (thermosiphon system) is shown schematically in fig 2.9a. In this system, the tank is located above the collector, and water circulates by natural convection whenever solar radiation on the collector adds energy to the water in the collector and thus establishes a density gradient. An extra energy source may be added to the top of the storage tank to maintain the water at the top of the tank at some minimum temperature needed to meet the load. The density gradient is a function of the temperature difference between the water at the top and bottom of the storage tank, and the flow rate is thus a function of the useful energy gain of the collector which produces that temperature difference.

Under these conditions, the system becomes self adjusting, with increasing gain leading to increasing flow rate through the collector-tank system. It has been observed by Lof and Close (1973) and by Cooper (1973) that under a wide range of conditions the difference in temperature of water through the collector in a natural circulation system is about 10°C.

Close (1962b) worked out an analysis of the circulation rates in a natural circulation system and compared computed and experimental inlet and outlet temperatures. He concluded, that the difference in the inlet and outlet temperature of a collector at any time are constant across the collector; this confirms the work of Lof (1967) and Cooper (1973). Gupta and Garg (1968) also showed that inlet and outlet temperatures for two collectors suggest nearly a constant temperature rise across the collectors.

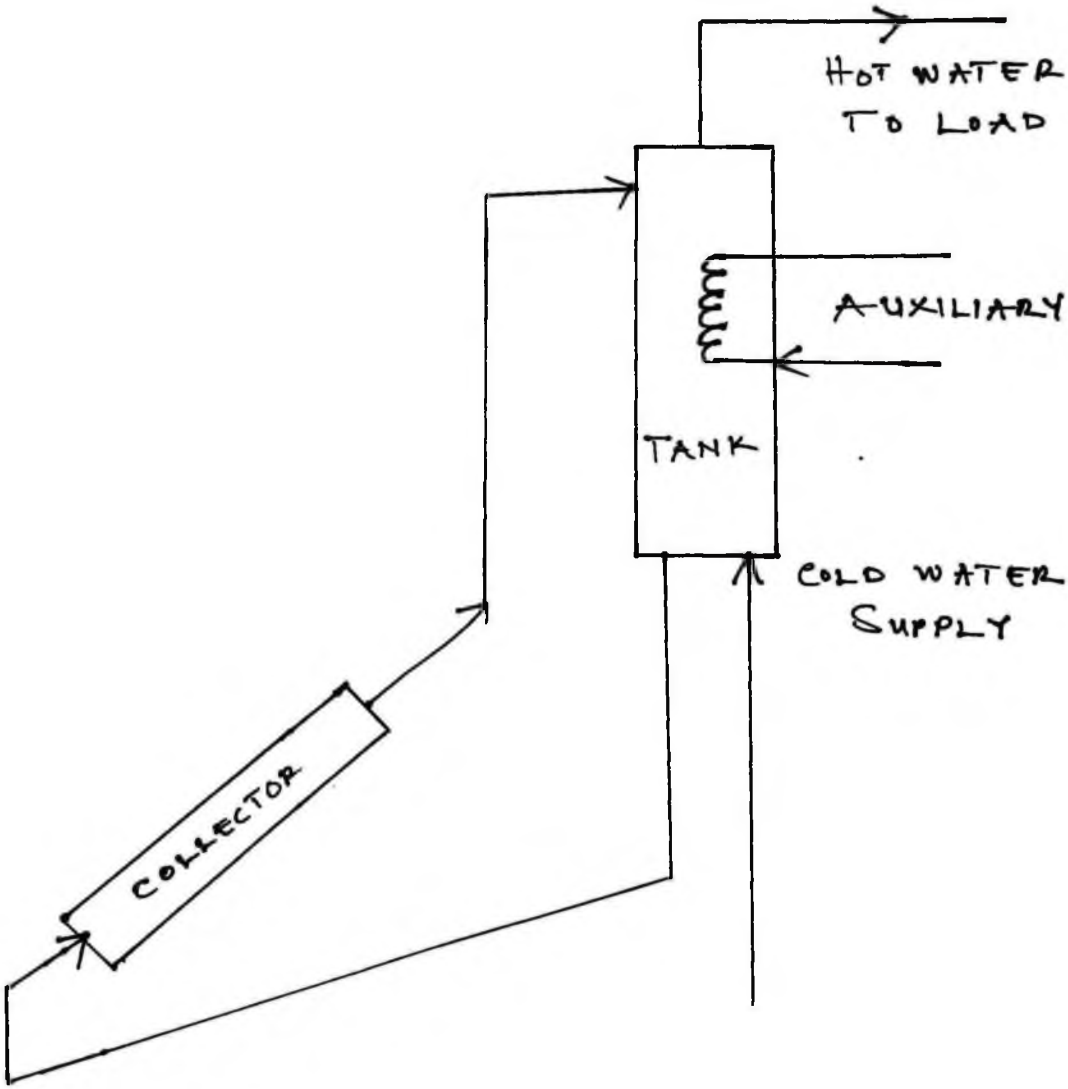

FIGURE 2.9a SCHEMATIC OF A NATURAL CIRCULATION SOLAR WATER HEATER WITH AUXILIARY ENERGY SOURCE ADDED TO STORAGE TANK.

Figure 2.9b shows schematically a forced circulation system.

In this system there is no need to locate the tank above the collector. A pump is required; which is controlled by a differential controller, turning on the pump when the temperature at the top header is several degrees higher than that at the bottom of the tank. A check valve is needed to prevent reverse circulation and resultant night thermal loses from the collector. An auxiliary energy source is shown; this adds an extra heat to the water going to the load.

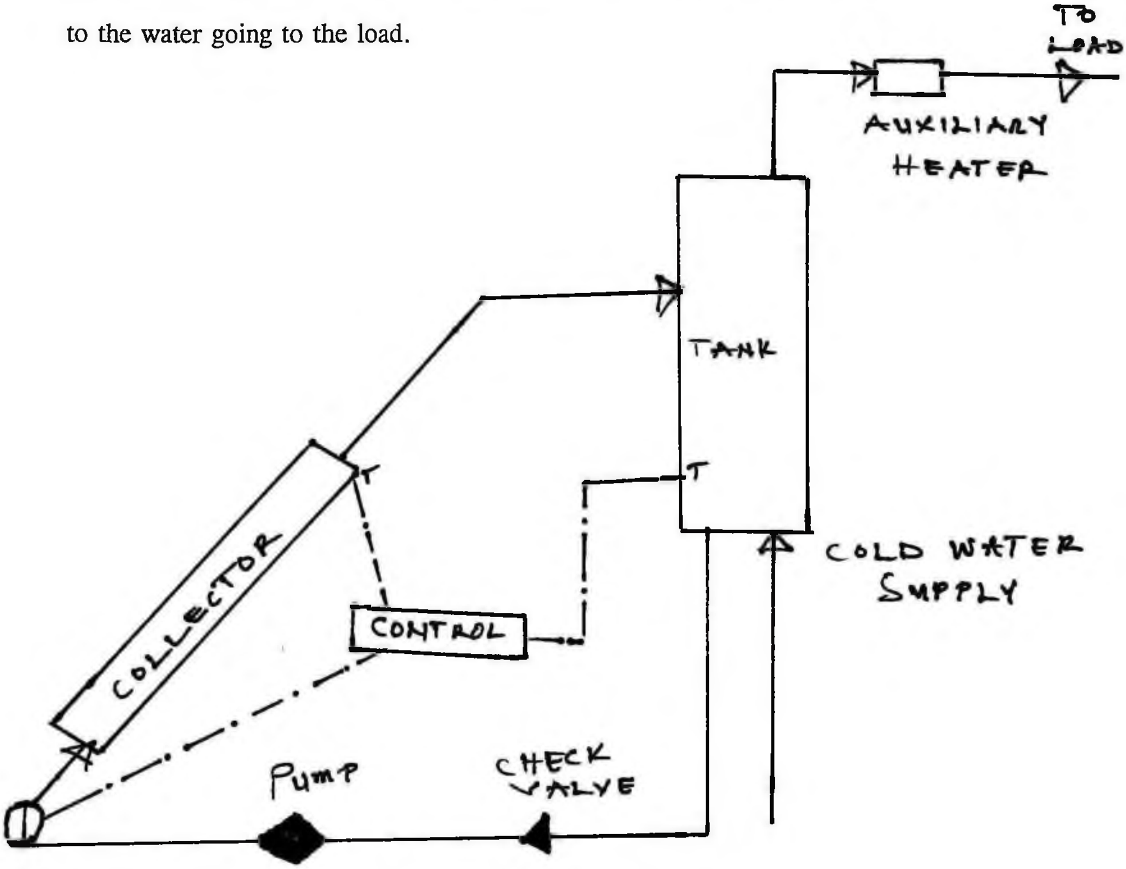

FIGURE 2.9b SCHEMATIC OF A FORCED CIRCULATION SOLAR WATER HEATER WITH AN AUXILIARY ENERGY SOURCE ON LINE TO LOAD.

2.9.1 COLLECTOR AND STORAGE TANKS

Flat-plate collectors are the most commonly used. The absorbers typically used are made of tubes with diameter between 1.2 to 1.5cm and laid parallel to each other, 12 to 15cm apart, soldered or brazed into the headers of about 2.5 cm in diameter. The tubes are soldered or otherwise thermally bonded to the plates. The most common absorber plate material is copper. The absorber plates are mounted in a metal or asbestos cement box, with 5 to 10 cm of insulation behind the plate and one glass cover (occasionally two) over the plates, leaving about 2.5 cm air gaps. The dimensions of a single collector are typically 1.2m by 0.6m or 1.2m by 1.2m; more than one collector may be used in an instalment. Figure 2.9.1 schematically shows a "conventional" solar water heater collector plate.

The storage tank must be well insulated; a common practice is to use about 20cm of wool on the sides, top and bottom. The piping from collector to tank must also be well insulated and arranged to minimize pressure drop. Piping of 2.5cm or larger is typical for household units.

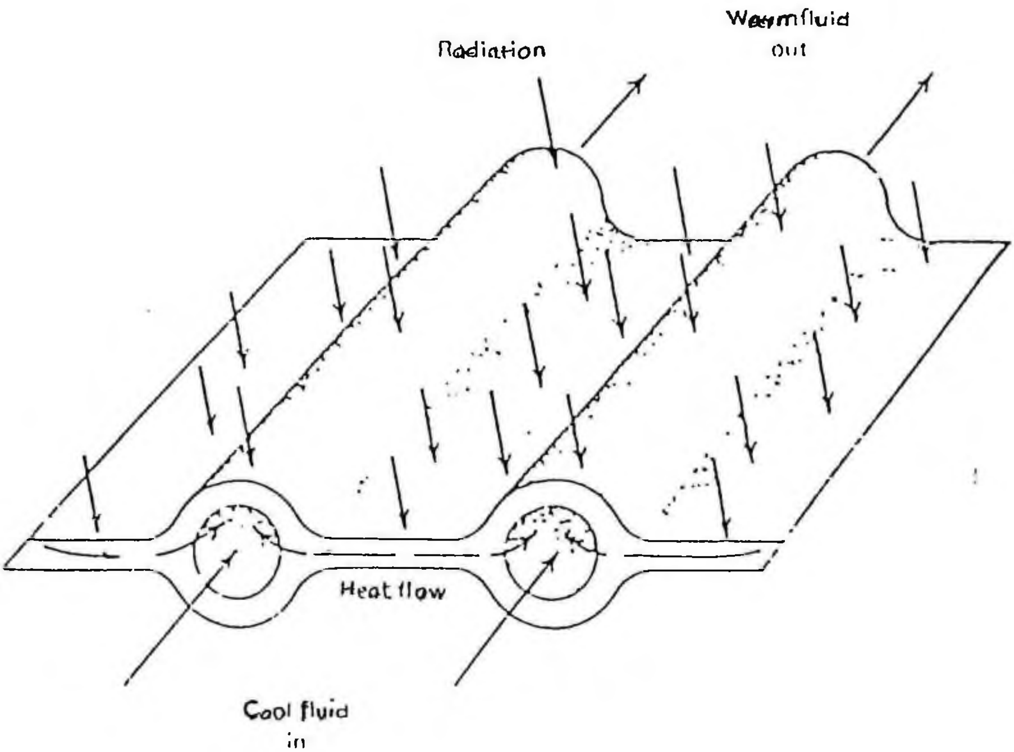

FIGURE 2.9.1 SOLAR WATER HEATER COLLECTOR PLATE.

2.9.1.1 GENERAL DESCRIPTION OF A FLAT-PLATE COLLECTOR

The important parts of a typical solar water heater flat-plate collector are shown in figure 2.9.1.1. A black solar energy absorbing surface, with means of transferring the absorbed energy to the water; the envelopes covering the topmost part over the solar absorber surface are transparent to solar radiation; this reduces heat loss by convection and radiation to the atmosphere; and the back insulation reduces conduction heat losses as the geometry of the system permits.

Flat-plate collectors are almost always mounted in a stationary position (e.g. as an integral part of a wall or roof structure) with an orientation optimized for a particular location in question for which the solar water heater is intended to operate.

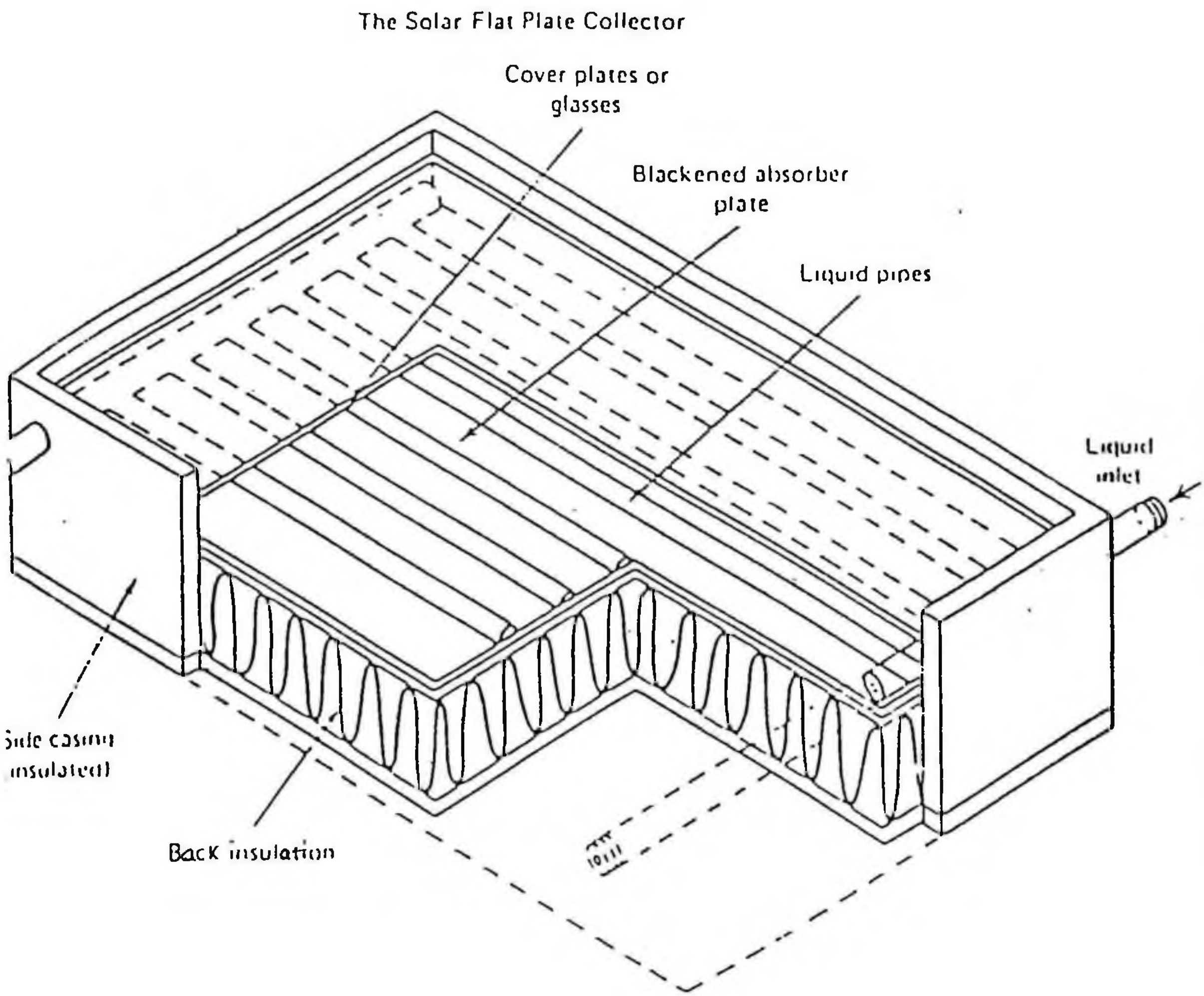

FIGURE 2.9.1.1 SOLAR WATER HEATER FLAT-PLATE COLLECTOR

2.9.2 EFFECTS OF DUST AND SHADING ON FLAT-PLATE COLLECTORS

The effect of dust and shading are difficult to generalize. Data reported by Dietz (1965) show that at the angles of incidence of interest (0 to 50°) the maximum reduction of transmittance of covers due to dirt is 2.7 percent. In an experiments on collectors in Boston area, Hottel and Woertz (1942) found that collector performance decreased by one percent due to dirty glass. In a rainless 30-day experiment in india, Garg (1974) found that dust decreases the transmittance by an average of eight percent for glass tilted at 45°. To account for dust in temperate climates, Garg suggested that radiation absorbed by the plate be reduced by two percent.

Shading effects can also be significant. When the angle of incidence is off normal, some structures will intercept solar radiation. Some of these radiation would be reflected to the absorbing plate when the side walls are of high-reflectance material. Based on experiments with two-cover collector, Hottel and Woertz (1942), recommended that the radiation absorbed by the plates be reduced by three percent to account for shading effect, if the net (unobstructed) glass area is used in calculations. Most modern collectors use one cover, and module areas are large, both of which reduce shading effects.

2.9.3 LOAD AND SIZING OF A SOLAR WATER HEATING SYSTEM

As with any other solar energy application, the optimum collector size of a solar water heater to meet a particular service hot-water need (i.e. load) depends on a combination of factors, including the initial investment, collector orientation, climate, and temperature of the cold water supply.

It is also imperative to know how much hot water would be needed each day, and how many collectors are necessary to provide the amount of hot water needed for a family. The hot water need for a family would vary from family to family. An example of the daily hot water requirement in China as reported by Zhang and Lin (1983) in an international Solar Energy Application Training Workshop held at the Natural Energy Research Institute, Langhou, China, is 80-100 litres/day for a family of four.

Clothes washing machine

hot wash/hot rinse	10.0 litres to 12.5 litres
hot wash/warm rinse	7.0 litres to 9.5 litres
hot wash/cold rinse	5.0 litres to 6.4 litres
warm wash/cold rinse	2.5 litres to 3.5 litres

Dish washing

Dish washing machine	2.5 litres to 4.0 litres
sink wash	1.0 litres to 2.0 litres

Personal Hygiene

Showering(per minute)	0.5 litres to 1.5 litres

The relation between daily hot water requirement W and the heat requirement Q is given as

$$Q = W (T_h - T_c) * C_w * Y_w \qquad (2.9.2.1)$$

where W is the daily hot water requirement in litres; $(T_h - T_c)$ is the temperature increase required in °C; C_w is the specific heat capacity of water; Y_w is the density of water (= 1 kg/litre).

The aperture area of the collector or the array is given as

$$A_c = Q / (Z * I) \qquad (2.9.2.2)$$

where, A_c is the aperture area of array (m^2); I is the average solar irradiation (kJ/m^2day); and Z is the efficiency of the array. In Australia for example systems are designed to produce hot water at 65°C, and at daily average usage of 45kg per person. Duffie and Beckman (1991) suggested that for an all-solar system characterized by an almost continuous good solar weather, a storage capacity of 2.5 times the daily requirement is suggested. Duffie and Beckman further reported that where radiation is intermittent and conventional energy is less expensive, and an auxiliary energy is to be used, the recommended tank size should be about 1.5 times the daily requirement. For a family of four a collector area of about $4m^2$ is suggested in their report. They further reported that the collector should be oriented approximately towards the equator at a slope of 0.9Φ for a maximum annual collection; Φ is the angular location north or south of the equator. Deviations up to 22° east or west of north (or south) would have small effect on annual performance of the collector was also reported by Duffie and Beckman (1991). The load information needed in a simulation is the quantity of hot water needed (usually at temperatures above some minimum level) as a function of the time, or the quantity of energy needed (measured relative to some reference temperatures above a minimum) as a function of time.

CHAPTER THREE

3.0 PRESENTATION OF RESULTS OF SURVEY

The project aims primarily at evaluating the economics and assessing the potential of solar water heaters in urban Ghana. Two types of data were collected for the study, primary and secondary data. The secondary data collected from the field by administration of questionnaire (see appendices A and B) and were analysed using, paradox and quattro pro, the results of which are presented in the form of tables. Below are the major summary of results and findings of the survey carried out in the study areas, Achimota, Legon, Madina, Labone and Airport residential areas. The table shows the distribution of energy sources used in households by location over the period 1990 to 1995.

TABLE (3.1) FUEL TYPE USED IN HOUSEHOLDS FOR WATER HEATING BY LOCATION

EL PE	PERCENTAGE OF HOUSEHOLD IN LOCATIONS									
	ACHIMOTA		LEGON		MADINA		LABONE		AIRPORT	
	1995	1990	1995	1990	1995	1990	1995	1990	1995	1990
ECTRICITY	16.1	20.1	84.0	82.4	29.8	29.0	70.0	69.8	90.0	89.2
'G	2.0	7.0	12.0	11.2	10.9	10.4	5.7	6.2	9.0	8.3
:ROSINE	49.3	39.8	3.9	5.2	3.0	32.4	15.0	14.9	0.7	2.5
IARCOAL	30.5	29.1	0.1	1.2	25.1	24.2	9.3	9.1	0.1	
REWOOD	3.1	4.0	0.0	0.0	0.0	4.2	4.0	0.0	0.0	0.0
)LAR IERGY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The results above reveal increases in the percentage of households that use electricity over the year 1990 to 1995 for water heating except for Achimota, this means an increase in electricity consumption over the period. The trend for charcoal, kerosine and LPG is not uniform. Virtually all the households never use solar energy in any form.

The table 3.2 below present the results of the distribution of the fuel types used in the commercial sector for water heating by location over the period 1990 to 1995.

TABLE (3.2) FUEL TYPE USED BY COMMERCIAL SECTOR FOR WATER HEATING BY LOCATION

	PERCENTAGE OF COMMERCIAL END USER IN LOCATIONS									
	ACHIMOTA		LEGON		MADINA		LABONE		AIRPORT	
UEL YPE	1995	1990	1995	1990	1990	1995	1990	1995	1990	1995
LECTRICITY	89.1	94.1	88.9	88.7	89.8	89.5	90.2	89.1	91.1	90
PG	10.9	5.9	11.1	11.3	11.2	10.5	9.8	10.9	8.9	10
EROSINE										
HARCOAL	0.0	0.O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IREWOOD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OLAR NERGY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table (3.2) above shows that none of the end-users in the commercial sector uses kerosine, charcoal firewood, and solar energy to heat water over the period, but uses electricity and LPG with a partial increase in the percentage of LPG end-users.

The result of tables 3.3 and 3.4 below shows the socio-economic distributionof households covered by the suvery within the study area.

TABLE (3.3) DISTRIBUTION OF HOUSEHOLDS COVERED BY THE SURVEY

INCOME GROUP	SOCIO-ECONOMIC STRATA	
	NUMBER OF HOUSEHOLDS	PERCENTAGE OF HOUSEHOLDS
LOW INCOME GROUP	104	52
MEDIUM INCOME GROUP	65	32.5
HIGH INCOME GROUP	31	15.5
TOTAL	200	100

TABLE (3.4) DISTRIBUTION OF HOUSEHOLDS COVERED IN THE SURVEY BY INCOME GROUP

INCOME GROUP	SOCIO-ECONOMIC STRATA			
	NUMBER OF HOUSEHOLDS	PERCENTAGE OF RESPONDENTS		PERCENTAGE OF HOUSEHOLDS
		HUSBANDS	WIVES	
LOW INCOME GROUP	104	4.5	5.1	52
MEDIUM INCOME GROUP	65	40.2	75.9	32.5
HIGH INCOME GROUP	31	55.3	19.0	15.5
TOTAL	200	100	100	100

Tables 3.3 and 3.4 reveals that within the low and medium income groups, majority of respondents are wives with 5.1% and 75.9% respectively, also majority of the households interviewed fall within the low income group, followed by the medium income, and the high income group.

The results of the level of frequency of the various energy sources in households and commercial sector within the low, medium and higher income groups are presented in tables 3.5 and 3.6 respectively.

TABLE (3.5) LEVEL OF FREQUENCY OF VARIOUS ENERGY SOURCES BY THE DIFFERENT INCOME GROUPS.

FUEL TYPE	LOW INCOME GROUP		MEDIUM INCOME GROUP		HIGH INCOME GROUP	
	% OF HOUSEHOLDS IN GROUP		% OF HOUSEHOLDS IN GROUP		% OF HOUSEHOLDS IN GROUP	
	NEVER USED	USED FREQUENTLY/ EVERYDAY	NEVER USED	USED FREQUENTLY/ EVERYDAY	NEVER USED	USED FREQUENTLY/ EVERYDAY
ELECTRICITY	10.4	89.6	0.4	99.5		99.7
LPG	85.2	14.8	45.2	54.8	25.7	75.3
KEROSINE	7.5	92.5	23.7	29.8	95.9	4.1
CHARCOAL	34.6	66.4	25.8	74.2	99.9	0.1
FIREWOOD	34.5	65.5	85.7	14.3	100.0	0.0
SOLAR ENERGY	99.8	0.0	100.0	0.0	100.0	0.0

Table 3.5 above shows that the most patronized energy sources of end-users is electricity, with the least being solar energy. Kerosine and charcoal are most often patronized by the low and medium income groups, but least within the high income group. Solar energy is never used in all the income groups.

TABLE (3.6) LEVEL OF FREQUENCY OF THE VARIOUS ENERGY SOURCES BY COMMERCIAL SECTORS.

FUEL TYPE	HOTEL		RESTAURANT		HOSPITAL/CLINIC	
	% OF COMMERCIAL SECTORS IN GROUP		% OF COMMERCIAL SECTORS IN GROUP		% OF COMMERCIAL SECTORS IN GROUP	
	NEVER USED	USED FREQUENTLY/ EVERYDAY	NEVER USED	USED FREQUENTLY/ EVERYDAY	NEVER USED	USED FREQUENTLY/ EVERYDAY
ELECTRICITY	0.0	100.0	0.0	100.0	0.0	100.0
LPG	15.3	84.7	6.3	93.7	21.2	78.8
KEROSINE	97.2	2.8	85.9	14.1	77.5	22.5
CHARCOAL	100.0	0.0	72.2	27.8	100.0	0.0
FIREWOOD	100.0	0.0	99.9	0.0	99.0	0.0
SOLAR ENERGY	76.9	0.1	99.8	0.0	100.0	0.0

Table 3.6 above shows that in the commercial sector electricity and LPG are the dominant energy source, with charcoal and kerosine less patronized, solar energy is rarely used, 0.1%. Results of the assesment of the energy needs of households and commercial sectors are presented in tables 3.7 and 3.8.

TABLE (3.7) ENERGY SOURCES USED IN HOUSEHOLDS AND COMMERCIAL SECTOR BY ENERGY NEED

	ENERGY SOURCE USED IN LOCATION - % OF HOUSEHOLDS						ENERGY SOURCE USED IN LOCATION - % OF COMMERCIAL SECTOR					
END USE	EL	LPG	KER	CHAR	FW	SOL	EL	LPG	KER	CHA	FW	SOL
GHTING	99.3*	0.0	2.5	0.0	0.0	0.2	100.0*	0.0	0.0	0.0	0.0	0.1
OKING	87.7	73.5*	89.5	75.2	0.0	0.0	98.5	32.6	0.1	0.0	0.0	0.0
ATER EATING	88.9*	2.2	56.9	1.5	0.0	0.0	99.2	45.8	0.0	0.0	0.0	30.3

EL- ELECTRICITY KER- KEROSINE CHAR- CHARCOAL FW -FIREWOOD
SOL -SOLAR ENERGY * - KEY ENERGY SOURCE

Table 3.7 above shows that within households the need for lighting is much greater than that for heating water and cooking, whilst in the commercial sector, lighting, cooking and water-heating have greater needs. The dominant energy in both the commercial sector and households is electricity.

TABLE (3.8) ENERGY SOURCES USED BY DIFFERENT INCOME GROUPS

END USE	LOW INCOME		MEDIUM INCOME		HIGH INCOME	
	KEY ENERGY SOURCE	MAIN ALTERNATIVE	KEY ENERGY SOURCE	MAIN ALTERNATIVE	KEY ENERGY SOURCE	MAIN ALTERNATIVE
LIGHTING	ELECTRICITY	KEROSINE	ELECT	KEROSINE	ELECTRICITY	KEROSINE
COOKING	CHARCOAL	FIREWOOD	LPG	CHAR/KERO	ELECTRICITY	LPG
HEATING WATER	CHARCOAL	FIREWOOD	ELECT	CHAR	ELECTRICITY	LPG

ELECT- ELECTRICITY LPG LIQUIFIED PETROLEUM GAS CHAR - CHARCOAL KERO - KREOSINE

Table 3.8 above reveals that electricity is the major energy source used by the high income group to satisfy all energy needs, with LPG as an alternative fuel, whilst the low and medium income groups have electricity as the major energy for lighting with charcoal, kerosine and LPG the key energy for cooking and water-heating. The results of the economic assessment of potential end-users of solar water-heating system within the study area are presented in tables 3.9, 3.10, 3.11, 3.12 below. Mode for payment and willingness to use solar water heater are also presented.

TABLE (3.9) MODE OF PAYMENT FOR SOLAR WATER HEATING SYSTEM BY INCOME GROUPS

	PERCENTAGE IN INCOME GROUP		
MODE OF PAYMENT	LOW INCOME	MEDIUM INCOME	HIGH INCOME
OUTRIGHT	0.1	4.1	54.3
HIRE PURCHASE	20.2	75.9	34.8
INSTALLMENT	76.8	20.0	11.9

The above table 3.9 shows that majority of households within the low income group 76.8% can afford to buy a solar water heater on installment, with the second majority in the medium income group 75.9% can afford to buy it on hire purchase basis. In the high income group 54.3% can afford a solar water heater outright.

TABLE (3.10) MODE OF PAYMENT FOR SOLAR WATER HEATING SYSTEM BY LOCATIONS

	PERCENTAGE OF INCOME GROUPS IN LOCATION														
	LOW INCOME					MEDIUM INCOME					HIGH INCOME				
MODE OF PAYMENT	AC	LE	MA	LA	AI	AC	LE	MA	LA	AI	AC	LE	MA	LA	AI
OUTRIGHT	0.5	12.3	0.5	0.8	0.4	2.5	23.2	0.3	.6	1.6	44.2	34.6	22.3	34.5	44.7
HIRE PURCHASE	34.6	26.4	11.6	22.9	43.5	55.7	42.5	48.4	55.2	47.9	23.5	56.2	54.1	55.2	45.3
INSTALLMENT		30.6	66.5	32.8	53.2	33.2	42.1	49.8	48.7	49.9	31.2	15.3	20.3	9.3	11.3

Table 3.10 reveals that majority of households 56.2% that can afford a solar water heater on hire purchase basis within the high income group are located at Legon, the second majority 55.7% located at Achimota can afford the system on hire purchase basis. The third majority 66.5% located at Madina can afford a solar water heating system on installment. Within the

high, medium, and low income groups, 44.7, 23.2, 12.2 percent located respectively at Airport residential area and Legon can afford the system outright .

AC - ACHIMOTA LE - LEGON MA MADINA LA LABONE RESIDENTIAL AREA

AI AIRPORT RESIDENTIAL AREA

TABLE (3.11) WILLINGNESS TO USE SOLAR WATER HEATING SYSTEM BY INCOME GROUPS

	PERCENTAGE OF HOUSEHOLDS IN INCOME GROUP		
WILLINGNESS	LOW INCOME	MEDIUM INCOME	HIGH INCOME
WILLING	9.3	22.3	51.4
UNWILLING	65.8	44.9	45.7
NEUTRAL	19.9	21.8	2.9

Table 3.11 above reveals that the potential for the use of solar water heating system is very high the high income group. The potential increases across the table as you move from the low to the high income group.

TABLE (3.12) WILLINGNESS TO USE SOLAR WATER HEATING SYSTEM IN THE COMMERCIAL SECTOR

	PERCENTAGE IN COMMERCIAL SECTOR		
WILLINGNESS	RESTUARANT	HOTEL	HOSPITAL/CLINIC
WILLING	21.1	15.6	12.2
UNWILLING	75.8	45.9	55.9
NEUTRAL	3.9	35.9	30.8

Within the commercial sector, the potential of using solar water heaters is very high in restuarants and hotel than hospitals and clinics. Results of the analysis of income and expenditure pattern of end-users are presented in tables 3.13 and 3.14 below.

TABLE (3.13) INCOME GROUP OF END USERS BY PERCENTAGE IN LOCATIONS

INCOME GROUP	INCOME RANGE PER MONTH (IN THOUSAND CEDIS)	PERCENTAGE IN LOCATION	
		WIVES	HUSBANDS
LOW INCOME	50 - 200	55.9	35.6
MEDIUM INCOME	200 - 300	14.2	44.2
HIGH INCOME	OVER 300	55.3	45.5

TABLE (3.14) INCOME AND EXPENDITURE PATTERN OF END USERS

INCOME GROUP	AVERAGE EXPENDITURE PER MONTH (IN THOUSAND CEDIS)
LOW INCOME	300
MEDIUM INCOME	450
HIGH INCOME	600

Table 3.13 and 3.14 shows the analysis of the income and expenditure pattern of end-user. The results reveal that for all the income groups the average expenditure is much higher than the corresponding income per month. Assessment of the awareness of solar water heaters within households and commercial sector are presented in table 3.15.

TABLE (3.15) AWARENESS OF THE USE OF SOLAR ENERGY TO HEAT WATER

SECTOR	AWARE	UNAWARE
HOUSEHOLD	88.1	11.8
COMMERCIAL	85.3	10.7

Table 3.15 shows that generally there is much awareness as to the use of solar water heaters in both households and in commerce.

TABLE (3.16) HOUSEHOLDS CHARACTERISTICS

INCOME GROUP	OTHER DEPENDANTS	HUSBANDS	WIFE	CHILDREN
LOW	3	1	1	5
MEDIUM	2	1	1	4
HIGH	--	1	1	3

Table(3.17) show that , the average size of a household is 7, 6 and 5 for low, medium, and high income group respectively. This are made up of husband, wife and children. There are other dependants for households in the low and medium income groups.

TABLE (3.17) HOUSEHOLDS SOCIO-ECONOMIC CHARACTERISTICS

INCOME GROUP	STATUS			
	GRADUTAE	DIPLOMATE	VOC/SEC	ILLITRATES
LOW	-	-	2.3	36.7(w)
MEDIUM	33.2(m)	-	33.5(w)	-
HIGH	45.6(m)	13.6(m)	53.5(w)	-

W- WOMEN M MEN

CHAPTER FOUR

4.0 ANALYSIS AND DISCUSSION OF RESULTS OF SURVEY

4.1 ANALYSIS OF DOMESTIC AND COMMERCIAL ENERGY CONSUMPTION

A total of 200 households and 100 commercial users were covered in the survey. Number of households in the low, medium, and high income groups are respectively 104, 65, and 31. Majority being households in the low income group which forms 52 percent, followed by medium income 32.5 percent and high income group forming the minority with 15.5 percent. The distribution of households in terms of socio-economic strata is summarized in Tables 3.3 and 3.4

4.2 HOUSEHOLD CHARACTERISTICS

4.2.1 HOUSEHOLD SIZE AND COMPOSITION

The average size of a household is seven, six, five. This is made up of husband, wife, and four children, for low, medium, and high income groups respectively table(3.16). Generally, households in the medium and high income group tend to have slightly fewer children, with three (3) children being common among these groups. Households in the low and medium income groups have some dependants staying with them.

4.2.2 HOUSEHOLD SOCIO-ECONOMIC CHARACTERISTICS

Over 75% of the respondents (mainly wives) in the households are in the medium income group and engaged in some income-earning activity, with the most common activity being trading. In the medium income group, most respondents are engaged in trading, whilst employed as a civil servant, or working in a private firm are the second common engagement.

In the higher income group, most respondents (mainly wives) are engaged in trading with the second majority being house wives.

Most (36.7%) of women respondents in the households in the low income group are illiterate, whilst 22.3% of them can barely read, 2.3% have had vocational training or secondary education. In the medium income group, 33.5% of the women have had vocational training or secondary education. In the high income group, 53.3% of them have had vocational training or secondary education, with 33.2% of them being graduates. Most (45.6%) of the male respondent in the high income group are graduates, and head of households, with 13.4% of them diplomates. Majority (55.9%) of the women respondents are in the low income group and 35.6% of their husbands earn one hundred thousand cedis or less a month see table (3.13). About 5% of the respondent however could not determine their income.

In the medium income group, 14.2% of the women respondent earn two hundred and fifty thousand cedis a month or less, whilst 42.6% earn an average of two hundred thousand cedis a month; majority of husbands (44.2%) earn between two hundred thousand and two hundred and fifty thousand cedis a month, whilst 21.2% of husbands earn an average of two hundred and fifty thousand cedis a month. Among the high income group, majority of the husbands (45.5%) earn over 300,000 cedis a month; however majority of women (55.3%) of women respondent in this group either earn 350,000 cedis or less a month or over 350,000 cedis a month (table 3.31 and 3.14). It can be seen that respondents in all the income groups spend more than they earn; and this could be attributed to the critical economic situation presently in the country. It was further observed that some repondent under stated their incomes whilst some could not estimate their expenditure level.

4.2.3 ANALYSIS OF HOUSEHOLDS AND COMMERCIAL ENERGY CONSUMPTION STRUCTURES

The urban centres of Ghana are better supplied with energy sources than the rural centres. The main fuels used in households and commercial sectors for cooking and water heating within the area covered by the survey are charcoal, kerosine, liquified petroleum gas (LPG), and electricity. Among the low income group charcoal is found to be the dominant fuel used for water heating, cooking and other domestic activities in the house; in the medium income group LPG is the main fuel for cooking with charcoal being an alternative source, electricity is the major fuel for water heating. Among the high income group electricity is the main fuel for all activities with LPG being the alternative fuel.

Within the commercial sectors electricity is the main energy resource used for lighting, cooking, water heating for dishwashing, and laundry. The reason is that it is easy to use and it enhances performance and quality of work. 93.7 percent of restaurants and 84.7% of hotels and 21.2% of hospitals interviewed use LPG as alternative fuel whilst the remaining 6.3%, 15.3%, and 78.8% respectively never use LPG at all. The only problem associated with the use of LPG is that it is not readily available. Virtually all the study areas are connected to the national electricity grid and enjoy fairly reliable supply of electricity. The only problem associated with some of the areas notably Labone and some parts of Airport residential area as reported by households is the difficulty in the use of electricity to cook due to power fluctuations and rampant power outages. With the commercial sector some reported low voltages at night, the rest have no problem associated with the use of electricity.

4.4 CONSUMPTION OF ENERGY BY STUDY AREA

Tables 3.7 and 3.8 show the energy sources used in the study areas for lighting, cooking and heating. The predominant fuel for cooking and heating water is electricity, the majority 88.9%, 73.5% and 99.3% of the respondents in the households use electricity for water heating, cooking and lighting respectively. Hundred percent, 32.6% and 45.8% of respondents in the commercial sector use electricity for lighting, cooking and water heating respectively. Majority of respondents 90 and 70 percent of households in Airport residential area and Labone residential area use electricity for water heating while 9 and 5.7 percent use liquified petroleum gas as an alternative energy source for all domestic household activities. 16.1 percent, 84.0%, 29.85% of households at Achimota, Legon and Madina respectively use electricity for water heating.

The commercial sector notably the hotels and restaurants within the study area use electricity as their major energy source and in some cases electricity together with liquified petroleum gas (LPG) are the main energy source used. Hospitals/clinics also use electricity as the major source of energy. 39.7% of hotels use electricity as the major energy source, and 10.6% use electricity with LPG. 49.6 percent of restaurants use only electricity as major energy source.

4.4.1 UTILIZATION OF SOLAR WATER HEATERS IN HOUSEHOLDS AND COMMERCIAL SECTOR

Most respondents 88.1% and 85.3% of the respondents in households and commercial sector respectively of the study area are aware table (3.15) and have significant knowledge of solar energy and its use in the domestic sector of the economy; but have not used it in any form. The remaining 21.1% know about solar energy and its application in solar water heaters but have never used solar water heaters. Most 45.3% of households in the high income group are interested in using solar water heaters in their homes as a means of reducing electric power consumption and to reduce the amount paid as electricity bill. Majority 65.8% of households in the low income group are not prepared to buy a solar water heater even if the current prices are subsidized to reduce the initial cost because the price of the heater is not within their income (table 3.11).

Among the medium income group 22.3% of respondents are willing to buy a solar water heater only if they could pay for it on instalment basis, with the reason being that they cannot afford it outright.

The minority 21.8, 2.9 and 19.9 percent of households in the low, medium and high income groups respectively are not certain of the use of solar water heaters. A total of 93.0 percent of respondents in the low, medium and high income groups are willing to acquire solar water heaters for installation in their homes, whilst 65.8, 44.9, 45.7 percent of households in the low, medium and high income groups respectively are not willing to use solar water heater, because of the high initial cost associated with the solar water heater. Virtually none of the hospitals\clinics and laundries within the study area uses solar energy in any form apart from drying cloths.

CHAPTER FIVE

5.0 CONCLUSIONS

5.1 PRINCIPAL FINDINGS ON DOMESTIC AND COMMERCIAL ENERGY SECTOR

It has been established that generally households in the high and medium income groups use electricity and liquified petroleum gas as the dominant or principal energy source for all household activities, and among the low income group the predominant fuels are charcoal and liquified petroleum gas (LPG). But the use of LPG is constrained by the difficulty of having gas cylinders refilled. From personal interview , it was found that Most households 21.2% in the low income group have switched from the use of electricity to LPG because they cannot afford the high electricity bills that they were paying. The situation in the commercial sector is not different; it has been established that electricity is the predominant fuel.

The choice of domestic fuel by households is largely determined by the level of income of the households, which also depends upon the types of economic activities undertaken and educational background. The use of LPG and electricity in household is constrained by two factors : availability and income level (affordability).

Generally there is a high possibility of the use of solar water heaters in the high and medium income groups. The percentage of users of solar water heaters could increase if the initial cost of ownership could be subsidized, or if the heaters are locally manufactured to reduce the initial cost. In the commercial sector it has been established that the possibility of using solar water heaters is also very high. Majority of hotels are prepared to use this facility as a means of reducing electricity consumption and to further reduce the high electricity bill paid monthly.

It is essential that developing country like Ghana first and foremost, define a strong institutional base for the management of its major source of energy for the majority living below the normal standard of living and who fall within the vicious circle of poverty.

Secondly, it is imperative for a strong legislative framework at the national level within which energy policy and planning can be developed and sustained, evaluated, and monitored, such as the law which established the former natioinal energy board.

Thirdly, since the number of experienced Professionals in the field of energy and energy management are not enough, it would be appropriate to develop sustained programmes of training, skill enhancement, and research both at the ministry and tertiary institutions. A crucial factor in the successful implementation of policies and programmes is the availability of stable funding. This necessitated the establishment of the national energy fund from taxes on petroleum products and other energy sources to fund short and long-term programmes.

Another important observation is the need to develop a comprehensive and implementable programmes, with measurable outputs, to achiev policy objectives.

It is essential that developing country, such as Ghana, ensure that the necessary energy required for development is made available without placing undue stress on the environment. One of the most important short-term priorities is to provide modern energy services to large sections of the population. There exist a wide range of options for meeting such energy needs, with varrying degrees of negative environmental implications. The immediate challenge to policy makers is to select those options that offer the posibilty of providing an adequate level of energy service to the growing population, while minimising the associated environmental impacts, without endangering the long-term development aspiration of the nation.

5.2 PROJECT LIMITATIONS

The sampling technique and the method of data collection under the study ensured the compilation of good representative data and information on households and commercial energy demand and supply patterns in urban Ghana. In this study, the assessment of environmental impact of household fuels is mainly qualitative and based primarily on subjective responses and perception of respondents covered by the survey. Quantitative analysis of environmental impact of the use of solar water heaters and household fuel could not be made. With the economic analyses local variation in prices justifies the carrying out of sensitivity and cost-benefit analysis. This constitutes the key limitations of the survey.

5.3 RECOMMENDATIONS

In order to meet the energy demand of both households and the commercial sector and the promotion of the use of solar water heaters in the domestic and commercial sectors in an environmentally sustainable manner, the following policies for implementing energy strategies could be adopted:

I. Intensify the promotion and use of alternative energy resources particularly solar energy by sponsoring of research and development of solar energy technologies in tertiary institutions.

II. Subsidizing prices and import duties on solar devices, by creation of tax incentives by Government.

III. Regulation to improve the flow of information

Ignorance about the opportunities for energy efficiency improvement or for alternative energy sources is a major obstacle to rational decision making in energy related purchases. Hence regulations that serve to improve the flow and dissemination of information can be very effective policy measures. For a wide range of energy-using activities, information flow could be improved by requiring companies to provide their customers in all sectors information regarding the energy performance and cost- effectiveness of alternative investment.

IV. Emphasis on energy need for the domestic sector

Energy policies that are to protect the poor and other disadvantaged in society, the low income groups of a society must be directed towards the basic needs. It is implicit that there should be special emphasis on energy services for the domestic sector, and energy policies oriented towards the maintaining of a safe and healthy environment should receive a high priority by Government

V. Government procurement

When a new technology is introduced there are institutional obstacles to the creation of new markets. Producers may be reluctant to enter new markets if the burden of convincing enough consumers to buy the new product are too great. The problem is compounded by the tendency of the consumers to be unwilling to take the large risk associated with purchases of "first-of-a-kind" product. Moreover, initial cost of the new product tends to be high, owing to the need to recover developmental cost, even if there may be good prospects of much lower cost later on, realized through the economies of mass production, and competition.

Government can help create new markets for socially desirable new products by procuring specific quantities of the products for meeting its own need. This could help reduce both the risk to producers of market development and the risk of being the first-of-a-kind purchaser, through government's demonstration of the attractions or shortcomings of the new products.

VI. There should be increased awareness of Ghanaian populace of the existence of alternative solar sources of energy (that may be used both at home and in commerce).

VII. The ministry of Energy and Mines must be charged with the responsibility of actually formulating policies (like encoursing research and development of solar devices locally) that will actually bring down the cost of these devices so that, as seen from the result of the study, those in the the low income bracket might also go for it. Benefits that might accrue to the environment if such a situation is achieved in the future, as seen from the results of the study cannot be over-emphasised.

The results show that for those in the low-income group charcoal (whose production contributes in no small way to environmental degradation) is the main source of energy for cooking and water-heating. The results also show that 65.8% of the people in the low income group (table 3.11) even through their level of awareness of the existence of the use of solar energy to heat water is very high (table 3.15) are unwilling to use solar water-heating system now because they can just not afford it.

APPENDIX A

UNIVERSITY OF GHANA DEPARTMENT OF PHYSICS

This questionnaire is to evaluate the potentials and the economics of solar water heaters in urban Ghana as a contribution to an environmentally sustainable framework. I would be most grateful if you could answer the questions below.

ANY INFORMATION GIVEN WILL BE TREATED CONFIDENTIAL PLEASE BE SPECIFIC AND ANSWER THE QUESTIONS AS BRIEFLY AS POSSIBLE AND ACCURATELY AS YOU CAN.

You may not discuss any part of the questionnaire with anybody outside your family, I am interested in your personal point of view, thank you.

DATE............. TOWNSHIP...................

HOUSEHOLDS

1. Sex (tick) 1. male ( ) 2. female ( )

2. Age group (tick)
   1. Between 25 and 35 ( )
   2. Between 35 and 45 ( )
   3. Between 45 and 50 ( )
   4. Above 50 ( )

3. Marital status (tick)
   1. Single ( )
   2. Married ( )
   3. Divorced ( )
   4. Widowed ( )
   5. Separated ( )

4. What Position do you occupy in the family?
   ....

5. How many children do you have? ....

6. Occupation (tick)
   1. Accountant ( )
   2. Engineer ( )
   3. Lawyer ( )
   4. Businessman/Businesswoman ( )
   5. Lecturer ( )
   6. Teacher ( )
   7. Farmer ( )
   8. Other (specify) ....

7. Highest Educational attainment (tick)

1. Graduate ( )
2. Diplomate ( )
3. Secondary ( )
5. Post secondary ( )
6. Vocational training ( )
7. Other (specify) ....

8. Are you engaged in any income-earning activity?

Yes ( ) No ( )

9. How much do you and your family earn in a month? (tick)

1. Below 50,000.00 cedis ( )
2. 50,000.00 100,000.00 ( )
3. 100,000.00 - 150,000.00 ( )
4. 150,000.00 - 200,000.00 ( )
5. 200,000.00 - 300,000.00 ( )
6. Over 300,000.00 ( )

10. What is your average level of your expenditure?

Per day		OR Per month	
1. Below 2,000 cedis	( )	1. Below 50,000 cedis	( )
2. 2,000.00- 2,000.00	( )	2. 50,000.00- 100,000.00	( )
3. 3,000.00- 3,000.00	( )	3. 100,000.00- 150,000.00	( )
4. 5,000.00- 5,000.00	( )	4. 150,000.00- 200,000.00	( )
5. 7,500.00- 7,500.00	( )	5. 200,000.00- 300,000.00	( )
6. Over 10,000.00	( )	6. Over 300,000.00	( )

11. What is the size of your family? (state number of members)

....

12. How many times a day do you use hot water in the house?

....

13. How many buckets of hot water on the average do you use in the house a day? ....

14. At what times in a day do you normally use hot water? (tick)

1. Never
2. Mornings only ( )
3. Afternoons Only ( )
4. Evenings only ( )
5. Mornings and Evenings ( )
6. At all times ( )
7. Other (specify).....................

15. What do you use hot water for? (tick)

1. Bathing ( )
2. Washing clothes(laundry) ( )
3. Washing dishes ( )
4. Other (specify).......................

16. When do you normally use hot water for bathing during the year?

1. Never ( )
2. During the cold season ( )
3. During the whole year ( )
4. Other (specify)..........................

17. What main fuel do you use in heating water?(tick)

1. Electricity ( )
2. LPG(gas) ( )
3. Kerosine ( )
4. Charcoal ( )
5. Firewood ( )
6. Other(specify).......................

18. How long have you been using your main fuel for heating water?

1. Less than 5 years ( )
2. 1 - 2 years ( )
3. 2 - 5 years ( )
4. Over 5 years ( )

19. Do you use other fuels to heat your water? Yes ( ) No ( )

20. What other fuel do you use in heating water apart from your main fuel ? (tick)

1. Electricity ( )
2. LPG(stove) ( )
3. Kerosine ( )
4. Charcoal ( )
5. Firewood ( )
6. None ( )
7. Other(specify)......................

21. Will you say that your main fuel of heating water is adequate enough to meet your need for hot water?

Yes ( ) No ( )

22. Will you say your main fuel of heating water is

1. Expensive ( )
2. Cheap ( )

to obtain?

23. Are there any drawbacks associated with your main fuel that you use in heating your water?

Yes ( ) No ( )

24. What are the main drawbacks associated with your main fuel of heating water?
    1. Expensive ( )
    2. Not easy to use ( )
    3. Not readily available ( )
    4. Don't know ( )
    5. Other (specify)...................

25. What do you do in order to find a solution to the drawbacks youhave mentioned above?
....

26. In trying to find a solution to the above problems what difficulties do you encounter?
....

27. Have you changed your main fuel for heating water within the past five years?
    Yes ( ) No ( )

28. What kind of fuel did you use for heating water five years ago?
    1. Electricity ( )
    2. LPG(gas) ( )
    3. Kerosine ( )
    4. Charcoal ( )
    5. Firewood ( )
    6. Other(specify)......................

29. What do you do to make your fuel for heating water last longer or cost less?
    1. Quench fire after heating ( )
    2. Keep fuel away from children ( )
    3. Other (specify)......................

ELECTRICITY

30. If you use Electricity, what kind of Electric heater do you use in heating water? (tick)
    1. Hand immersion electric heater ( )
    2. Bath room Electric heater ( )
    3. Electric Kettle heater ( )
    4. Other (specify)...................

31. How are you charged for your electricity consumption?
    1. Monthly ( )
    2. Quarterly ( )
    3. Yearly ( )
    4. Other (specify).................

32. How much did you pay as your last electricity bill?
    .... cedis

33. What measures do you take in order to reduce your electricity bill?
....

34. Which year did you purchase your electric heater? 19....

35. Was your electric heater at that time

1. New ( )
2. Second-hand ( )

36. Please give an estimate of your expenses per year for repair work and maintenance of your electric heater.

.... cedis

37. Which fuel(s) for heating water in your opinion is(are) safe to use? (tick)

1. Electricity ( )
2. LPG(gas) ( )
3. Kerosine ( )
4. Charcoal ( )
5. Firewood ( )
6. None ( )
7. Other(specify)..................

38. Give reasons in support of your answer(s) to question 37 above?

....

39. Which source(s) of heating water in your opinion is(are) most convenient to use? (tick)

1. Electricity ( )
2. LPG(gas) ( )
3. Kerosine ( )
4. Charcoal ( )
5. Firewood ( )
6. None ( )
7. Other(specify)...................

40. Give reasons in support of your answer(s) to question 39 above?

....

SOLAR ENERGY

41. Do you know about solar energy (energy from the sun)

Yes ( ) No ( )

42. Do you use solar energy appliances?

1. Never ( )
2. Previously, not now ( )
3. Occasionally ( )
4. Frequently ( )
5. Everyday ( )
6. Other(specify).................

43. If solar energy is used occasionally, frequently, or everyday, what do you use it for?

1. Cooking ( )
2. Heating of water ( )
3. Electric appliances ( )
4. Other (specify)................

44. How long have you been using this solar facility

1. Less than 1 year ( )
2. 1 2 years ( )
3. 2 - 5 years ( )
4. Over 5 years ( )

45. Are you satisfied with your solar facility?

1. Very satisfied ( )
2. Satisfied ( )
3. Not too sure ( )
4. Unsatisfied ( )
5. Very unsatisfied ( )

46. What information do you have about solar water heaters?

....
....

47. As an electrical energy savings device, will you like to use solar water heater in your house?

Yes ( ) No ( )

48. Give reasons for your answer to question 47 above?

....
....
....

49. For a family of four a small a solar water heater is able to provide about 180 litre of 60°C hot water every day. The price of owning such a device is about 1.6 million cedis. For a larger family a bigger solar water heater is able to provide about 325 litre of 60°C hot water every day. The cost of owning such a device is about 2.5 million cedis.
Which of the following modes of payment would you prefer for buying this water heater?

1. Outright payment ( )
2. Hire purchase ( )
3. Installment basis ( )
4. Other (specify)..................

APPENDIX B

UNIVERSITY OF GHANA DEPARTMENT OF PHYSICS

This questionnaire is to evaluate the potentials and the economics of solar water heaters in urban Ghana as a contribution to an environmentally sustainable framework. I would be most grateful if you could answer the questions below.

ANY INFORMATION GIVEN WILL BE TREATED CONFIDENTIAL PLEASE BE SPECIFIC AND ANSWER THE QUESTIONS AS BRIEFLY AS POSSIBLE AND ACCURATELY AS YOU CAN.

DATE............. TOWNSHIP...................

HOTELS, RESTAURANTS, GUEST HOUSES, AND HOSPITALS

1. Do you own or manage a (tick)
   1. Hotel ( )
   2. Restaurant ( )
   3. Guest house ( )
   4. Evenings only ( )

3. Do you use hot water? Yes ( ) No ( )

4. What do you use hot water for? (tick)
   1. Bathing ( )
   2. Washing clothes(laundry) ( )
   3. Washing dishes ( )
   4. Other (specify).......................

5. How many times a day do you use hot water?
   ....

6. At what times in a day do you normally use hot water? (tick)
   1. Never ( )
   2. Mornings only ( )
   3. Afternoons only ( )
   5. Mornings and Evenings ( )
   6. At all times ( )
   7. Other (specify)..................

7. When do you normally use hot water during the year?
   1. Never ( )
   2. During the cold season ( )
   3. During the whole year ( )
   4. Other (specify).......................

8. What volume of hot water on the average do you use in a day?

....

9. What main fuel do you use in heating your water?(tick)

1. Electricity ( )
2. LPG(gas) ( )
3. Kerosine ( )
4. Charcoal ( )
5. Firewood ( )
6. Other(specify)...................

10. How long have you been using your main fuel for heating water?

1. Less than 5 years ( )
2. Between 5 - 10 years ( )
3. More than 10 years ( )
4. Other (specify).......................

11. Do you use other fuels to heat your water? Yes ( ) No ( )

12. What other fuel do you use in heating water apart from your main fuel ? (tick)

1. Electricity ( )
2. LPG(stove) ( )
3. Kerosine ( )
4. Charcoal ( )
5. Firewood ( )
6. None ( )
7. Other(specify).....................

13. Will you say that your main fuel of heating water is adequate enough to meet your need for hot water?

Yes ( ) No ( )

14. Will you say your main fuel of heating water is

1. Expensive ( )
2. Cheap ( )

to obtain?

15. Are there any drawbacks associated with your main fuel that you use in heating your water?

Yes ( ) No ( )

16. What are the main drawbacks associated with your main fuel of heating water?

1. Expensive ( )
2. Not easy to use ( )
3. Not readily available ( )
4. Don't know ( )
5. Other (specify)....................

17. What do you do in order to find a solution to the drawbacks youhave mentioned above?

....

18. In trying to find a solution to the above problems what difficulties do you encounter?

....

19. Have you changed your main fuel for heating water within the past five years?

Yes ( ) No ( )

20. What kind of fuel did you use for heating water five years ago?

1. Electricity ( )
2. LPG(gas) ( )
3. Kerosine ( )
4. Charcoal ( )
5. Firewood ( )
6. Other(specify).......................

21. What do you do to make your fuel for heating water last longer or cost less?

1. Quench fire after heating ( )
2. Keep fuel away from children ( )
3. Other (specify).....................

ELECTRICITY

22. If you use Electricity, what kind of Electric heater do you use in heating water? (tick)

1. Hand immersion electric heater ( )
2. Bath room Electric heater ( )
3. Electric Kettle heater ( )
4. Other (specify)...................

23. How are you charged for your electricity consumption?

1. Monthly ( )
2. Quarterly ( )
3. Yearly ( )
4. Other (specify)................

24. How much did you pay as your last electricity bill?

.... cedis

25. What measures do you take in order to reduce your electricity bill?

....

26. Which year did you purchase your electric heater? 19....

27. Was your electric heater at that time

1. New ( )
2. Second-hand ( )

28. Please give an estimate of your expenses per year for repair work and maintenance of your electric heater.

.... cedis

29. Which fuel(s) for heating water in your opinion is(are) safe to use? (tick)

1. Electricity ( )
2. LPG(gas) ( )
3. Kerosine ( )
4. Charcoal ( )
5. Firewood ( )
6. None ( )
7. Other(specify)..................

30. Give reasons in support of your answer(s) to question 29 above?

....

31. Which source(s) of heating water in your opinion is(are) most convenient to use? (tick)

1. Electricity ( )
2. LPG(gas) ( )
3. Kerosine ( )
4. Charcoal ( )
5. Firewood ( )
6. None ( )
7. Other(specify)...................

32. Give reasons in support of your answer(s) to question 31 above?

....

SOLAR ENERGY

33. Do you know about solar energy (energy from the sun)

Yes ( ) No ( )

34. Do you use solar energy appliances?

1. Never ( )
2. Previously, not now ( )
3. Occasionally ( )
4. Frequently ( )
5. Everyday ( )
6. Other(specify).................

35. If solar energy is used occasionally, frequently, or everyday, what do you use it for?

1. Cooking ( )
2. Heating ( )
3. Electric appliances ( )
4. Other (specify)................

36. How long have you been using this solar facility

1. Less than 1 year ( )
2. 1 2 years ( )
3. 2 5 years ( )
4. Over 5 years ( )

37. Are you satisfied with your solar facility?

1. Very satisfied ( )
2. Satisfied ( )
3. Not too sure ( )
4. Unsatisfied ( )
5. Very unsatisfied ( )

38. What information do you have about solar water heaters?

....

....

39. As an electrical energy saving device ,will you like to use solar water heater?

Yes ( ) No ( )

40. Give reasons for your answer to question 39 above?

....

....

41. Solar water heaters exist in many sizes. The price of a solar water heater able to provide about 325 litre of 60°C hot water is about 2.5 million cedis.Which of the following mode of payment would you prefer for buying this water heater?

1. Outright payment ( )
2. Hire purchase ( )
3. Installment basis ( )
4. Other (specify)...................

APPENDIX C

ECONOMIC AND FINANCIAL ANALYSIS FOR A HOUSEHOLD

The domestic sector (household) is the most obvious market for solar water heaters in Ghana. Domestic average hot water consumption from the survey was found to be 150 litres of 60°C of water per day for bathing (consumed in the morning and evening) for a family of four, this is expected to rise during the rainy season. The inlet temperature of water is 25°C, which gives a temperature difference of 35°C. The average daily solar intensity is 5 kw-h/m^2,

Recalling equation 2.9.2.1,

$$Q = W\,(T_h - T_c) * C_w * Y_w$$

the total energy (heat value) required per day to heat 150 litres of water is

$$Q = (4.19 * 1000 * 150 * 35)/(1000 * 3600) = 6.1 \text{ kw-h}$$

Annual requirement is then 365 * 6.1 ie 2226.5 kw-h.

For a household to acquire its first solar water heating system (thermosyphonic solar water heater) with a flat-plate collector, from the simulation results, the following input data for the solar system and electrical heater were applied

(a) An efficiency of 50% was assumed

(b) Considering the average daily solar intensity of Accra to be 5kw-h/m^2, collector area of 4.40 m^2 was chosen ie two 2.2 m^2 module (collector sizing),

(c) Investment cost (including tax and installation) is estimated to be $1800

(d) Back-up energy, 30 % of total energy requirements = 668 kw-h p.a

(e) Maintenance and operation cost within the economic lifetime is assumed negligible

(f) economic lifetime 10 years

(g) Rate of inflation assumed to be 10% p.a.

Note that the efficiency of 50%, investment cost of $1800 was assumed based on for the available information on the collector and storage tank. The construction materials are of medium quality. The Initial investment could be higher than the assumption made.

For the electrical system an efficiency of 100% was assumed. The kw-h electricity required is then equal to the kw-h heating required, an initial investment cost of half that of the solar system $900 used, over the same economic lifetime of ten years. Energy price (base year) of US cents 7/kw-h over the same inflation rate 10 % p.a.

APPENDIX D

CALCULATION OF FINANCIAL INDICATORS

The difference in the investment cost for the solar water heater and the electric water heater is $900. This when compared with the difference in the annual energy costs is $109 at the base year energy price, but with an inflation rate of ten percent per annum the annual energy cost is $282.

The pay-back of the marginal investment (i.e. the additional $900 required for the solar system) when calculated is about 2.4 years with undiscounted values and 3.3 years for discounted values at a discount rate of 20% in nominal terms. The return on investment (ROI) of the marginal investment is found to be 48% in the inflated terms. The economic and financial analyses shows that the marginal investment is profitable over the economic life-time and has a reasonable pay back period. Note that the simulation program used for the economic and financial analyses requires the currency in dollars.

APPENDIX E

E U R S O L

Simulation Program for Thermal Solar Systems
C.E.C. Project OPSYS, 1986-1990.

Simulation number 1

Date: Aug 1, 1995
Time: 12 h 40' 2"

Execution time: 0 h 0 min 9 sec

SIMULATED SYSTEM TYPE: Eursol Nr. 1

Solar water heater with the following options:

Model: unstratified tank(s), one collector node.

Collector loop: thermosyphon loop.

Auxiliary water heating: series connected once through heater.

METEOROLOGICAL DATA FOR ACCRA

●HS%^

Longitude of the time zone standard meridian:	: 17.00°
Local geographic longitude:	: 0.00°
Local geographic latitude:	: 8.00°
Collector plane azimuth angle:	: 0.00°
Collector plane tilt angle:	: 40.00°

COLLECTOR ARRAY PARAMETERS		
Collector array surface area	1.000	m²
Collector thermal capacity per sqm.	10.000	kJ/(m².K)
Effective tau-alpha product	0.800	-
Constant term of heat loss coef.	4.500	W/(m².K)
Temp. coef. of heat loss coef.	0.040	W/(m².K²)
Collector efficiency factor	1.000	-
Average fluid specific heat	4.185	kJ/(kg.K)
Average fluid density	998.000	kg/cbm
Density temperature coefficient	0.034	% /K
Fluid dynamic viscosity	0.001	Pa.s

COLLECTOR LOOP PIPING PARAMETERS		
Piping heat loss coefficient	0.500	Watt/(m.K)
Length of collector loop hot leg	0.300	meter
Length of collector loop cold leg	1.200	meter
Piping ambient temperature	20.000	°C

THERMOSYPHON LOOP PARAMETERS		
Equivalent downcomer loop length	1.200	meter
Downcomer piping diameter	2.220	cm
Total pipe-fittings head loss coef.	4.000	-
Collector outlet height	1.000	meter
Storage tank outlet height	1.300	meter
Storage tank inlet height	1.100	meter

COLLECTOR LOOP FLUID CIRCULATION ON-OFF CONTROL		
Safety Thermostat Switch-ON Temp.	95.000	°C
Safety Thermostat Switch-OFF Temp.	90.000	°C

UNSTRATIFIED SOLAR STORAGE TANK		
Subm. heat exch. tot.heat tr. coef.	2000.000	Watt/K
Total volume of the storage tank	85.000	Liter
Total heat loss coefficient	0.726	Watt/K
Ambient temperature (for all tanks)	20.000	°C
Initial temperature	20.000	°C

HOT WATER CONSUMPTION TEMPERATURES AND USAGE		
Cold water inlet temperature	25°C	°C
Hot water consumption temperature	60.000	°C
Hot water usage 1st day of the week	85.000	Liter/day
Hot water usage 2nd day of the week	85.000	Liter/day
Hot water usage 3rd day of the week	85.000	Liter/day
Hot water usage 4th day of the week	85.000	Liter/day
Hot water usage 5th day of the week	85.000	Liter/day
Hot water usage 6th day of the week	85.000	Liter/day
Hot water usage 7th day of the week	85.000	Liter/day

HOURLY FRACTIONS OF THE DAILY HOT WATER USAGE PROFILE:

Hour	Fraction	Hour	Fraction	Hour	Fraction	Hour	Fraction
1	0.0220	7	0.0140	13	0.0360	19	0.0680
2	0.0000	8	0.0480	14	0.0500	20	0.1160
3	0.0000	9	0.0720	15	0.0270	21	0.0960
4	0.0000	10	0.0840	16	0.0230	22	0.0690
5	0.0000	11	0.0700	17	0.0210	23	0.0550
6	0.0000	12	0.0450	18	0.0380	24	0.0460

T A B L E   O F   R E S U L T S

All energy values are expressed in MJ.
Designation of the output quantities:

E 1 = Total incident solar radiation.
E 2 = Collector energy output.
E 3 = Collector loop piping heat losses.
E 4 = Collector loop circul.pump consumption.
E 5 = Solar storage tank energy input.
E 6 = Solar storage tank heat losses.
E 7 = Storage energy output to hot water.
E 8 = External auxiliary energy supply to DHW.
E 9 = Net energy demand for hot water usage.

Month	E 1 E 8	E 2 E 9	E 3	E 4	E 5	E 6	E 7
Jan	326.7 264.7	108.8 353.0	5.2	0.0	103.7	11.4	88.4
Feb	378.8 199.4	147.7 318.9	7.9	0.0	139.7	17.3	119.5
Mar	378.6 217.9	160.6 353.0	9.8	0.0	150.8	20.1	135.2
Apr	533.2 130.8	262.0 341.7	19.1	0.0	242.8	33.4	210.9
May	577.5 109.7	306.5 353.0	24.3	0.0	282.2	39.4	243.3
Jun	588.3 92.9	330.7 341.7	26.8	0.0	303.9	41.4	248.8
Jul	447.3 139.2	262.0 353.0	22.1	0.0	239.8	34.4	213.9
Aug	560.8 93.3	332.4 353.0	28.0	0.0	304.4	42.5	259.7
Sep	463.6 137.8	257.9 341.7	18.8	0.0	239.2	32.0	203.8
Oct	437.9 173.6	217.8 353.0	14.3	0.0	203.5	27.2	179.5
Nov	326.3 224.1	135.9 341.7	7.3	0.0	128.6	16.6	117.6
Dec	314.3 255.1	116.3 353.0	5.5	0.0	110.8	13.1	97.9
TOT	5333.3 2038.4	2638.6 4156.9	189.1	0.0	2449.4	328.9	2118.5

E U R S O L

Simulation Program for Thermal Solar Systems
C.E.C. Project OFSYS, 1986-1990.

Simulation number 1

Date: Aug 1, 1995
Time: 12 h 43' 18"

Execution time: 0 h 0 min 11 sec

SIMULATED SYSTEM TYPE: Eursol Nr. 1

Solar water heater with the following options:

Model: unstratified tank(s), one collector node.

Collector loop: thermosyphon loop.

Auxiliary water heating: series connected once through heater.

T A B L E O F R E S U L T S

All energy values are expressed in MJ.
Designation of the output quantities:

E 1 - Total incident solar radiation.
E 2 - Collector energy output.
E 3 - Collector loop piping heat losses.
E 4 - Collector loop circul.pump consumption.
E 5 - Solar storage tank energy input.
E 6 - Solar storage tank heat losses.
E 7 - Storage energy output to hot water.
E 8 External auxiliary energy supply to DHW.
E 9 - Net energy demand for hot water usage.

Month	E 1 E 8	E 2 E 9	E 3	E 4	E 5	E 6	E 7
Jan	412.7 177.1	219.6 353.0	14.1	0.0	205.6	26.3	175.9
Feb	441.6 133.7	230.5 318.9	16.8	0.0	213.7	28.3	185.1
Mar	623.8 106.5	314.4 353.0	26.1	0.0	288.3	39.2	246.6
Apr	621.2 97.0	312.8 341.7	27.8	0.0	285.0	39.0	244.6
May	762.5 54.3	388.3 353.0	38.9	0.0	349.4	50.5	298.7
Jun	751.2 44.3	388.6 341.7	39.7	0.0	348.9	50.7	297.3
Jul	753.8 44.8	402.1 353.0	42.3	0.0	359.8	52.9	308.2
Aug	826.6 25.6	436.9 353.0	47.0	0.0	389.9	62.3	327.5
Sep	596.5 79.2	338.5 341.7	32.2	0.0	306.3	43.4	262.5
Oct	560.8 106.1	310.3 353.0	25.9	0.0	284.5	39.1	246.9
Nov	475.8 128.5	261.2 341.7	20.3	0.0	241.0	33.1	213.2
Dec	285.9 232.6	149.7 353.0	9.1	0.0	140.6	16.8	120.4

APPENDIX F

E U R S O L

Simulation Program for Thermal Solar Systems
C.E.C. Project OPSYS, 1986-1990.

Simulation number 1

Date: Jul 27, 1995
Time: 13 h 38' 50"

Execution time: 0 h 0 min 9 sec

SIMULATED SYSTEM TYPE: Eursol Nr. 1

Solar water heater with the following options:

Model: unstratified tank(s), one collector node.

Collector loop: thermosyphon loop.

Auxiliary water heating: series connected once through heater.

METEOROLOGICAL DATA FOR ACCRA.

Longitude of the time zone standard meridian:	: 17.00°
Local geographic longitude:	: 0.00°
Local geographic latitude:	: 8.00°
Collector plane azimuth angle:	: 0.00°
Collector plane tilt angle:	: 40.00°

COLLECTOR ARRAY PARAMETERS		
Collector array surface area	1.200	m²
Collector thermal capacity per sqm.	10.000	kJ/(m².K)
Effective tau-alpha product	0.800	-
Constant term of heat loss coef.	4.500	W/(m².K)
Temp. coef. of heat loss coef.	0.040	W/(m².K²)
Collector efficiency factor	1.000	-
Average fluid specific heat	4.185	kJ/(kg.K)
Average fluid density	998.000	kg/cbm
Density temperature coefficient	0.034	% /K
Fluid dynamic viscosity	0.001	Pa.s

COLLECTOR LOOP PIPING PARAMETERS		
Piping heat loss coefficient	0.500	Watt/(m.K)
Length of collector loop hot leg	0.300	meter
Length of collector loop cold leg	1.200	meter
Piping ambient temperature	20.000	°C

THERMOSYPHON LOOP PARAMETERS		
Equivalent downcomer loop length	1.200	meter
Downcomer piping diameter	2.220	cm
Total pipe-fittings head loss coef.	4.000	-
Collector outlet height	1.000	meter
Storage tank outlet height	1.400	meter
Storage tank inlet height	1.200	meter

COLLECTOR LOOP FLUID CIRCULATION ON-OFF CONTROL		
Safety Thermostat Switch-ON Temp.	95.000	°C
Safety Thermostat Switch-OFF Temp.	90.000	°C

UNSTRATIFIED SOLAR STORAGE TANK		
Subm. heat exch. tot.heat tr. coef.	2000.000	Watt/K
Total volume of the storage tank	90.000	Liter
Total heat loss coefficient	0.820	Watt/K
Ambient temperature (for all tanks)	20.000	°C
Initial temperature	18.000	°C

HOT WATER CONSUMPTION TEMPERATURES AND USAGE		
Cold water inlet temperature	25°C	°C
Hot water consumption temperature	60.000	°C
Hot water usage 1st day of the week	90.000	Liter/day
Hot water usage 2nd day of the week	90.000	Liter/day
Hot water usage 3rd day of the week	90.000	Liter/day
Hot water usage 4th day of the week	90.000	Liter/day
Hot water usage 5th day of the week	90.000	Liter/day
Hot water usage 6th day of the week	90.000	Liter/day
Hot water usage 7th day of the week	90.000	Liter/day

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